ABSTRACT

Title of Document: RELIABILITY-BASED DESIGN OF PIPING: Internal Pressure, Gravity, Earthquake, and Thermal Expansion

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Although reliability theory has offered the means for reasonably accounting for the design uncertainties of structural components, limited effort has been made to estimate and control the probability of failure for mechanical components, such as piping. The ASME B&PV Code, Section III, used today for the design of safety piping in nuclear plants is based on the traditional Allowable Stress Design (ASD) method.

This dissertation can be considered as a primary step towards the reliability-based design of nuclear safety piping. Design equations are developed according to the Load and Resistance Factor Design (LRFD) method. The loads addressed are the sustained weight, internal pressure, and dynamic loading (e.g., earthquake). The dissertation provides load combinations, and a database of statistical information on basic variables (strength of steel, geometry, and loads).

Uncertainties associated with selected ultimate strength prediction models - burst or yielding due to internal pressure and the ultimate bending moment capacity- are quantified for piping. The procedure is based on evaluation of experimental results cited in literature. Partial load and resistance factors are computed for the load combinations and for selected values of the target reliability index, β. Moreover, design examples demonstrate the procedure of the computations.

A probabilistic-based method especially for Class 2 and 3 piping is proposed by considering only cycling moment loading (e.g., thermal expansion). Conclusions of the study and provided suggestions can be used for future research.

RELIABILITY-BASED DESIGN OF PIPING:
Internal Pressure, Gravity, Earthquake, and Thermal Expansion

By

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Dedication

With gratitude and love to my parents

Zacharias P. Avrithis

and

Maria Xatzistergou-Avrithi

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CHAPTER 1: INTRODUCTION

This chapter provides the objective of the dissertation, the background and needs of research in the field, as well as the organization of the chapters. Initially, a brief discussion about nuclear energy, nuclear plants, and piping is provided.

1.1. Nuclear Energy and Nuclear Plants

It is common knowledge and concern that although the consumption of energy is bound to increase the coming years, the resources of fossil energy (oil, gas, and coal) are limited and being exhausted in increasing rates. Research is turning towards the renewable energy (solar, geothermal, and biomass) and the improvement of technology (reactors and materials) for nuclear plants.

Nuclear energy satisfies today 8% of the world's energy needs and is an efficient source for the production of electricity. Power plants in U. S. produce 20% of country's electricity, while in France the 80%. U.S. has the largest number of nuclear power plants (104) followed by France (59), Russia (32), Korea (26), U.K. (22), and India (21). More specifically, in U.S., as of April, 2005 there are 104 industrial power reactors, which are licensed by the U.S. Nuclear Regulatory Commission (NRC) to operate, producing in total 97,400 net megawatts (electric). From them, 69 reactors are categorized as Pressurized Water Reactors (PWR), producing almost two thirds of the total electric power and the rest 35 are Boiler Water Reactors (BWR). The plants are located at 64 sites and 31 states.

From 1973 to 1987 there was a steady increase in the construction of nuclear plants in U.S. and from 1987 till now the number of reactor plants fluctuates insignificantly, with few of them shutting-down and others renewing their license. The last permission for a new nuclear power plant was issued in 1999. Nevertheless, the capacity of the plants nowadays is increased due to license extensions and upgrading of existing reactors. Moreover, several new plants are going to be built.

Disadvantages of the use of nuclear energy are the production and disposal of radioactive waste and the high cost for the construction of nuclear reactors. Moreover, accidents in nuclear plants like in Chernobyl, near Kiev, Ukraine (1986), which is the worst accident ever with 31 deaths and radioactivity spread in the former Soviet Union and Europe, and the Three Mile Island accident near Harrisburg, Pennsylvania (1979), the worst in U.S. history, make the public opinion and governments skeptical about nuclear energy. On the other hand, an advantage of nuclear energy is that it does not contribute to global warming, since no carbon dioxide, CO_2, is produced.

Nevertheless, nuclear energy is a good source for production of electricity and with advanced security measures not as dangerous as the public thinks it is. Moreover, the energy crisis and the dependence of industrial countries on oil production of countries in Middle East, Africa or South America has made countries (USA, France, etc.) consider the construction of new power plants that will supplement their energy needs and their independence from foreigner economies.

The nuclear power industry has been developing and improving reactor technology for almost five decades. Generation I reactors were developed in 1950-60s and today still run only in England (GCR). Generation II reactors are in operation in all countries. About 85% of the world's nuclear electricity is generated by reactors derived from designs originally developed for naval use. These and other second-generation nuclear power reactors have been considered to be reliable and safe, but Generation III reactors, the Advanced Reactors, have started to replace them. In Japan, Generation III reactors are running, while Generation IV reactors are in development. Generation IV technology is very promising, since not only can provide economical electric power, but also can generate hydrogen for other energy needs.

1.2. Nuclear Plants

The dissertation deals with piping operating in Boiler Water Reactors (BWR) or Pressurized Water Reactors (PWR) nuclear plants, which are the types of nuclear plants that exist in U.S. today. Both BWR and PWR are characterized as Light Water Reactors (LWR), since they use light (common) water both as coolant and as neutron moderator. Water, therefore, is the main link in the process that converts the fission energy to electrical energy in such plants.

More specifically, in BWR the water is heated by the nuclear fuel and boils to steam inside the reactor vessel and then is directed to the turbine for the production of electricity. In PWR the water is heated by the nuclear fuel and pressurized in order not to boil. Then it is pumped from the reactor pressure vessel to a steam generator and used to boil a separate supply of water, which turns into the steam that spins the turbine for the production of electricity. Both PWR and BWR reactors are based on the Rankine cycle.

That is, through thermodynamic processes water is made to undergo changes involving energy transitions and subsequently returns to its original state. BWR are manufactured by General Electric, and PWR by the Babcock and Wilcox Company and the Westinghouse Electric Corporation that has also immersed the former Combustion Engineering Inc.

1.3. Nuclear Piping

Nuclear piping consists of the pipes, their interconnection including in-line components such as pipe fittings and flanges, pipe supporting elements such as pumps and valves, the supports of the pipes but not the support structures like building frames, foundations, etc. that their design is also not included in the ASME B&PV Design Code (2001).

This study deals with straight pipes and not fittings like elbows, tees, reducers, etc. that necessarily exist in all pipelines. Straight pipes constitute the majority of piping and unlike other components they do not have only a local influence. Although it can be claimed (Rodabaugh, 1978) that usually pipe failures do not occur on straight parts of piping, but mostly on other parts like elbows due to concentration of stresses, etc. straight pipes are the first step for developing a new design method, which can be then extended to include nuclear piping as defined above.

Pipes in a structural context can be considered as secondary components in the power plant installation, whereas considering their functional role in the plant as passive components like vessels, electrical cables, and structures in opposition to the active components such as pumps, fans, relays, and transistors, whose functioning depends on an external input, such as actuation, mechanical movement, or supply of power and therefore influence in an active manner the system's processes.

In ASME B&PV Code, Division I, Part III safety piping is categorized in three classes. The level of importance, associated with the function of pipes as well as for other components, decreases from Class 1 to Class 3. In a nuclear power plant, approximately 66% of the total quantity of process piping is safety-related. From the safety related piping only 10% belongs to Class 1 (Stephenson, 1999). A brief description and the relevant Code's sections for the piping classes are provided below.

***Class 1*:** Class 1 pipes are within the reactor coolant pressure boundary and they should prevent the release of fission products in the environment (Section NB). In Class 1 belong also the reactor vessel, other piping, pumps, and valves.

***Class 2*:** Class 2 pipes are important to the safety and designed for situations such as emergency core cooling (ECCS), accident mitigation containment heat removal, post-accident fission product removal and containment isolation (Section NC). Other Class 2 components are pressure vessels, other piping, pumps, valves, and storage tanks.

***Class 3*:** Class 3 pipes are part of the cooling water and auxiliary feed water systems, (Section ND). These pipes can also be designed according to the ASME B31.1 Code. Other Class 3 components are pressure vessels, other piping, pumps, valves, and storage tanks.

Table 1-1 summarizes piping systems of a PWR plant and shows that the majority of piping is classified as Class 2 or 3 components.

Table 1-1: Piping Systems in a Pressurized Water Reactor Plant (Rodabaugh, et al., 1987)

System	Class 1	Class 2	Class 3
Reactor Coolant	✓	✓	
Residual Heat Removal	✓	✓	
Safety Injection	✓	✓	
Chemical and Volume Control	✓	✓	✓
Primary Component Cooling Water		✓	✓
Spent Fuel Pool Cooling Cleanup			✓
Reactor Makeup Water			✓
Containment Spray		✓	✓
Steam Generator Blow-down		✓	✓
Sample		✓	✓
Service Water			✓
Nitrogen Gas Service		✓	✓
Radioactive Gaseous Waste		✓	✓
Demineralized Water		✓	
Floor and equipment Drains		✓	
Main Steam		✓	✓
Condensate			✓
Feed-water		✓	✓
Diesel Generator Air			✓
Diesel Generator Fuel and Lube Oil			✓
Diesel Generator Cooling Water			✓
Post-accident Containment Combustible Gas Control		✓	
Reactor Coolant System Pressurized Relief Piping	✓	✓	
Equipment Vent		✓	
Containment On-line Purge		✓	
Waste Process Liquid		✓	
Fire Protection		✓	

1.4. Objective

Our society demands the safety and reliability of structures. When it comes to nuclear plants this demand is even more pronounced, considering the consequences that a failure can have in human lives and the environment. Although reliability theory has offered the means of reasonably accounting for the design uncertainties of structural components, little effort has been made to estimate and control the probability of failure for mechanical components.

Mechanical components, such as piping in nuclear plants, although they are sheltered within buildings, they are themselves exposed to a variety of loading and it is due to them that failures in the past have caused the loss of human lives. A failure of a mechanical component can trigger many adverse events and finally lead to a disaster.

This dissertation proposes a methodology for the reliability-based design of all classes of nuclear straight pipes by making use of the design equations and theories used for years in the ASME B&PV Code, Section III, NB, NC, and ND-3600. Design for fatigue addresses, under some limitations, only Class 2 and 3 piping. The design variables are determined and their uncertainties are estimated based on reported experimental data, literature review, and engineering judgment. Load combinations are proposed and the partial safety load and resistance factors are estimated for selected values of failure probabilities or else reliability indices.

It is recognized that the piping engineering community and the writers of the Code (ASME, NRC) should contribute to the development of the LRFD with their experience. Moreover, as it is often mentioned, experimental data and advanced finite element analysis are necessary tools for the development of the LRFD, too. In this work, available data was collected and reasonable values were assumed in cases of unavailable or limited data.

The LRFD method, among others, can provide a clear, simplified, and reasonable methodology for piping design. This dissertation is a primary step towards the probabilistic design of piping according to the LRFD method.

1.5. Background

The need for quantifying the design uncertainties in a systematic and uniform way by using probabilistic methods such as the Load and Resistance Factor Design (LRFD), leaded many industries, mostly in the area of civil engineering, to use reliability-based codes. More specifically, in the United States LRFD is used for steel structures (AISC, 1986), concrete structures (ACI, 1977), timber structures (ASCE, 1992), offshore oil platforms (API, 1989), bridges (AASHTO, 1994), and Category I structures in nuclear power plants (AISC, 2003; ACI, 2001). Moreover, the pipeline industry is adopting the LRFD, too (API RP1111, 1999). LRFD Codes for civil structures are also used in Canada and the European Union (CISC, 1974; CEC, 1984).

An effort to develop load and resistance factor equations for piping was made by Schwartz, et al. (1981) and Ravindra, et al. (1981), who presented a baseline and load combinations for the essential service water nuclear piping systems. More recently, Gupta, et al. (2003) performed an exploratory study for the use of LRFD for Class 1 piping, while Ayyub, et al. (2005) demonstrated the advantages and methodology of the LRFD for piping. Payne, et al. (1989) showed that an alternative probabilistic-based design for tubular members will facilitate decisions in design, which will properly balance economics, safety and uncertainties.

Table 1-2 summarizes load combinations for structural and mechanical components of nuclear plants based on literature review. More specifically, the ASCE, SMiRT-4 reference presents combinations of impulsive loads acting on a BWR-Mark I containment. Ravindra, et al. (1981) and Schwartz, et al. (1981) provide load combinations for the essential service water line (ESW) piping components, which are Class 2 components. Hwang, et al. (1987) developed practical probability-based load and resistance criteria for reinforced concrete containment and shear wall structures in nuclear plants. It can be noticed that in all these combinations, the loads involved are similar to the ones that are applicable to piping design such as the Operating Basis and Safe Shutdown Earthquake, the Safety Relief Discharge Load, the thermal loads, etc. Nevertheless, only the work of Ravindra, et al. (1981) and Schwartz, et al. (1981) refer exclusively to piping design.

Table 1-2: Load Combinations for Nuclear Plant Facilities and Components

Load Combinations*	Loads	Reference
$1.4D + 1.7L + 1.0F + 1.0P_o + 1.5SRV$ $1.0D + 1.3L + 1.0F + 1.0P_o + 1.0T_o + 1.0R_o + 1.3SRV$ $1.0D + 1.0L + 1.0OF + 1.0P_o + 1.0T_o + 1.0R_o + 1.25\sqrt{(OBE)^2 + (SRV)^2}$ $1.0D + 1.0L + 1.0F + 1.25P_B + T_A + R_A + 1.25\sqrt{(SRV)^2 + (SBA / IBA)^2_{LOCA}}$ $1.0D + 1.0L + 1.0F + 1.25P_A + 1.0T_A + 1.0R_A + 1.0SRV$ $\left.\begin{array}{l} 1.0D + 1.0L + 1.0F + 1.1P_B + 1.0T_A + 1.0R_A + \\ 1.1\sqrt{(OBE)^2 + (SRV)^2 + (SBA / IBA)^2_{LOCA}} \end{array}\right\}$ $1.0D + 1.0L + 1.0F + 1.1E_o + 1.1P_A + 1.0T_A + 1.0R_A + 1.0SRV$ $1.0D + 1.0L + 1.0F + 1.0P_o + 1.0T_o + 1.0R_o + 1.0\sqrt{(SSE)^2 + (SRV)^2}$ $1.0D + 1.0L + 1.0F + 1.0P_B + 1.0T_A + 1.0R_A + 1.0R_R + 1.0\sqrt{(SSE)^2 + (SRV)^2}$ $1.0D + 1.0L + 1.0F + 1.0E_{SS} + 1.0P_A + 1.0T_A + 1.0R_A + 1.0RR + 1.0SRV$	*D*=Dead *L*=Live *F*=Prestressing T_o=Operating Temperature R_o=Operating Reactions P_o=Operating Pressure *SRV*=Safety/Relief Valve E_o=OBE E_{ss}=SSE P_B=SBA and IBA Pressure T_A=Pipe Break Temperature Load R_A=Pipe Break Temperature P_A=LBA Pressure (including all pool hydrodynamic loadings) R_R=Reactions and Jet Forces (Pipe Break)	ASCE, SMiRT-4 (1977)
Design: *P+W* Service Limit A/B: *TRNG* Service Limit B: *P+W+OBE* *P+W+HYDTR* Service Limit C: *P+W+SSE* *P+W+OBE+HYDRT* $\varphi_{11}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W$ $\varphi_{12}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W + \gamma_{TH} c_{TH} (TRNG)$ $\varphi_{12}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W + \gamma_H c_H (HTR_N)$ $\varphi_{12}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W + \gamma_{E_{1o}} c_{Eo} (OBE)$ $\varphi_{13}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W + \gamma_{E_{11}} c_{Eo} (OBE) + \gamma_{H_1} c_H (HTR_N)$ $\varphi_{14}R_1 \geq \gamma_P c_P P_d + \gamma_W c_W W + \gamma_{E_{12}} c_{E_S} (SSE)$ $\varphi_2 R_2 \geq \gamma_{E_{12}} c_{E_{oA}} (OBE)$ $\varphi_2 R_2 \geq \gamma_{E_{22}} c_{E_{SA}} (SSE)$ $\varphi_2 R_2 \geq \gamma_{E_{23}} c_{E_{oA}} (OBE) + \gamma_{H_2} c_{H_A} (HTR_N)$ $\varphi_2 R_2 \geq \gamma_{H_3} c_{H_A} (HTR_N)$	*P*=Design Pressure *W*=Weight *OBE*=Operating Basis Earthquake *HYDTR*=Hydraulic Transient *TRNG*=Thermal Range *SSE*=Safe Shutdown Earthquake HTR_N=Hydraulic Transient φ_{ij}=Resistance Factors γ_{ij}=Load Factors c_i=Influence Coefficients that transform loads into moments	Ravindra, et al. (1981) and Schwartz, et al. (1981)
$\gamma_D D + \gamma_L L + T_o + \gamma_{R_1} R_o$ $\gamma_D D + \gamma_{L_1} L + T_o + \gamma_{R_1} R_o + \gamma_{SRV} (SRV)$ $\gamma_D D + \gamma_{L_1} L + T_o + \gamma_R R_o$ $\gamma_D D + \gamma_{L_1} L + (\gamma_{ES} E_{ss} \text{ or } \gamma_{W_t} W_t) + T_o + \gamma_{R_1} R_o$ $\gamma_D D + \gamma_{L_1} L + \gamma_{E_1} E_{ss} + T_\alpha + R_\alpha + \gamma_p P_a$	*D*=Dead *L*=Live T_o=Operating Temperature E_{ss}=SSE P_α=Loca Pressure	Hwang, et al. (1987)

* The notations are uniquely defined in "Loads" column of the table per respective cited references

1.6. Organization

The dissertation consists of 8 chapters and 3 appendices. Chapter 1 presented the objective and the background of the work done in this area of study. Chapter 2 illustrates both the Allowable Stress Design (ASD) used in the Code[†] as well as the proposed Load and Resistance Factor Design (LRFD). It also describes how the partial safety factors applied to mean values of variables are calculated according to the LRFD. Chapter 3 summarizes the available probabilistic information for the resistance and load variables for piping. Chapter 4 presents strength models and calculates the bias of the burst or yielding resistance of pipes due to internal pressure and the bias for the ultimate bending capacity of pipes. Chapter 5 gives the developed load combinations and performance functions. Chapter 6 provides the specific probabilistic characteristics of the variables used in the calculation of the partial load and resistance factors, whereas also a summary of recommended adjusted resistance factors for a predefined set of partial load factors for each performance function and different reliability indices are presented. Chapter 7 introduces a probabilistic framework for the fatigue design of Class 2 and 3 nuclear piping. Finally, Chapter 8 presents the basic conclusions of this work and gives recommendations for future research. Appendix A provides a summary of the Code equations and Appendix B a summary of types and grades of steel used for the design of nuclear pipes operating today in nuclear plants. Appendix C shows analytically the calculated partial load and resistance factors applied to mean values of variables as well as the calculated adjusted nominal resistance factors for predefined sets of nominal load factors. Figure 1-1 presents the structure of the dissertation as described above.

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†: The word “Code” refers to the ASME B&PV Code (2001)

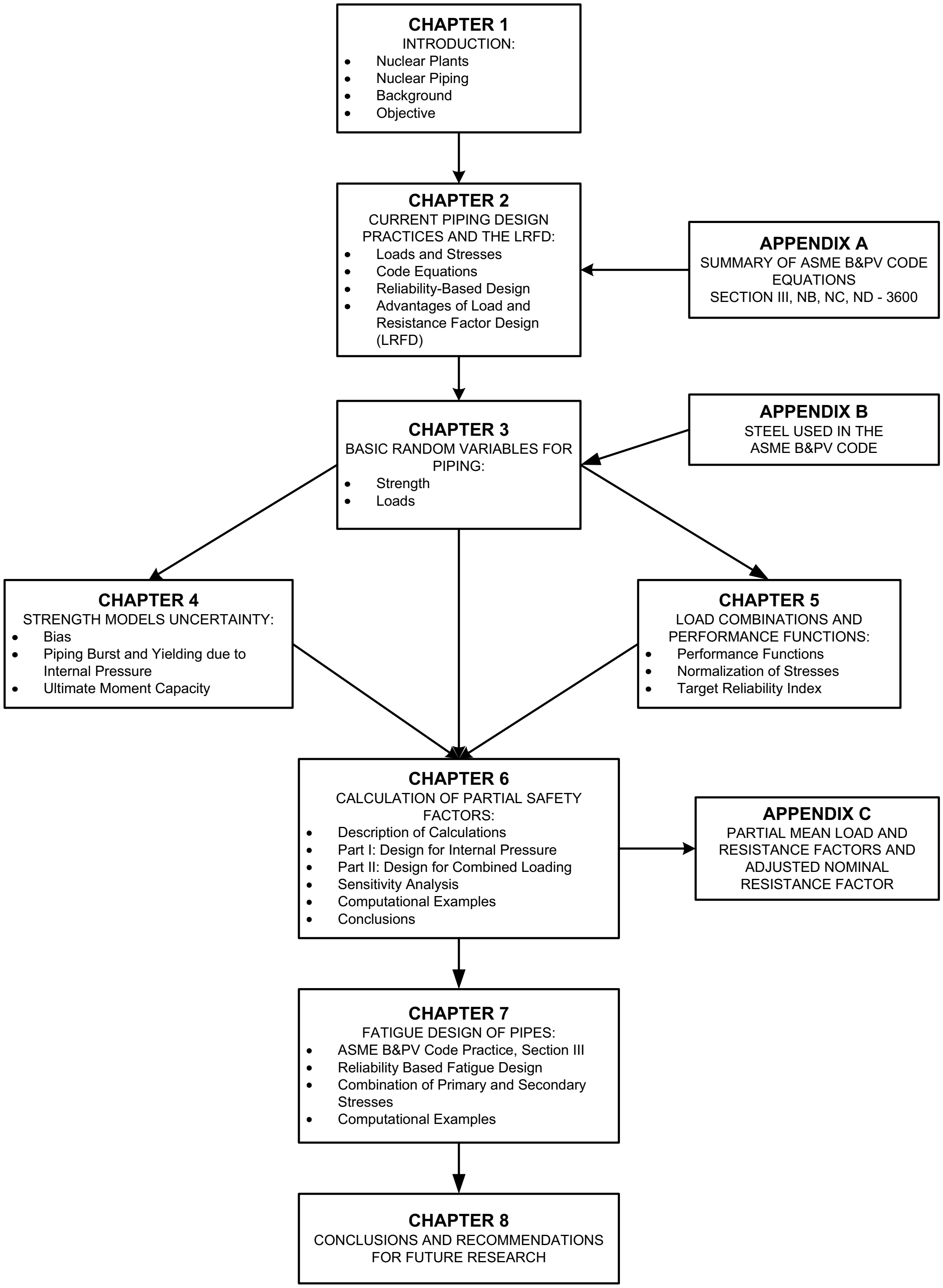


Figure 1-1: Structure of the Dissertation

CHAPTER 2: CURRENT PIPING DESIGN PRACTICES AND THE LRFD

This chapter describes initially the concepts used in the current Code and the methodology, namely the Allowable Stress Design (ASD) for piping. Then, the principles and methodology for a reliability-based design are presented. A comparison of the two methods, ASD and LRFD, moreover is provided. The steps for the calculation of mean safety factors according to the Load and Resistance Factor Design method are demonstrated and an overall illustration of the advantages of the LRFD for piping is given.

2.1. Current Piping Design Practices

First, general information about the ASME B&PV Code, Section III, is provided and then a discussion about the service levels, the loads and stresses definitions is given. The equations and criteria used today for the design for moment loading and internal pressure are discussed, and the derived conclusions are used for the development of the performance functions for the LRFD.

2.1.1. The ASME B&PV Code, Section III

The Allowable Stress Design also called Working Stress Design (WSD) is a reliability I method used for years in the ASME Codes. For this study the ASME B&PV

Code, Section III, Parts NC-3600 (Class 2 piping), and ND-3600 (Class 3 piping) with the included subsections referring to straight pipes are of interest. From Part NB-3600 (Class 1 piping) only equations similar to that of Classes 2 and 3 piping are addressed. The design of pipes in these sections is characterized as ***design by rule*** in opposition to the design by analysis (NB-3200) or by experiment.

The ASME B&PV Code was first issued in 1963 covering only the design of vessels. It is just in the fourth edition of 1971 that the Code was expanded to cover the design of pumps, valves, and piping. New editions of the Code are provided every 3 years. Nevertheless, the last edition approved by the Nuclear Regulatory Commission (NRC) is that of 1992. In this study the equations provided in the edition of 2001 are summarized in Appendix A. The ASME B&PV Code is used or accepted in more than 80 countries around the world. A historical overview of the Code is provided by Ling (2000) and Canonico (2000). In what follows, an illustration of some of the basic concepts like the service levels used in the design of piping according to the ASME B&PV Code but also in the proposed new design is provided. Furthermore, a description of the loading and type of stresses is also presented.

2.1.2. Service Levels

It is in the fourth edition of the ASME B&PV Code (1971) that the concept of normal, upset, emergency and faulted conditions of Class 1 components was introduced; and it is in the sixth edition of 1977 that the concept of Design and Service Limits was presented, covering moreover Class 2 and 3 components. The normal condition is referred thereafter in the Code as Service Limit A, the upset condition as Service Limit B, the emergency condition as Service Limit C, and the faulted condition as Service Limit

D. Other service levels except from the Service Limits A to D are the design and testing service levels. Nevertheless, in this study the testing service level is not addressed.

The design and service limits define: a) the frequency of the occurrence of the loading, and b) the expected type of structural behavior. The most infrequent, namely accidental or faulted, loading and more severe damage are expected for Service Limit D. A definition for the different service levels is as follows:

Design: The piping should remain functional under the design internal pressure and sustained weight. Design equations are applied to all classes of piping and moreover are used in order to define their geometry (thickness, external diameter, etc.). Then, if required, the piping is tested for the different service limits.

Service Limit A: The piping must withstand the loading under normal operation of the plant. Moreover, the piping remains in elastic region under bending stress resulting from deadweight and peak pressure.

Service Limit B: The loading in this service limit occurs often enough and also the effects of an Operating Basis Earthquake and larger pressure are taken into consideration. The piping must withstand these loadings without damage requiring repair. As it concerns bending loading, a hinge formation is not allowed.

Service Limit C: For this service limit, loads as defined in Level B can also be taken into consideration. Nevertheless, this limit permits large deformations in areas of structural discontinuity, which may necessitate the removal of the pipe.

Service Limit D: This service limit permits gross general deformation with some consequent loss of dimensional stability and damage requiring removal of the component or support of service. The loads are expected once in the lifetime of the plant and are a result of faulted or accidental conditions.

2.1.3. Stresses and Loads

The present Code equations for piping design are expressed in terms of stresses. There are three categories of stresses, as presented in the design by analysis part of the Code NB-3200, namely the primary, the secondary and peak stresses. Figure 2-1 summarizes the different stresses and the loads causing them, while Figure 2-2 presents the relevant failure modes. Of course, only some of these stresses will be encountered in this study in an effort to express the design in a probabilistic framework and achieve a consistent reliability (safety).

Primary stresses are result of primary loads, which cause primary principal stresses, shear stresses or bending stresses and must satisfy the laws of equilibrium of external and internal forces and moments. A primary stress is not self-limiting. Therefore, as long as the load is applied, the stress is present and does not reduce with time or as deformation takes place. Primary stresses lead to gross deformations and finally to rupture.

Secondary stresses are principal stresses, shear stresses or bending stresses that are developed due to constraints or displacements of the pipe. These displacements can be caused either by thermal expansion or by outwardly imposed restraint and anchor movements. Secondary stresses are self-limiting. Therefore, local yielding and minor distortions of the piping can relieve these stresses. Failure from one application of the stress is not expected.

Peak stresses are developed for example where there are stress concentrations at a structural discontinuity or thermal gradients through a pipe's wall. The basic characteristic of peak stress is that it does not cause any noticeable distortion and is objectionable only as a possible source of a fatigue crack or brittle fracture.

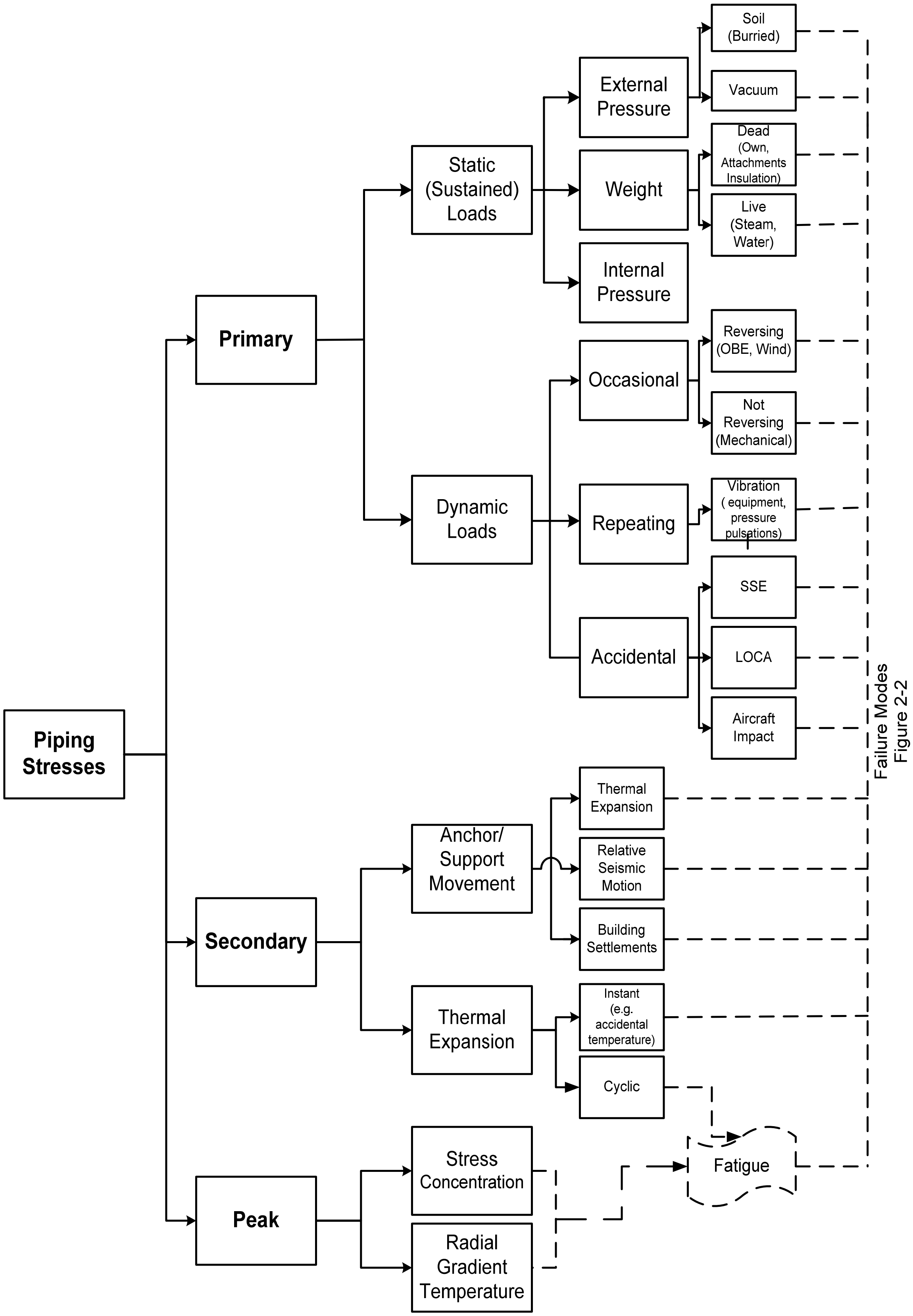


Figure 2-1: Piping Stresses and Loads

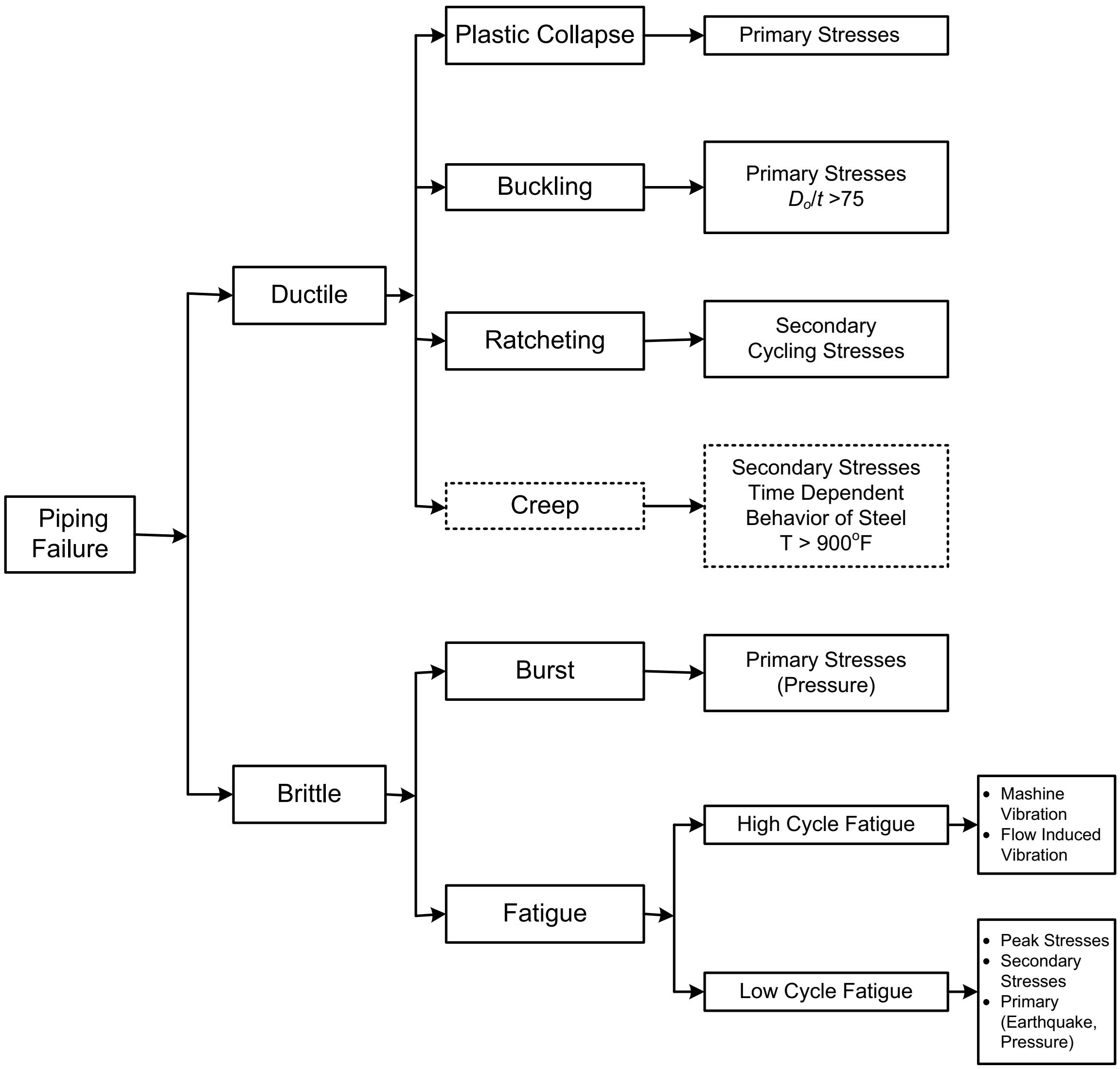


Figure 2-2: Failure Modes for Piping and their Cause

Except from the above division that is provided with respect to the stresses that the loads produce, the primary loads can also be categorized according to their variation in time, as follows:

Constant Loads: Such loads are the weight of pipes and other sustained equipment that do not vary significantly with time.

Pulse Loads: The accidental pressure can be considered as a pulse load. The normal operating pressure can not be considered constant with time, since it might not be always present. Moreover, due to earthquakes or mechanical loads its characteristics change and obtain peak values.

Intermittent Loads: Such loads are dynamic like earthquake and mechanical loads (wave pulses), which vary in time and in magnitude as they take place.

Figure 2-3 presents the loads as defined above. Repeating loads e.g. vibrations due to rotating equipment such as compressors, pumps, turbine drivers, etc. will not be addressed.

Another division should be made among dynamic loads, since this division is considered in the Code, too. There are two types of dynamic loadings, namely reversing and not reversing.

Reversing Dynamic Loads, as shown in Figure 2-1, are loads like earthquake, or reversing pressure pulses after an initial thrust force, which cycle about a mean value.

Not Revering Dynamic Loads are those loads that do not cycle about a mean value. Such loads are the initial thrust force due to sudden opening or closure of valves, waterhammer, etc. Both types of loads we call in this study mechanical although in the ASME Code the term is used to express primary loads other than pressure. Figure 2-4 shows different categories of dynamic loads as illustrated in the ASME B&PV Code (2001).

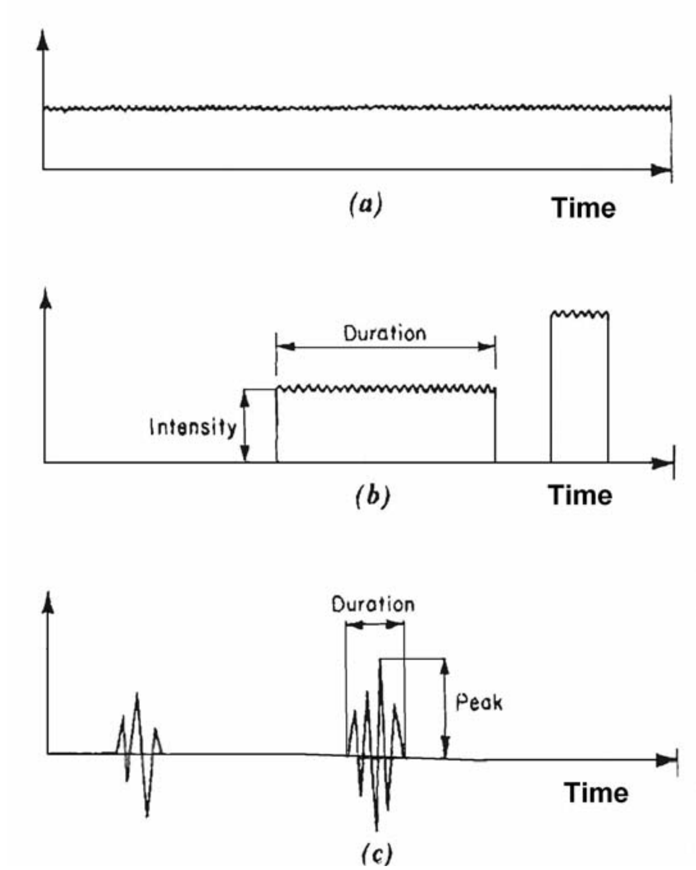


Figure 2-3: (a) Constant Loads, (b) Pulse Loads and (c) Intermittent Loads (Hwang, et al., 1987)

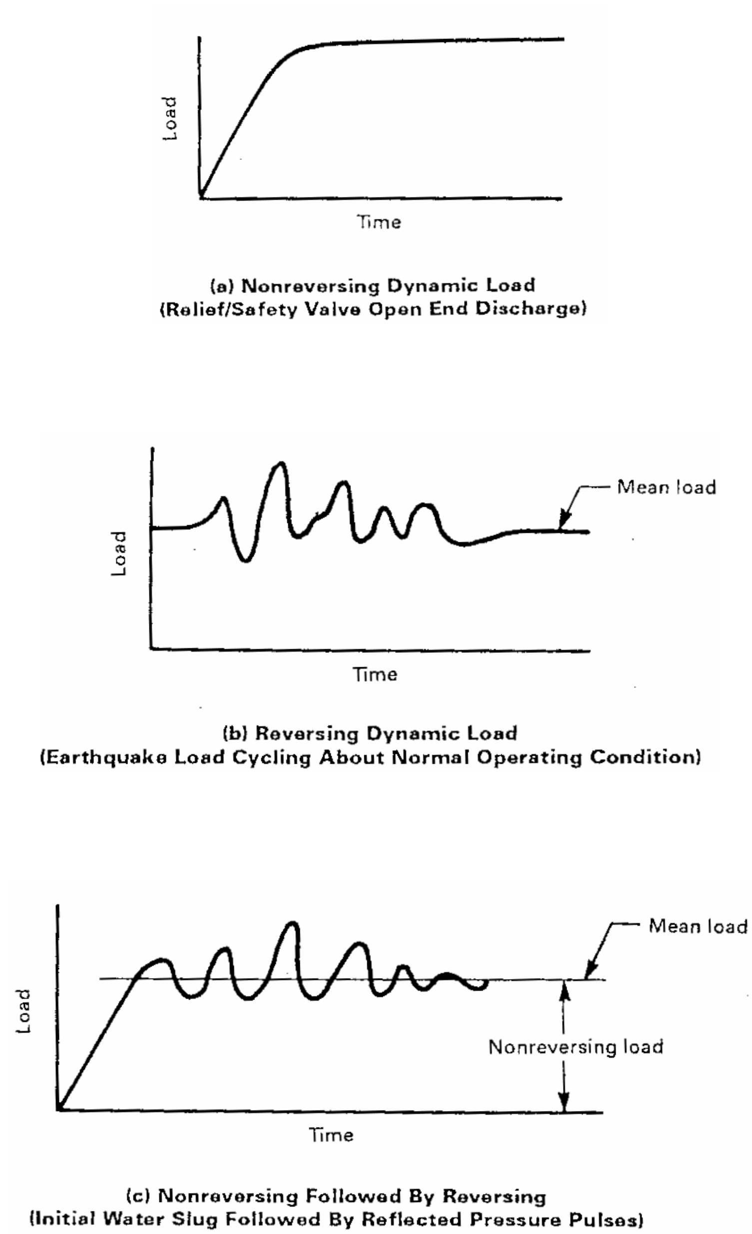


Figure 2-4: Examples of Reversing and Nonreversing Dynamic Loads (ASME B&PV Code, 2001)

2.1.4. Equations in ASME B&PV Code

The design equations in the Code are based on the Allowable (Working) Stress Design. Therefore, the resistance and the loads have nominal values R_N and S_N, respectively, which are a percentage of their mean values. In the case of piping under consideration, the nominal resistance of steel can be considered to be about two standard deviations below the mean value, whereas the nominal values of loads can also be conservative values above their mean. As it will be shown in Chapter 3, for each design temperature the Code provides different nominal values for the yield, S_y, (Section II, Part D, Table Y-1) or ultimate, S_u, (Section II, Part D, Table U) strength of steel.

2.1.4.1. Bending Primary Stresses

The bending stresses in NC and ND-3600 of the Code are calculated for a linear elastic behavior of the material and a factor, ρ, accounts for the nonlinearities as Eq. (2-1) shows. The safety factors in Eq. (2-2) are based on the judgment and past experience of the standard writers (ASME, NRC) in the analysis and structural behavior of piping, as well as on experimental results.

$$\rho R_A = \rho \frac{R_N}{S_f} \geq \sum_{i=1}^{n} S_{N\,i} \qquad (2\text{-}1)$$

$$S_f = \frac{R_N}{S_N} \qquad (2\text{-}2)$$

where S_{Ni} are the nominal values of n stresses for elastic linear material given for bending as $S_{Ni}=M/Z$, where M is the developed moment and Z the elastic section modulus, or as $PD_o/4t$ for the effect of internal pressure. R_A is an allowable stress equal to S_y, S_h or S_m depending on the piping class. Table 2-1 presents how the different allowable stresses are defined in the Code, including also the allowable stress for fatigue, S_A. Table 2-2 presents the values of ρ and the resultant resistance stress for operation at room temperature.

Table 2-1: Definition of Stresses Symbols Used in the Code

Symbol	Definition	Value	Use	Class
S_y	Nominal Yield Strength at Loading Temperature	S_y	Section II, Part D Table Y-1	All
S_u	Nominal Ultimate Strength at Loading Temperature	S_u	Section II, Part D Table U	All
S_h	Allowable Stress at Loading Temperature	min{0.25S_u, 0.667S_y) or min{0.25S_u, 0.9S_y) if stainless at elevated temperatures	Section II, Part D Table 1B	2, 3
S_m	Allowable Stress at Loading Temperature	min{0.333S_u, 0.667S_y) or min{0.25S_u, 0.9S_y) if stainless at elevated temperatures	Section II, Part D Table 2A	1
S_c	Allowable Stress at R.T. (cold)	Equal to S_h for its value at room temperature	Section II, Part D Table 1B	2, 3
S_A	Allowable Stress Range for Expansion Stresses	$S_A = f(1.25S_c + 0.25S_h)$	For f Table NC-3611.2(e)-1	2, 3

Table 2-2: Values of ρ and Resultant Resistance Stress for Operation at Room Temperature

Class	Service Level	Equation in Appendix A	ρ	Additional Limit	Resultant Resistance Stress at Room Temperature
1	Design	A-4	1.5	Not Available	min{0.5S_u, S_y}
	B	A-15	1.8	$\leq 1.5S_y$	min{0.60S_u, 1.2S_y)
	C	A-22	2.25	$\leq 1.8S_y$	min{0.74S_u, 1.5S_y)
	D	A-32	3	$\leq 2S_y$	min{S_u, 2S_y)
2, 3	Design	A-5	1.5	Not Available	min{0.37S_u, S_y}
	B	A-16	1.8	$\leq 1.5S_y$	min{0.46S_u, 1.2S_y}
	C	A-27	2.25	$\leq 1.8S_y$	min{0.56S_u, 1.5S_y)
	D	A-38	3	$\leq 2S_y$	min{0.75S_u, 2S_y)

As discussed by many researchers (Ayyub, et al., 2005; Mello, et al., 1974; Rodabaugh, et al., 1978) the resultant resistance stress reflects the accepted structural behavior of the piping. For example the 1.2S_y limit for Service Level B, can be considered as a conservative value for the shape factor, s, as explained below, and the 1.5 for Service Level C as a value representing the allowance for a formation of a plastic mechanism.

Table 2-3 presents the limit theory loading for linear perfectly plastic behavior of the material. More specifically, it shows the load needed to cause a first yield at the exterior fiber of the pipe's most critical cross-section, the load needed for the formation of a single hinge and the one that causes a collapse mechanism for different loading and boundary conditions of pipes. In the table s is the shape factor and is equal to the ratio of the plastic, Eq. (2-3), to the elastic section modulus, Eq. (2-4), of pipe's cross-section. For D_o/t=10, s is 1.40, whereas as $D_o/t \rightarrow \infty$, s equals 1.27. Thus, the margin between the yield moment, M_y and the limit moment, M_P, which is the moment at first hinge, depends on the ratio of the external diameter to thickness, D_o/t. Moreover, the margin between the yield moment and the plastic moment, which is the moment that causes a collapse mechanism, depends not only on the D_o/t ratio but also on the indeterminacy of the pipe. In case 1 of Table 2-3, for example, the simply supported pipe, as other statically determined pipes, reaches the plastic moment as soon as the first hinge is formed.

For Service Limit D the resultant resistance stress is much higher, since large deformations are allowed in order for strength hardening of the material to develop, too.

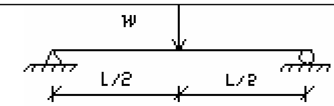
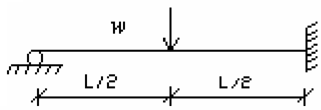
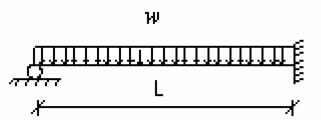
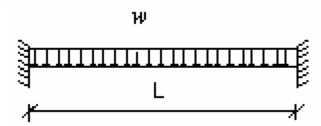
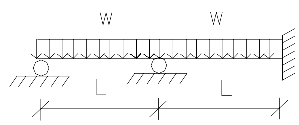
$$Z = \frac{\pi\left(D_o^{\ 4} - d^4\right)}{32 D_o} \tag{2-3}$$

$$Z_P = \frac{D_o^{\ 3} - d^3}{6} \approx (D_o - t)^2 t \tag{2-4a}$$

or

$$Z_P = \frac{D_o^{\ 3}}{6}\left[1 - \left(1 - \frac{2t}{D_o}\right)^3\right] \tag{2-4b}$$

Table 2-3: Limit Theory Loading

Case	Pipe	First Yield Load, w	First Hinge Load, w_p	Plastic Load, w_c
1		$\frac{4M_Y}{L}$	$\frac{4M_P}{L} = ws$	ws
2		$\frac{16M_Y}{3L}$	$\frac{16M_P}{3L} = ws$	$1.125\,ws$
3		$\frac{8M_Y}{L^2}$	$\frac{8M_P}{L^2} = ws$	$1.47\,ws$
4		$\frac{12M_Y}{L^2}$	$\frac{12M_P}{L^2} = ws$	$1.33\,ws$
5		$\frac{9.34M_Y}{L^2}$	$\frac{9.34M_P}{L^2} = ws$	$1.16\,ws$

L=length as in figures, M_y=first yield moment, M_p=first hinge moment, w=applied load as in figures, s=shape factor

The criterion used in the Code in order to express the effect of internal pressure and other accompanying primary loads is the Tresca. More specifically, given an element of straight, circular pipe subjected to three principal stresses, $\sigma_L>\sigma_H>\sigma_R$, the Tresca criterion states that yielding is dependent on the maximum shear stress at yielding in a uniaxial tensile test and equals half the difference between the maximum and minimum principal stresses. Hence,

$$\tau_{max} = \frac{(\sigma_L - \sigma_R)}{2} = \frac{S_y}{2} \tag{2-5}$$

where σ_L=longitudinal stress, σ_H=hoop stress, σ_R=radial stress of pipe, and S_y=the yield strength of steel.

Considering also conditions for thin wall cylinders and the radial stress, σ_R, to be zero, Eq. (2-5) yields

$$\sigma_L = S_y \tag{2-6}$$

If the straight pipe is subjected to internal pressure and bending and by neglecting the shear forces, or other axial forces for being relative small compared to the induced moment stresses, Eq. (2-6) gives:

$$2\tau_{\max} = \frac{PD_o}{4t} + \frac{M}{Z} = S_y \tag{2-7}$$

where, $PD_o/4t$ is the longitudinal stress due to internal pressure P and M/Z is the term that represents the maximum longitudinal stress due to bending at the outer fiber of the most critical cross-section of the pipe. Moreover, M is considered as the resultant moment of three orthogonal components at any cross-section, and therefore the stress M/Z is not truly longitudinal but rather a conservative estimate of the longitudinal stress.

The negligence of other forces (axial, shear) in the failure criterion is discussed by Antaki (1993), who actually states that the criterion is based on the assumption of large moments such as other forces are neglected. Nonetheless, it can be claimed that the negligence of shear stresses is not very important especially for slender beams-pipes, since shear stresses are normally much smaller than the moment stresses in piping systems. Moreover, the shear stresses are negligible at locations, where moment stresses are maximum. That is not the case though, when big concentrated loads arising from the attachment of heavy equipment on pipes are present, although in such cases the usual practice is to provide a support that sustains the increased load.

For the combination of stresses also the Von-Mises criterion could have been used as other researchers have done (Rodabaugh, 1979). Under the same assumptions used for the Tresca criterion, the Von Mises criterion, which considers that yielding commences when the energy, U_S, stored due to the change of pipe's shape becomes equal to the yield strength, S_y, yields:

$$\sigma_L^{\ 2} + \sigma_H^{\ 2} - \sigma_L \sigma_H = S_y^{\ 2} \tag{2-8}$$

It is obvious that the Tresca criterion, Eq. (2-7), is much simpler than the Von Mises criterion, Eq. (2-8), which moreover involves the hoop stress σ_H that is dependent on the boundary conditions of pipe. In the case of a thin wall circular, cylindrical tube subjected to axial force and internal pressure the maximum divergence of the two criteria is 15%, with the Tresca criterion being more conservative. This divergence is usually considered as not appreciable (Armenákas, 2006). The ASME B&PV Code, Section III uses the Tresca criterion with the assumption of large moments and so does the proposed LRFD method.

2.1.4.2. Stress Indices

The equations in the ASME BVP Code have generally the following form:

$$B_1 \frac{PD_o}{2t} + B_2 \frac{M}{Z} \leq \rho S \tag{2-9}$$

where, M is the resultant moment and P is the applicable pressure for the different service levels and accompanied loadings and ρ a multiplier of the allowable stress. Moreover, S is the allowable stress of steel at the design temperature, t and Z are respectively the thickness and the elastic section modulus of pipe.

It is noticeable that indices like B_1 and B_2 are also used. These indices for straight pipes are B_1=0.5, and B_2=1 that yield Eq. (2-7). Therefore, the indices have a meaning for pipe components other than straight pipes. More specifically, they are multipliers used to obtain the stress of piping components such as elbows and reducers with respect to the stress of straight pipes. While B_i indices are multipliers for primary stresses there are also the C_i and i indices that are applicable to secondary and peak stresses, respectively, and account for the increased flexibility and intensification of stresses of components like elbows, tees, reducers, etc. Nevertheless, all these indices except B_1 = 0.5, are equal to 1 for straight pipes and in this work their statistical properties are not examined. Discussion for these indices is provided among others by Kumar, et al. (2002), Yu, et al. (1999), Matzen, et al. (2002), Venkataramana, et al. (2004), Markl, et al. (1955). Stress indices are given in Table NB-3681(a)-1 of the Code.

2.1.4.3. Internal Pressure

In the Code, in Sections NB-3600, NC-3600, and ND-3600 the design for internal pressure defines a) the minimum thickness of piping and b) the allowable pressure for each service level.

a) Minimum thickness of piping

The minimum thickness of piping is evaluated according to NB-3641, NC-3641, ND-3641, and here is given by Eq. (2-10).

$$t_m = \frac{P_{Des}\, D_o}{2\,(S + P_{Des}\, y)} + A \qquad (2\text{-}10)$$

where P_{Des} is the design internal pressure, D_o is the pipe's outside diameter, S is the maximum allowable stress for pipes of Class 2 (S_m for pipes of Class1 and $S\,E$ for pipes of Class 3) at the design temperature, y a coefficient having the value of 0.4 or $y = d/(d{+}D_o)$, when the ratio D_o/t_m is less than 6, d is the pipe's inside diameter, E is a joint efficiency factor reducer of the allowable stress, depending on the type of longitudinal joint used, and *A* an additional thickness that accounts for the reduction of the thickness during erection or during the functional life of piping (e.g., corrosion, erosion, etc.). Values of *A* as given in the Code are presented in Table 2-4.

Table 2-4: Values of Additional Thickness *A* (ASME B&PV CODE, 2001)

Type of Pipe	*A* (in)
Threaded steel and nonferrous pipe:	
¾ in nominal (DN 20) and smaller	0.065
1 in nominal (DN25) and larger	Depth of groove
Grooved steel and nonferrous pipe	Dept of groove plus 1/64 in

Equation (2-10) is the Boardman model and constitutes an approximation of the hoop stress calculated by the Lamé model, considering moreover the maximum principal stress criterion of failure. In other ASME Codes (e.g., B31.1), the *y* in the Boardman model considers also the creep of steel in temperatures over 900^{o}F, but not in the ASME B&PV Code, since these pipes usually operate in temperatures lower than about 800^{o}F.

b) Allowable pressure

Figure 2-5 defines the terms of pressure used in the ASME B&PV Code for each service level, where different pressure loading can occur due for example to an acting earthquake, water hammer, a shock wave from a pipe that breaks, overpressure due to malfunctions of the system, etc. Moreover, although valves are responsible for keeping a constant pressure in piping, within each service level there is actually a variation of the pressure.

Design pressure is the pressure that engineers estimate initially as the maximum pressure for the normal functioning of a pipe in order to calculate its schedule and minimum thickness. Should a higher value of thickness is selected than the minimum obtained using the design pressure, the resultant allowable pressure becomes greater than the design pressure by a quantity, *b*, as Figure 2-5 shows, otherwise the two are equal. For Service Limits B, C, and D the ASME Code permits an augmentation of the allowable (maximum) pressure, P_α, which reflects in return an augmentation of the allowable stress, *S*. Table 2-5 shows the permissible pressure for each service limit and the resultant permissible allowable stress for Class 1 pipes based on the definition of allowable stresses provided in Table 2-1. It can be seen for example that for Service Limit D the pipe's stress can exceed the yield strength of steel for Class 1 pipes but also for Class 2 and 3 piping, since in that latter case the resultant allowable stress is equal to min$\{0.50f_u, 1.33f_y\}$. An extensive discussion for the calculation of hoop stress and the validity of different models is provided in Chapter 4.

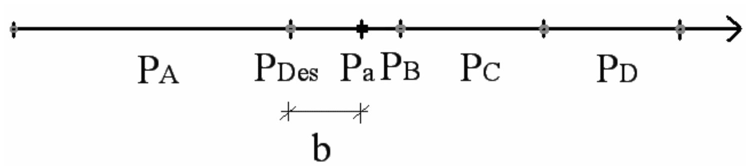


Figure 2-5: Magnitude of Pressure in an Augmenting Scale for Different Service Levels for a Pipe's Operation

Table 2-5: Permissible Pressure for Class 1 Piping According to ASME B&PV Code, Section III

Service Level	Symbol	Permissible Pressure	S_m*	Resultant Allowable Stress
Design	P_{Des}	P_α		min$\{0.33S_u, 0.67S_y\}$
A	P_A	P_α		min$\{0.33S_u, 0.67S_y\}$
B	P_B	$1.1P_\alpha$	min$\{0.333S_u, 0.667S_y\}$	min$\{0.37S_u, 0.73S_y\}$
C	P_C	$1.5P_\alpha$		min$\{0.5S_u, S_y\}$
D	P_D	$2P_\alpha$		min$\{0.67S_u, 1.33S_y\}$

*Allowable stress according to ASME B&PV Code, Section II for Class 1 cold pipes

2.1.4.4. Other Codes for the Design of Piping

Antaki (1999) presents a comparative study of Canadian and European Codes used for the design of piping. As it is the case of structural codes, the European countries (England, Germany, France, Finland and Norway are the countries that have developed their own codes for the design of nuclear piping) have unified their Codes under EN 13480-3. There is also the Japanese and Russian Codes but as far as the author knows, all these codes are using the ASD method, while some of them are more detailed about the load combinations than the ASME B&PV Code.

2.2. Reliability-Based Design

Codes using reliability analysis can be divided in four levels (Madsen, et al., 1986). Level I codes are like the Allowable Stress Design used in the ASME B&PV Code that uses safety factors. In that context the proposed method, the Load and Resistance Factor Design can also be considered as Level I code, since it uses safety factors, although for their derivation level II reliability methods are utilized. Often the LRFD is referred as semi-probabilistic design method. For Level II codes a target reliability index defines the design criteria as for example does the direct reliability method. Level III and IV Codes are used in advanced research. More specifically, Level III codes use full reliability analysis and try to achieve an optimum reliability level or probability of failure, while Level IV codes use optimization in order to reduce the cost and increase the benefits of the design.

2.2.1. The Load and Resistance Factors Design Method

The Load and Resistance Factor Design (LRFD) method is based on the requirement that a reduced by a factor φ nominal resistance is larger than the linear combination of magnified by factors γ_i nominal loads, as Eq. (2-11) shows:

$$\varphi R_n \geq \sum_{i=1}^{n} \gamma_i L_{n\,i} \tag{2-11}$$

The factors are determined probabilistically and therefore correspond to a predefined level of safety and a predefined service life. Different load and strength factors are used for each type of load and the strength. This is a major difference from the ASD method, in which only one factor tries to account for all the uncertainties in the design. Usually, the higher the uncertainty associated with a load, the higher the corresponding load factor is; and the higher the uncertainty associated with strength, the lower the corresponding strength factor is.

2.2.1.1. Procedure for the Development of Load and Resistance Factor Design

For the development of Load and Resistance Factor Design the following steps are followed that moreover are illustrated in Figure 2-6:

- Definition of data space
- Identification of limit states and derivation of performance functions
- Characterization of model uncertainty and probabilistic characteristics of basic random variables
- Selection of target reliability index, β

- Computation of partial safety factors

Information for the steps mentioned above is provided in the following sections or in separate chapters. More specifically, the definition of the data space is presented in Section 2.2.1.2, a general discussion about the performance functions is provided in Section 2.2.1.3, while specifically for the performance functions for piping as well as for the target reliability index, *β*, details are given in Chapter 5. The probabilistic characteristics of the basic random variables are given in Chapter 3 and the characterization of the model uncertainty is illustrated in Chapter 4. In Section 2.2.1.4 the calculation of partial safety factors applied to mean values of variables is presented, whereas the procedure for obtaining partial safety factors applied to nominal values of variables is given in Chapter 6.

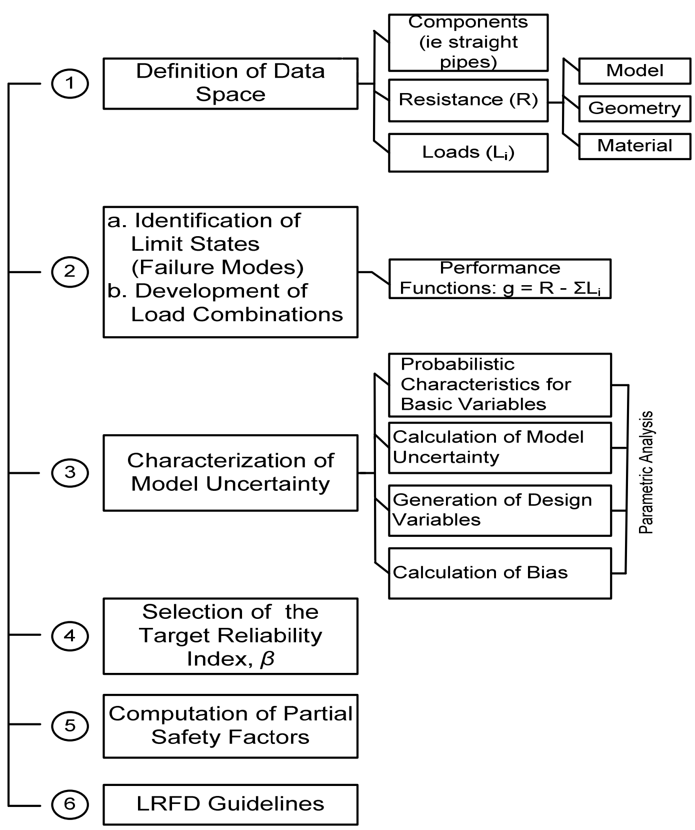


Figure 2-6: Steps for the Development of Load and Resistance Factor Design

2.2.1.2. Data Space

For the development of reliability-based codes, the data space should be first determined such as suitable limitations are applied. More specifically, the type of components, the material, the geometry, the structural modeling, and the considered loads need to be specified. For the reliability-based design of piping the following parameters are considered in this study:

The pipes belong to all safety piping classes as defined in Section 1.3. Class 2 and 3 piping constitutes the majority of piping installed in nuclear plants. Class 3 piping is also present in other power plants like those that burn coal and their design can be made according to the ASME B&PV Code or ANSI B31. Chapter 7 that includes the design of piping for thermal expansion addresses only Class 2 and 3 piping. No equations are provided for the buckling of pipes or for the effects of external pressure (e.g., buried pipes). The working fluids in pipes are mainly water and steam. Pipes operate in different temperatures up to 800^{o}F for stainless steel, and 700^{o}F for carbon steel. In Chapter 6, calculations for carbon steel address 800^{o}F temperature, too. This is because statistical information was available for carbon steel and 800^{o}F. Similar limits in temperature exist also in the current design, which permits creep of steel not to be considered.

The material of pipes is either stainless, austenitic steel or carbon steel. These types of steel show corrosion resistance and are intended to perform well under high temperatures. They are representative materials for nuclear piping, although the author recognizes the existence of other types of steel (e.g., duplex steel, low alloy stainless steel, etc.), which are not addressed in this study. With the introduction of new technology reactors, new, improved types of steel may also get introduced.

Although for Class 3 the usual material is carbon steel all calculations will address both materials. Different design equations are developed for carbon and stainless steel, since, as shown in Chapter 3, these steels have different statistical properties. The steel behavior is considered to be linear elastic–perfectly plastic and limit theory is considered. The pipes can be considered and analyzed as space frame structures. For Service Level D also strain hardening is judged to be considered, since for this service level accidental loads of large magnitude and large deformations are considered. Therefore, a larger allowable stress is permitted and the Tresca yield surface is expanded approximately 2.15 times. This value is the mean value of the ratio of the ultimate to yield strength with a coefficient of variation approximately equal to 0.19. Detailed discussion about Service Level C is provided in Section 5.1.

2.2.1.3. Performance Functions

The performance functions or limit state equations are equations that express mathematically the relation between the load(s) and the resistance. Once the performance function becomes equal to zero, a limit state for the design is reached. The term limit state is used in the reliability-based design and shows that a component becomes unfit for its intended use under the specific loading conditions. Therefore, in a successful design the component should not reach the limit state. Limit states are divided in strength, serviceability or fatigue limit states. Serviceability limit states ensure the functionality of pipes (e.g., no yielding or acceptable deformations) while the strength ones characterize the ultimate capacity of components.

As mentioned previously, the performance functions include terms of strength, R, and loading, L. In order to avoid an undesirable limit state, the strength of the component should be greater than its loading. Equation (2-12) shows a general performance function as the difference of the strength and load, which can also be considered as demand minus offer.

$$g_1 = R - L \tag{2-12}$$

where g_1=performance function, R=strength (resistance) and L=load to which the structure is subjected. The failure in this case is defined in the region, where g_1 is less than zero, or R is less than L, that is:

$$g_1 < 0 \quad \text{or} \quad R < L \tag{2-13}$$

As an alternative approach to that of Eq. (2-12), the performance function can also be written as:

$$g_2 = \frac{R}{L} \tag{2-14}$$

where now the failure is defined in the region where g_2 is less than one, or R is less than L, that is:

$$g_2 < 1 \text{ or } R < L \tag{2-15}$$

Equation (2-12) or (2-14) relate the strength and load and moreover, by considering them as random variables, the probability of failure of a component can be defined as:

$$P_f = \text{Prob}\,(g_1 < 0.0) = \text{Prob}\,(R < L) \tag{2-16}$$

or

$$P_f = \text{Prob}\,(g_2 < 1.0) = \text{Prob}\,(R < L) \tag{2-17}$$

The probability of failure as defined by Eq. (2-16) is shown schematically in Figure 2-6. In the general case that the performance function is expressed according to Eq. (2-18) as:

$$g(\boldsymbol{X}) = g(X_1, X_2, ..., X_n) \tag{2-18}$$

in which $\boldsymbol{X}$ is a vector of basic random variables (X_1, X_2, ..., X_n), the probability of failure attains the form of the joint probability distribution function of X_{i}, as Eq. (2-19) shows.

$$P_f = \underset{\text{over } g\leq 0}{\int ... \int} f_X(x_1, x_2, ..., x_n)\, dx_1\, dx_2 ... dx_n \tag{2-19}$$

The calculation of this integral is a difficult task and therefore usually a Monte Carlo simulation, preferably with variance–reduction techniques, is used. Alternatively, the probability of failure can be approximated by Eq. (2-20) (Ayyub, et al., 2003).

$$P_f = \Phi(-\beta) = 1 - \Phi(\beta) \tag{2-20}$$

where Φ(**.**)=cumulative probability distribution function of the standard normal distribution, and β=reliability index. The probability of failure obtained by Eq. (2-20) is accurate when the performance function is linear and the implicated random variables normally distributed. Anyhow, in most practical cases the equation provides sufficient accuracy for P_f, (Ayyub, et al., 2003).

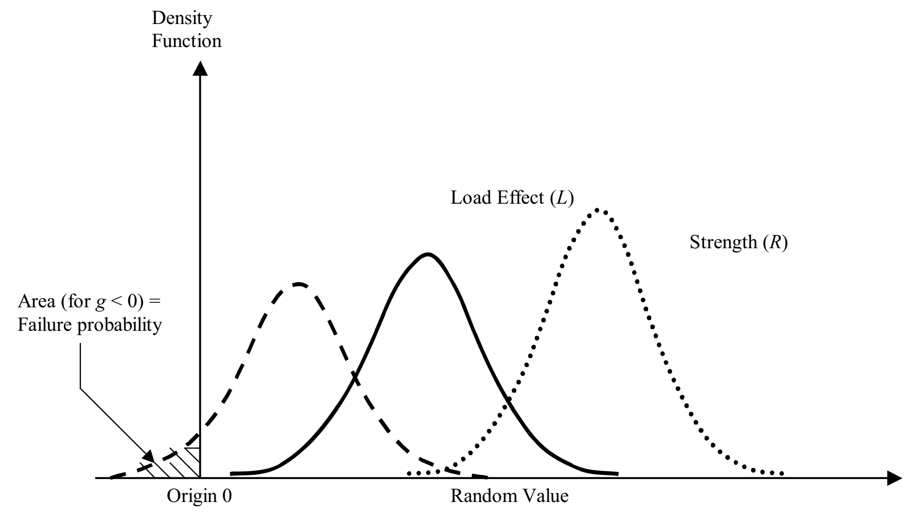


Figure 2-6: Reliability Density Functions of Resistance (R) and Load (L) and Probability of Failure (Ayyub, et al., 2003)

2.2.1.4. Calculation of Safety Factors Applied to Mean Values of Variables

The reliability methods used in order to quantify the partial safety factors applied to mean values of variables are the First Order Second Moment (FOSM) and the Advanced First–Order Second Moment (AFOSM) methods. Both are variations of the First-Order Reliability Method (FORM). More specifically, the FOSM method ignores the distribution of the random variables and considers only the moments (coefficient of variation and mean value). Therefore, it is accurate only when the random variables are normally distributed and the performance functions linear. Moreover, the performance function $g(\boldsymbol{X})$ in Eq. (2-18) is linearized at the mean values of the X_i variables. This results in an invariance problem, since the converged reliability index is dependent on the specific form of the performance function (Novak, et al., 2002; Haldar, et al., 2000). The

FOSM method is usually used for preliminary design. Under the limitations of FOSM the target reliability index, β, is given by Eq. (2-21) (Ayyub, et al., 2003).

$$\beta = \frac{\mu_R - \mu_L}{\sqrt{\sigma_R^2 + \sigma_L^2}} \tag{2-21}$$

where μ_R=mean value of strength R, μ_L=mean value of the load effect L, σ_R=standard deviation of strength R, and σ_L=standard deviation of the load effect L. The reliability index according to this definition is commonly referred to as the Hasofer-Lind (1974) index.

In this study, the AFOSM method will be utilized, which moreover takes into account any type of distribution for the random variables and even non-linear limit states, in order to evaluate the partial safety factors applied to mean variables (mean factors). In this study the variables are considered uncorrelated, although with transformations the method can be used also for correlated variables. If, generally, the performance function is expressed according to Eq. (2-18) in which $\boldsymbol{X}$ is a vector of basic random, uncorrelated variables (X_1, X_2, ..., X_n) for the strength and the loads, then the variables can be reduced in a coordinate system $\boldsymbol{X'}$ having zero mean and unit standard deviation. Hence, the limit state is reached when $g(\boldsymbol{X'})=0$, and therefore, failure occurs when $g(\boldsymbol{X'})<0$. In a reduced coordinate system the reliability index, β, is defined as the shortest distance from the origin to the failure surface at the most probable failure point, as Figure 2-7 shows. The AFOSM is beneficial not only because it considers variables with different distributions but also it has not the invariance problem described above.

For the calculation of the mean partial safety factors a modified Rackwitz-Fiessler iterative algorithm is used (Ayyub, et al., 2003), as briefly described below:

1. Assume a design point x_i^* and obtain $x_i^{'*}$, using the following equation:

$$x_i^{'*} = \frac{x_i^* - \mu_{X_i}}{\sigma_{X_i}} \tag{2-22}$$

where $x_i^{'*} = -\alpha_i^* \beta$, μ_{X_i} =mean value of the basic random variable, and σ_{X_i} =standard deviation of the basic random variable. Usually, the mean values of the basic random variables are used as initial values for the design points. The notations x^* and $x^{'*}$ are used for the design point in the regular coordinates and in the reduced coordinates, respectively.

2. Evaluate the equivalent normal distributions for the non-normal basic random variables at the design point using the following equations:

$$\mu_X^N = x^* - \Phi^{-1}\left(F_X(x^*)\right)\sigma_X^N \tag{2-23}$$

and

$$\sigma_X^N = \frac{\varphi\left(\Phi^{-1}\left(F_X(x^*)\right)\right)}{f_X(x^*)} \tag{2-24}$$

where μ_X^N = mean of the equivalent normal distribution, σ_X^N = standard deviation of the equivalent normal distribution, $F_X(x^*)$ = original cumulative distribution function (CDF) of X_i evaluated at the design point, $f_X(x^*)$=original probability density function (PDF) of X_i evaluated at the design point, $\Phi(\cdot)$=cumulative density function of the standard normal distribution, and $\varphi(\cdot)$=probability density function of the standard normal distribution.

3. Compute the directional cosines (α_i^*, i=1, 2, ..., n), using the following equations:

$$\alpha_i^{\ *} = \frac{\left(\dfrac{\partial g}{\partial X'_i}\right)_*}{\sqrt{\sum_{i=1}^{n}\left(\dfrac{\partial g}{\partial X'_i}\right)_*^2}} \tag{2-25}$$

   where,

$$\left(\frac{\partial g}{\partial X'_i}\right)_* = \left(\frac{\partial g}{\partial X_i}\right)_* \sigma_{X_i}^N \tag{2-26}$$

4. With α_i^*, $\mu_{X_i}^N$, and $\sigma_{X_i}^N$ now known, the following equation can be solved for β:

$$g\left[(\mu_{X_1}^N - \alpha_{X_1}^* \sigma_{X_1}^N \beta), ..., (\mu_{X_n}^N - \alpha_{X_n}^* \sigma_{X_n}^N \beta)\right] = 0 \tag{2-27}$$

5. Using the β obtained from step 4, a new design point can be obtained from the following equation:

$$x_i^* = \mu_{X_i}^N - \alpha_i^* \sigma_{X_i}^N \beta \qquad \text{for } i=1, 2,\ldots, n \tag{2-28}$$

6. Repeat steps 1 to 5 until a convergence of β is achieved. Finally, the reliability index will be the shortest distance to the failure surface from the origin in the reduced coordinates system as explained above.
7. Calculate the mean partial safety factors, using the coordinates of the failure point. By noting R*, and L_i* the values of resistance and loads at the design point on the failure boundary the partial factors are given as:

$$\varphi = \frac{R^*}{\mu_R} \tag{2-29a}$$

$$\gamma_i = \frac{L_i^*}{\mu_{L_i}} \tag{2-29b}$$

where, μ_R, μ_{Li} are the mean values of resistance and loads, respectively.

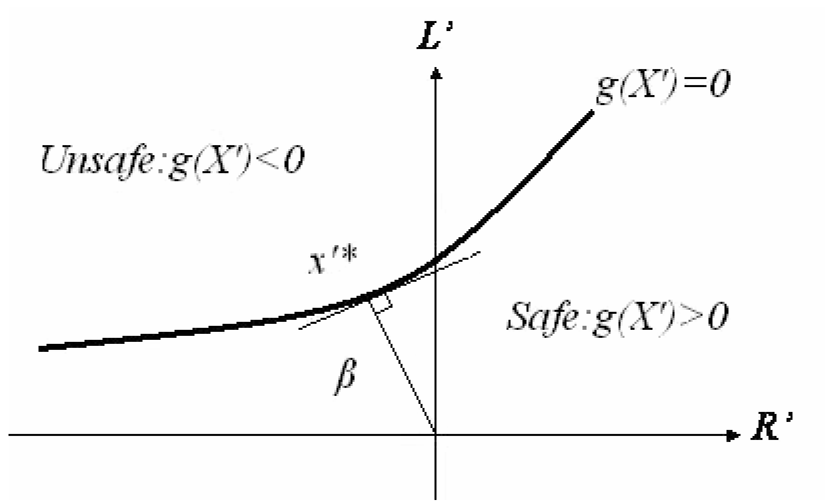


Figure 2-7: Space of Reduced Random Variables Showing the Reliability Index, β, and the Most Probable Failure Point x'^*

2.2.2. Direct Reliability Design

This method is a level II reliability method and here is used in the fatigue design of piping presented in Chapter 7. For a given a performance function and the probabilistic characteristics of all implicated variables, the converged reliability index is computed and then compared to a predefined desirable reliability index, β. For an adequate design the converged reliability index, β_c, should be greater than the target reliability index. Hence, the convergence of the used AFOSM is achieved with respect to the value of the reliability index.

2.3. Comparison of ASD and LRFD

Table 2-6 summarizes the characteristics of the two methods, such as their comparison will be facilitated. Figure 2-8, in addition, shows schematically the definition of symbols used in Table 2-6 for LRFD. The existing probability of failure is graphically presented by the intersection of the distributions of the load (*L*) and resistance (*R*) (dark grey). The use of factors for both the resistance and the load limit the probability of failure to a predefined quantity P_f. As the nominal values used in the ASD method are based only on the mean values of variables, it can be inferred that as the distribution or the coefficient of variation of the resistance or the load changes, the load and resistance partial factors of LRFD can follow these changes, whereas the deterministic safety factor, based only on mean values of variables, results in highly diverse and unknown probabilities of failure (Ang, et al., 1975; Rao, 1992).

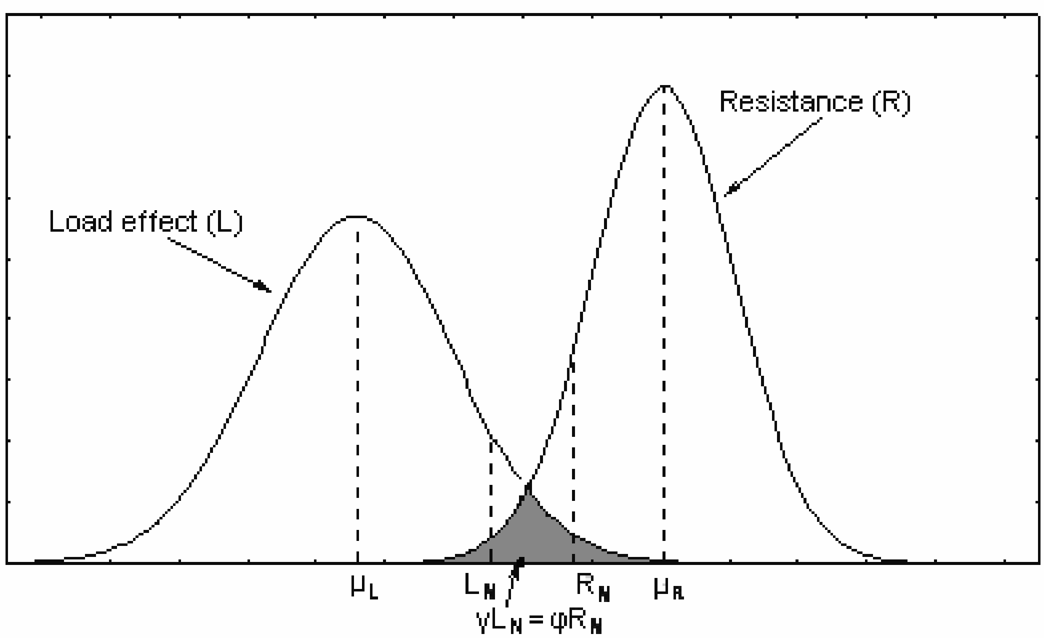


Figure 2-8: Relationships among Nominal (L_N, R_N), Mean (μ_L, μ_R), and Factored Values (γL_N, φR_N) for the Load and the Resistance

Table 2-6: Characteristics of the ASD and LRFD Methods

	Allowable Stress Design (ASD)	Load & Resistance Factor Design (LRFD)
Format:	$\frac{R_N}{S_f} \geq \sum_{i=1}^{k} L_{Ni}$	$\varphi_N \; R_N \geq \sum_{i=1}^{k} \; \gamma_{N\,i} L_{N\,i}$
Safety factors:	One: S_f applied to the nominal resistance R_N	Multiple: φ_N for the nominal resistance R_N and γ_{Ni} for each nominal load or load effect L_{Ni}.
Calculation of safety factors:	1. They are based only on nominal values of load and resistance (L_N, R_N) that correspond to percentile values of the mean. All uncertainties are considered through this one factor. 2. They are based on the experience of Code writers in the design, analysis and structural behavior of pipes under different loading conditions as well as on experimental results. Over the years and for particular structures, safety factors have been firmly established.	1. Although the method is not a full probabilistic method, it takes into consideration the types and the moments of the distribution of loads and resistance. Uncertainties are considered through multiple factors. 2. The resultant load and resistance factors are calculated for a reliability index, β, which reflects the acceptable probability of failure and in consequence the acceptable risk for the service life of components. This attribute is significant, since values of β can be used in reliability studies.
Consistency:	Through calibration the implemented values of the reliability index, β, usually range significantly.	The variation of the reliability index, β, is small and controlled by the Code writers.

2.4. Advantages of LRFD

LRFD offers important benefits when compared with ASD and more specifically:

- It provides consistent reliability among classes of pipes and materials. In ASD the reliability index can vary for different materials and design temperatures and usually is unknown.

- It is consistent with the design of other industries (ACI, AISC, AASHTO, API) and other sections of the Code, such as the Section XI, where a probabilistic framework is used in order to program in-service inspections or decide for repairs.
- It facilitates the risk analysis of systems in nuclear plants, since a known probability of failure can be assigned to critical pipes that may trigger a top event (e. g., break of a pipe) or be part of the events sequence, should for example the top event is the malfunction of a valve that leads to overpressure, etc.
- It facilitates the understanding of the design and moreover it simplifies it. For example, the tables of allowable stresses will be substituted with factors applied to steel strength, which will be less in volume.
- The understanding of the implied reliability indices (calibration) for the current piping design will help ameliorate the design by increasing the safety, where is needed, or by decreasing conservatisms that lead to higher costs.
- The methodology can be used for many performance functions and for a reliability-based design for fatigue.
- The LRFD format favors future changes as a result of gained information in prediction models, materials and load characterization.
- The piping design according to the LRFD can be more analytical than the general equations proposed by the ASME B&PV Code in the sections of design by rule and namely, NB-3600, NC-3600, and ND-3600, facilitating hence the designers in selecting the appropriate equations for the piping design.

CHAPTER 3: BASIC RANDOM VARIABLES FOR PIPING

Although the nominal or design values of dimensions, loads and strength of materials are used by the engineers as precised values, their actual values are random in nature. A reliability-based design necessitates that these uncertainties be quantified. Therefore, each load and the resistance are treated as random variables, where their distribution and moments –mean value and standard deviation or coefficient of variation- are determined by collecting and analyzing data from experimental results, published literature and experts' opinion. The variables, whose probabilistic characteristics are obtained this way, are fundamental quantities in the design and are called basic.

The basic random variables examined herein are: (a) the strength variables, namely the yield, S_y, and ultimate strength of steel, S_u, (b) the geometrical characteristics such as the thickness, t, the outside diameter, D_o, the section modulus Z, or Z_P and the ratio of the external diameter to thickness, $\theta = D_o/t$, and (c) the load variables such as the sustained weight, the internal pressure P, other mechanical loads such as the valve relief surcharge, and the seismic loading. Information is also provided for accidental loads (thermal loading, LOCA). Section 3.1 presents the probabilistic characteristics of the strength basic variables and Section 3.2 under separate headings provides those for the considered loading. Nevertheless, variables concerning the reliability-based fatigue design of pipes are separately provided in Chapter 7.

3.1. Strength Variables

Strength variables include the yield and ultimate strength of steel and the geometrical properties of pipes. The material mainly used for nuclear pipes are austenitic stainless steels. These are iron-based alloys with chromium, Cr, and nickel, Ni, as primary alloying elements and are specifically intended to operate at high-temperature, while they demonstrate also corrosion resistance. More common materials are AISI Type 304 complying with ASTM A312, A376, A358, A409, or A813, and Types 304L, 316, 316L, and 347. Carbon steels are also used for all classes of pipes and mainly the SA 106 Grade B and SA 333 Grade 6 steels. Carbon steels are the predominant materials mainly for oil refineries and chemical plants piping.

The type of reactor specifies the material of the pipes in nuclear plants. Piping materials for Pressurized-Water Reactors (PWR), Boiling-Water Reactors (BWR), Sodium-cooled Fast and Thermal Reactors (SGR), are as provided in the previous paragraph. Other less used materials for PWR reactors are ferritic steel ASTM 516 clad with Type 308L austenitic stainless steel. A detailed table of steels used for nuclear pipes is given in Appendix B.

In Section 3.1.1 the statistical properties of the yield strength are discussed, and in 3.1.2 these of ultimate strength. Pipes in nuclear plants are designed to operate at room temperature or in elevated temperatures, therefore properties and probabilistic characteristics of steel should be considered for different operating temperatures. Stainless pipes are permitted to operate up to 800^{o}F, whereas carbon pipes up to 700^{o}F. For higher temperatures steel is susceptible to time dependent behavior and continuous deformation (namely creep), which is beyond the scope of this work. Section 3.1.3 presents statistical information about the geometrical properties of pipes.

3.1.1. Yield Strength of Steel

The yield strength is specified by the offset method of 0.2 per cent. Tables in this chapter present the collected data. More specifically, Table 3-1 presents the minimum and maximum values of the yield strength of steel based on the reviewed literature. Table 3-2 presents statistical data from cited experiments. The nominal yield strength is the specified minimum yield strength value (SMYS) given in the ASME B&PV Code, Part II and also presented in Appendix B. The bias given in the following tables is defined as the ratio of the mean strength of steel at operating temperature to its nominal strength at room temperature.

Ware (1995) estimated the margins in the ASME Code for nuclear piping stainless steels, Types 304 (cast and wrought) and 316. He gave the best fit curves shown in Table 3-3 for different temperatures, x (^{o}F), for the yield strength, S_y, (ksi). He assumed a normal distribution for the yield strength in order to estimate the confidence level that the specified ASME Code minimum yield strength (SMYS) has with respect to the experimental data. He concludes that the yield strength value on the best-fit curve could be used as the mean of the yield strength distribution for a given temperature and the ASME Code value (SMYS), as the 97% lower confidence limit. Table 3-3 shows also best fit curves obtained by Sikka, et al. (1977). Moreover, Table 3-4 provides information about the bias of steel at elevated temperatures. Table 3-5 summarizes the statistical properties of yield strength. Properties of carbon steel in elevated temperatures are based on the work of Simmons, et al. (1955). Table 3-5 also shows the recommended values used for the calculation of the partial safety factors. It can be noticed that the bias was slightly lowered no more than 3% from the average value, in order to consider the fact that usually steel not fulfilling the requirements of a grade is classified as steel of the immediate lower grade.

Table 3-1: Data for the Yield Strength, S_y, of Carbon and Stainless Steel at Room Temperature

Steel Type	Min (ksi)	Max (ksi)	Reference
Carbon			
SA-106B	35	NA	Davis (1996)
Carbon Steels	30	40	GP Courseware (1982)
SA-106B	28.9	39.5	Simmons, et al. (1955)
Stainless			
AISI, TP 304	42	NA	Lynch (1989)
AISI, TP 304-L	39	NA	Lynch (1989)
Stainless Steels	40	50	GP Courseware (1982)
AISI, TP 316	42	NA	Benjamin (1983)
AISI, TP 316-L	39	NA	Benjamin (1983)
AISI, TP 304	29.73	110.23	Cardarelli (1999)
AISI, TP 304L	24.66	44.96	
AISI, TP 304LN	29.73	NA	
AISI, TP 304N	34.81	NA	
AISI, TP 347	29.73	44.96	
AISI, TP 304	NA	35	Macdonald, et al. (1989), annealed sheet and strip
AISI, TP 304L	NA	38	
AISI, TP 316	NA	40	
AISI, TP 316L	NA	32	
AISI, Type 316LN	NA	38	
AISI, Type 321	NA	35	
AISI, TP 347	NA	40	

NA=Not Available

Table 3-2: Experimental Data for the Yield Strength of Carbon and Stainless Steel

Steel	Mean (ksi)	Bias	*COV*	Number of Specimens	Reference
Carbon steel					
SA106-GR B	45.6	1.30	NA	NA	Scott, et al. (1994)
SA106-GRB	43.65	1.25	NA	NA	ANL (Chopra, et al. 1996)
SA106-GRB	43.51	1.24	NA	NA	Terrell (Chopra, et al. 1996)
SA106-GRB	35.08	1.00	0.10	6	Simmons, et al. (1955)
SA 106-GR B	36	1.02	NA	NA	Wesley (1993)
SA 106-GR B	41.93	1.20	NA	3	Marschall, et al. (1993)
SA333-6	43.8	1.25	NA	NA	Higuchi (1991)
SA333-6	55.55	1.59	NA	NA	
A-515, Grade 60	39.1	1.22	NA	2	Brust, et al. (1994)
Low strength	NA	1.10	0.07	NA	Assakaff (1998)
High strength	NA	1.20	0.09	NA	
Stainless steel					
TP 304	38	1.27	NA	NA	Stoner, et al. (1991)
SA312-TP 304	37	1.23	NA	NA	Wesley (1993)
SA 376-TP 304	36.05	1.20	NA	2	
SA 358-TP 304	42.77	1.43	0.027	3	
TP 316L	37.5	1.50	NA	2	
TP 316L	37.71	1.51	NA	NA	Touboul, et al. (1999)
AISI 316	39.16	1.31	NA	NA	Prost, et al. (1983)
TP 304	35.67	1.19	NA	NA	Spaeder, et al. (1974)
TP 304 Pipe	37.7	1.26	0.17	14	ASTM DS5S2 (1969)†
TP 304 L	33.8	1.35	0.1065	13	
TP 316	38	1.27	0.168	14	
TP 316L	33.7	1.35	0.19	6	
TP 347	38.2	1.27	0.136	18	
SA312, TP316, 316H	42	1.40	NA	NA	Wesley, et al. (1990)

NA=Not Available, † Stainless steel type 321 is reported also in the study but not considered here, since as commented the data are unreasonable.

Table 3-3: Best Fit Curves for Yield Strength of Stainless Steel

Stainless Steel	Best Fit Curve (*Mean Value*)	x=70°F (ksi)	*COV*	Reference
TP 304, Wrought	$y = -5.12\,(10^{-8})\,x^3 + 1.10\,(10^{-4})\,x^2 - 8.23\,(10^{-2})\,x + 42.9$ **R^2=0.81**	37.66	0.108	Ware (1995)
TP 304, Cast	$y = -5.12\,(10^{-8})\,x^3 + 1.04\,(10^{-4})\,x^2 - 7.423\,(10^{-2})\,x + 41.8$ **R^2=0.877**	37.09	0.102	
Type 316	$y = -2.44\,(10^{-8})\,x^3 + 6.81\,(10^{-5})\,x^2 - 6.55\,(10^{-2})\,x + 42.8$ **R^2=0.862**	38.54	0.118	
TP 304	$y = -3.26\,(10^{-8})\,x^3 + 7.62\,(10^{-5})\,x^2 - 6.61\,(10^{-2})\,x + 42.09$ **R^2=0.866**	37.82	0.069	Sikka, et al. (1977)
TP 316	$y = -2.88\,(10^{-8})\,x^3 + 7.76\,(10^{-5})\,x^2 - 6.98\,(10^{-2})\,x + 42.76$ **R^2=0.841**	38.24	0.100	tube specimens

R^2=Coefficient of multiple determination, TP=Type

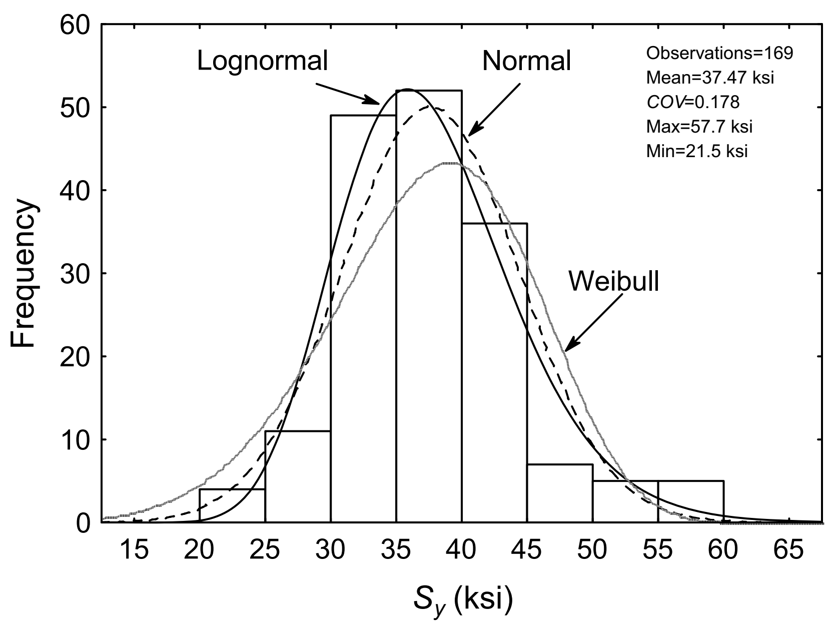


Figure 3-1: Histogram for the Yield Strength of Stainless Steel at Room Temperature Based on the Test Data in the Report of Simmons, et al. (1965) Including All Types of Steel Except from Steel TP321 and All Types of Specimens

Table 3-4: Mean Values and Bias of Yield Strength for Stainless Steel at Elevated Temperatures

Temp. °F	304		304L		316		316L		347		Temp. °F
	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	
75	37.7	1.26	33.8	1.35	38	1.27	33.7	1.35	38.2	1.27	75
100	36.19	1.21	32.78	1.31	36.86	1.23	32.69	1.31	37.43	1.25	100
150*	33.93	1.13	30.76	1.23	34.77	1.16	30.67	1.23	36.29	1.21	150*
200	31.67	1.06	28.73	1.15	32.68	1.09	28.65	1.15	35.14	1.17	200
300	28.27	0.94	26.03	1.04	29.64	0.99	25.61	1.02	32.47	1.08	300
400	26.01	0.87	23.66	0.95	26.60	0.89	23.59	0.94	30.56	1.02	400
500	24.50	0.82	21.97	0.88	25.08	0.84	21.57	0.86	28.65	0.96	500
600	23.37	0.78	20.96	0.84	23.94	0.80	20.56	0.82	27.50	0.92	600
700	22.24	0.74	20.28	0.81	22.8	0.76	19.55	0.78	26.36	0.88	700
800	21.49	0.72	19.60	0.78	22.42	0.75	18.53	0.74	25.98	0.87	800
900	20.36	0.68	18.93	0.76	22.04	0.73	17.86	0.71	25.59	0.85	900
1000	19.60	0.65	17.91	0.72	21.66	0.72	16.85	0.67	25.59	0.85	1000
1100	19.23	0.64	16.90	0.68	20.90	0.70	15.84	0.63	25.21	0.84	1100
1200	19.23	0.64	15.21	0.61	20.52	0.68	14.15	0.57	24.83	0.83	1200

*Interpolated Value

Table 3-5: Summary of Probabilistic Characteristics for Yield Strength

Steel	Temperature (°F)	Bias				*COV*				Distribution
		Min	Max	Avg	Rec.	Min	Max	Avg	Rec.	
Carbon	Room Temperature	1.00	1.59	1.16	**1.13**	0.07	0.10	0.09	**0.08**	Lognormal
	200	0.75	1.01	0.95	**0.93**	NA	NA	0.10	**0.08**	
	400	0.66	1.03	0.90	**0.87**	NA	NA	0.15	**0.13**	
	600	0.67	0.89	0.77	**0.75**	NA	NA	0.13	**0.13**	
	800	0.77	0.86	0.82	**0.70**	NA	NA	0.06	**0.13**	
Stainless	Room Temperature	1.06	1.50	1.30	**1.26**	0.03	0.19	0.14	**0.15**	Lognormal
	200	1.06	1.17	1.12	**1.10**	0.11	0.13	0.12	**0.15**	
	400	0.87	1.02	0.93	**0.90**	0.04	0.26	0.14	**0.15**	
	600	0.78	0.92	0.83	**0.80**	0.08	0.27	0.18	**0.15**	
	800	0.72	0.87	0.77	**0.75**	0.07	0.22	0.17	**0.15**	

Rec.=Recommended value, Avg.=Average value, Min=Minimum value, Max=Maximum value, N.A.=Not Available

3.1.2. Ultimate Strength of Steel

Data for the ultimate strength, S_u, of carbon and stainless steels are provided in Tables 3-6 and 3-7. Table 3-8 gives the best fit curves for different temperatures, x (°F), for the ultimate steel strength, S_u (ksi), predicted by Ware (1995) and Sikka, et al. (1977). For carbon steel SA106-GrB Stevenson, et al. (1999) suggest a lognormal distribution for the ultimate strength, while Hill, et al. (2000) propose an average value of 67.2 ksi with standard deviation 4.05 ksi for operation at room temperature. Table 3-9 shows the bias of the ultimate strength of stainless steel at elevated temperatures, while Table 3-10 summarizes the probabilistic properties and recommended values to be used for the calculation of the partial safety factors. For the recommended bias of ultimate strength evaluation was based on same criteria as for the yield strength. The properties of ultimate strength at elevated temperatures are based on the work of Simmons, et al. (1965), and Simmons, et al. (1955) for stainless and carbon steel, respectively.

Table 3-6: Data for the Ultimate Strength of Carbon and Stainless Steels for Nuclear Piping at Room Temperature

Steel Type	Min S_u (ksi)	Max S_u (ksi)	Reference
Carbon Steel			
SA-106B	60	NA	Davis (1996)
Carbon Steels	55	65	GP Courseware (1982)
SA 106 B	60	NA	Rajdeep Metals, Mumbai
SA 106 B	59.7	72	Simmons, et al. (1955)
Stainless Steel			
Stainless Steels	78	100	GP Courseware (1982)
AISI, Type 316	84	NA	Benjamin (1983)
AISI, Type 316-L	81	NA	
AISI, Type 347	85	NA	Davis (2000)
Type 304	74.7	NA	Ukrainian Industrial Energetic Company
Type 304-L	70.34	NA	
Type 316	74.7	NA	
Type 316-L	70.34	NA	
A 312 TP 304	75	NA	Rajdeep Metals, Mumbai
A 312 TP 304L	70	NA	
AISI, Type 304	74.69	150.11	Cardarelli (1999)
AISI, Type 304L	65.27	89.92	
AISI, Type 304LN	74.69	NA	
AISI, Type 304N	79.77	NA	
AISI, Type 347	74.69	89.92	
AISI, Type 304	NA	85	Macdonald, et al. (1989) annealed sheet and strip
AISI, Type 304L	NA	75	
AISI, Type 316	NA	90	
AISI, Type 316L	NA	75	
AISI, Type 316LN	NA	85	
AISI, Type 321	NA	90	
AISI, Type 347	NA	95	
AISI, Type 304	84	NA	Lynch (1989)
AISI, Type 304-L	81	NA	

NA=Not Available

Table 3-7: Experimental Data for the Ultimate Strength of Carbon and Stainless Steel

Steel	Mean (ksi)	Bias	*COV*	Specimens	Reference
Carbon Steel					
SA106-GR B	75.4	1.26	NA	NA	Scott, et al. (1994)
SA106-GR B	68.03	1.13	0.06	6	Simmons, et al. (1955)
SA 106-GR B	68	1.13	NA	NA	Wesley (1993)
SA 106-GR B	75.24	1.25	0.035	3	Marschall, et al. (1993)
SA106-GRB	82.96	1.38	NA	NA	ANL (Chopra, et al. 1996)
SA106-GRB	75.85	1.26	NA	NA	Terrell (Chopra, et al. 1996)
SA333-6	70.92	1.18	NA	NA	Higuchi (1991)
SA333-6	79.62	1.33	NA	NA	Higuchi (1995)
Low strength	NA	1.05	0.06	NA	Assakkaf (1998)
SA516 GR70	84	1.20	NA	NA	Wesley, et al. (1990)
Stainless Steel					
SA 376-Type 304	87.65	1.17	NA	2	Marschall, et al. (1993)
SA 358-Type 304	105.23	1.40	0.034	3	
A-515, Grade 60	63.9	1.07	NA	2	Brust, et al. (1994)
Type 316L	86.6	1.24	NA	2	
Type 316L	88.33	1.26	NA	NA	Touboul, et al. (1999)
AISI 316	86.3	1.15	NA	NA	Prost, et al. (1983)
Type 304	91	1.21	NA	NA	Stoner, et al. (1991)
SA312-Type 304	86	1.15	NA	NA	Wesley (1993)
304 Pipe	84.0	1.12	0.063	14	ASTM DS5S2 (1969)†
304 L	79.2	1.13	0.034	14	
316	83.3	1.11	0.077	14	
316L	78.9	1.13	0.037	9	
347	87.0	1.16	0.057	18	

NA=Not Available, † Stainless steel type 321 is reported also in the study but not considered here, since as commented the data are unreasonable.

Table 3-8: Best Fit Curves for Ultimate Strength of Stainless Steel

Steel	Best Fit Curve (Mean Value)	Value for x=70°F (ksi)	*COV*	Reference
TP 304, Wrought	$y = -1.27(10^{-7})x^3 + 2.38(10^{-4})x^2 - 1.46(10^{-1})x + 95$ **R^2=0.871**	85.90	NA	Ware (1995)
TP 304, Cast	$y = -1.43(10^{-7})x^3 + 2.56(10^{-4})x^2 - 1.56(10^{-1})x + 93.1$ **R^2=0.831**	83.38	NA	
TP 316	$y = 1.28(10^{-10})x^4 - 4.75(10^{-7})x^3 + 5.46(10^{-4})x^2 - 2.31(10^{-1})x + 96.3$ **R^2=0.957**	82.65	NA	
TP 304	$y = -9.55(10^{-8})x^3 + 1.90(10^{-4})x^2 - 1.291\ x + 95.44$ **R^2=0.969**	79.56	0.035	Sikka, et al. (1977)
TP 316	$y = -5.39(10^{-8})x^3 + 9.45(10^{-5})x^2 - 6.35(10^{-2})\ x + 83.58$ **R^2=0.954**	79.58	0.05	tube specimens

R^2=Coefficient of multiple determination, TP=Type

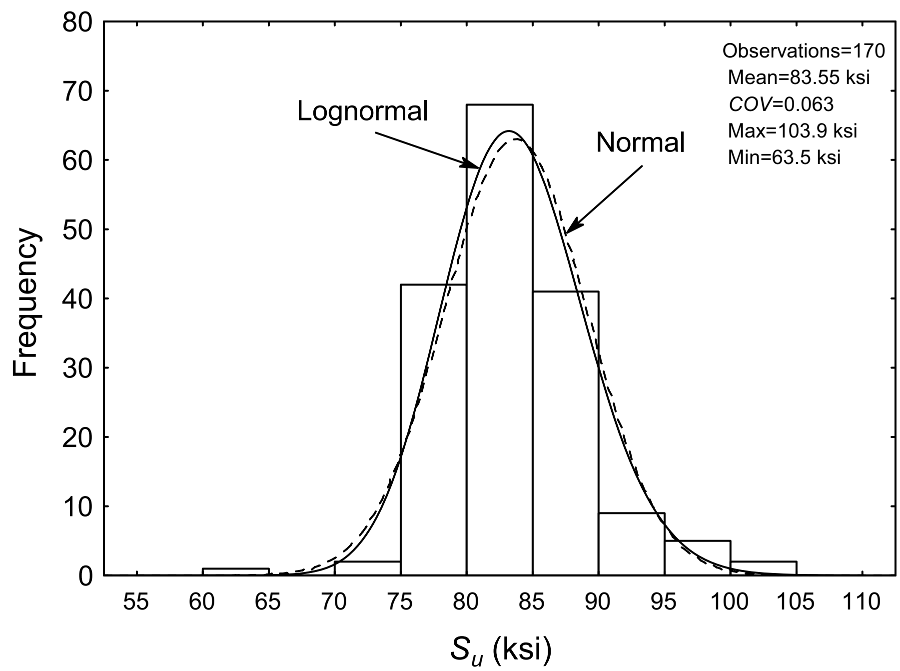


Figure 3-2: Histogram for the Ultimate Strength of Stainless Steel at Room Temperature Based on the Test Data in the Report of Simmons, et al. (1965) Including All Types of Steel, Except from Steel TP321, and All Types of Specimens

Table 3-9: Mean Values and Bias of Ultimate Strength for Stainless Steel at Elevated Temperatures

Temp. °F	304		304L		316		316L		347		Temp. °F
	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	Mean (ksi)	Bias	
75	84	1.12	79.2	1.13	83.3	1.11	78.9	1.13	87	1.16	75
100	81.48	1.09	76.82	1.10	80.8	1.08	76.53	1.09	84.39	1.13	100
150*	78	1.04	72.78	1.04	78.30	1.04	72.98	1.04	80.04	1.07	150*
200	73.92	0.99	68.73	0.98	75.80	1.01	69.43	0.99	75.69	1.01	200
300	69.72	0.93	62.57	0.89	74.14	0.99	65.49	0.93	69.6	0.93	300
400	67.20	0.90	60.19	0.86	72.47	0.97	63.91	0.91	65.25	0.87	400
500	66.36	0.89	59.4	0.85	72.47	0.97	63.12	0.90	63.51	0.85	500
600	66.36	0.89	58.61	0.84	73.3	0.98	63.12	0.90	62.64	0.83	600
700	66.36	0.89	57.82	0.83	72.47	0.97	63.12	0.90	61.77	0.82	700
800	65.52	0.87	57.02	0.82	71.64	0.96	62.33	0.89	61.77	0.82	800
900	63.84	0.85	55.44	0.79	69.14	0.92	59.96	0.86	61.77	0.82	900
1000	59.64	0.80	52.27	0.75	64.97	0.87	56.81	0.81	60.90	0.81	1000
1100	53.76	0.72	47.52	0.68	59.14	0.80	52.07	0.74	58.29	0.78	1100
1200	43.68	0.58	41.98	0.60	51.65	0.69	46.55	0.67	53.94		1200

*Interpolated Value

Table 3-10: Summary of Probabilistic Characteristics for Ultimate Strength

Steel	Temperature (°F)	Bias				*COV*				Distribution
		Min	Max	Avg.	Rec.	Min	Max	Avg.	Rec.	
Carbon	Room Temperature	1.05	1.38	1.19	**1.15**	0.035	0.06	0.05	**0.06**	Lognormal
	200	0.91	1.15	1.07	**1.05**	NA	NA	0.08	**0.06**	
	400	1.02	1.36	1.20	**1.17**	NA	NA	0.10	**0.10**	
	600	0.95	1.30	1.13	**1.10**	NA	NA	0.10	**0.10**	
	800	0.80	0.99	0.91	**0.88**	NA	NA	0.10	**0.10**	
Stainless	Room Temperature	1.07	1.40	1.15	**1.13**	0.034	0.077	0.06	**0.06**	Lognormal
	200	0.98	1.01	1.00	**0.98**	0.04	0.05	0.05	**0.06**	
	400	0.86	0.97	0.90	**0.88**	0.03	0.06	0.05	**0.06**	
	600	0.83	0.98	0.89	**0.88**	0.03	0.06	0.05	**0.06**	
	800	0.82	0.96	0.87	**0.85**	0.03	0.06	0.05	**0.06**	

Rec.=Recommended value for calculations, Avg.=Average value, Min=Minimum value, Max=Maximum value, NA=Not Available

3.1.3. Comparison of LRFD Definition of Steel Strength with ASME Practice

Initially, in Figures 3-3 and 3-4 the yield and ultimate strength of steel at different operating temperatures is shown for stainless and carbon steel, respectively. In addition, Figure 3-5 provides physical properties of carbon steel at different temperatures. In all cases the curves represent the mean values of properties. Figures 3-6 to 3-9 show (for carbon steel SA 106B and austenitic steel SA 312 Type 312) the steel properties used in LRFD, namely the mean values of the steel strength and the nominal values that are the specified minimum at room temperature for any operating temperature. These values are given in Tables 1A and 2A in Section II, Part D of the ASME B&PV Code. The mean and nominal values (S_y, S_u) for the LRFD are connected with a line. The bias, calculated in previous sections, is the ratio of these values for the steel under consideration.

Figures 3-6 to 3-9 moreover present the nominal (minimum) strength of steel for different operating temperatures (S'_y, S'_u) that is used in the ASME B&PV Code. More specifically, these values are given in Table U1 for the ultimate strength of steel and in Y-1 for the yield strength of steel of the ASME Code, Section II, Part D. The figures also show the allowable stresses of the Code for pipes of Class 1, S_m, and S for pipes of Classes 2 and 3.

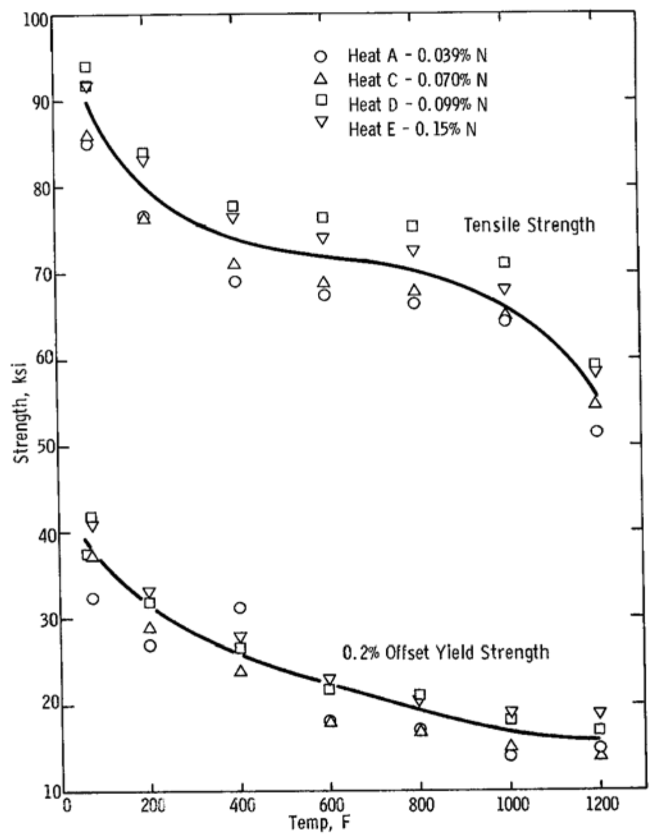
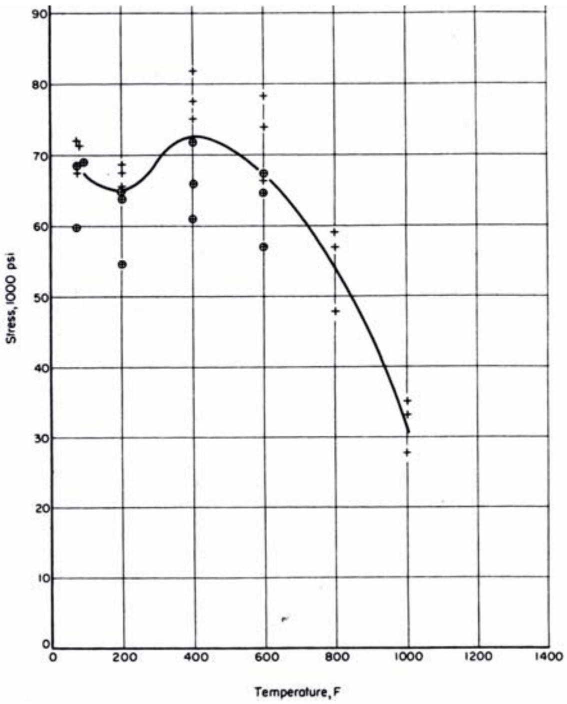
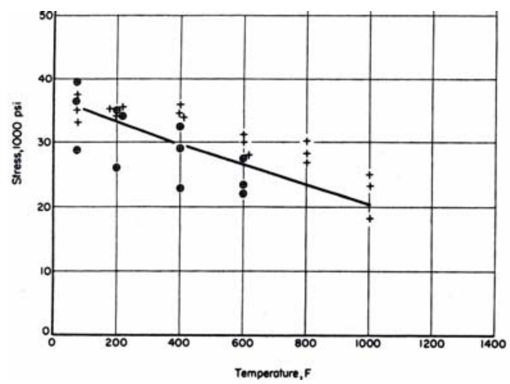


Figure 3-3: Behavior of Type 316 Stainless Steel at Different Temperatures (Cullen, et al., 1969)



(a)



(b)

Figure 3-4: Behavior of Carbon Steel SA106B at Elevated Temperatures, a) Ultimate Strength, b) Yield Strength (Simmons, 1955)

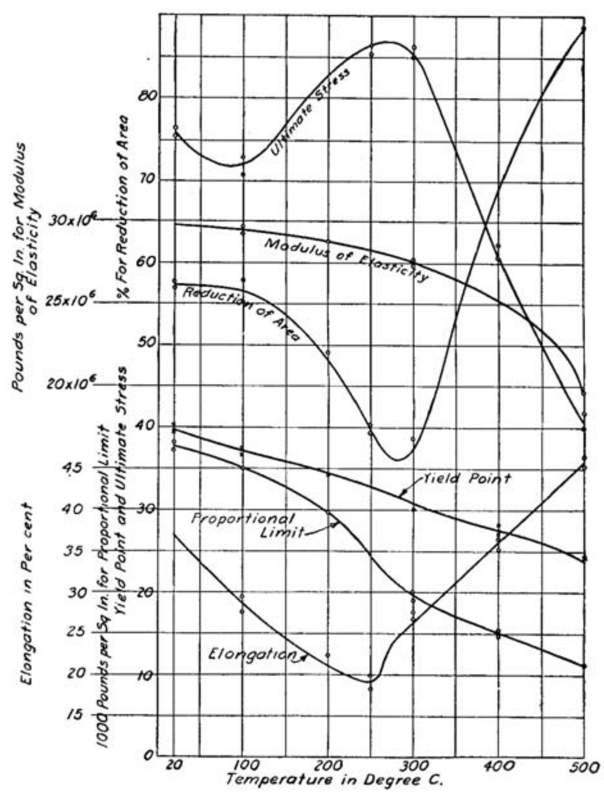


Figure 3-5: Physical Properties of Carbon Steel at Elevated Temperatures (Timoshenko, 1930)

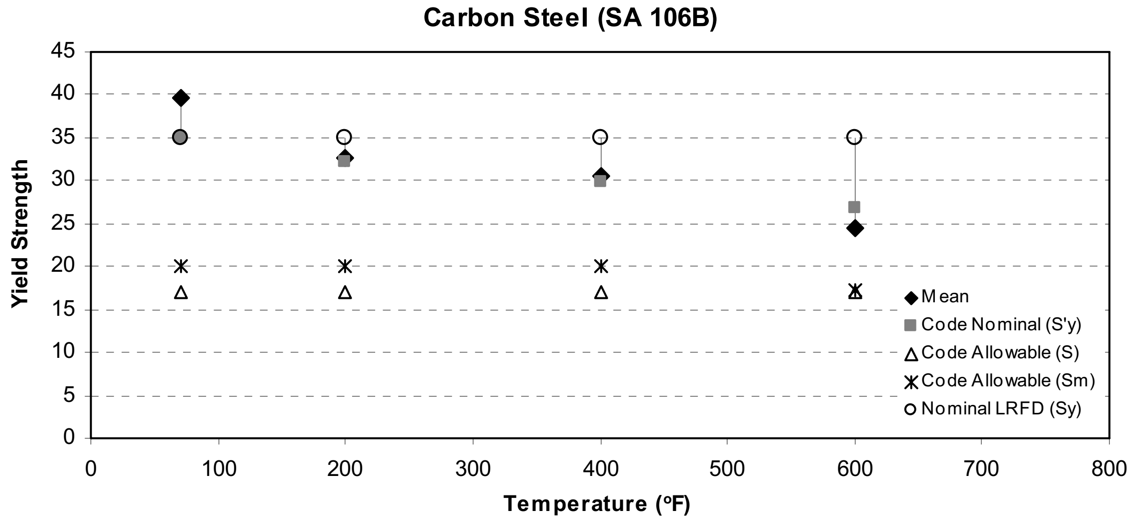


Figure 3-6: Values of Yield Strength Used in LRFD and ASME Code for Carbon Steel SA 106B at Different Operating Temperatures

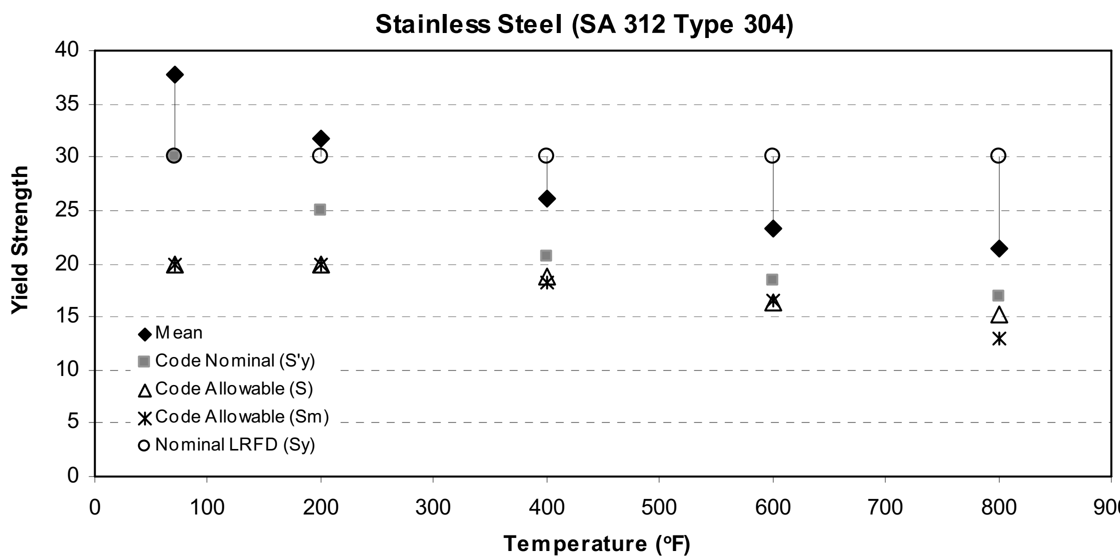


Figure 3-7: Values of Yield Strength Used in LRFD and ASME Code for Stainless Steel SA 312 Type 304 at Different Operating Temperatures

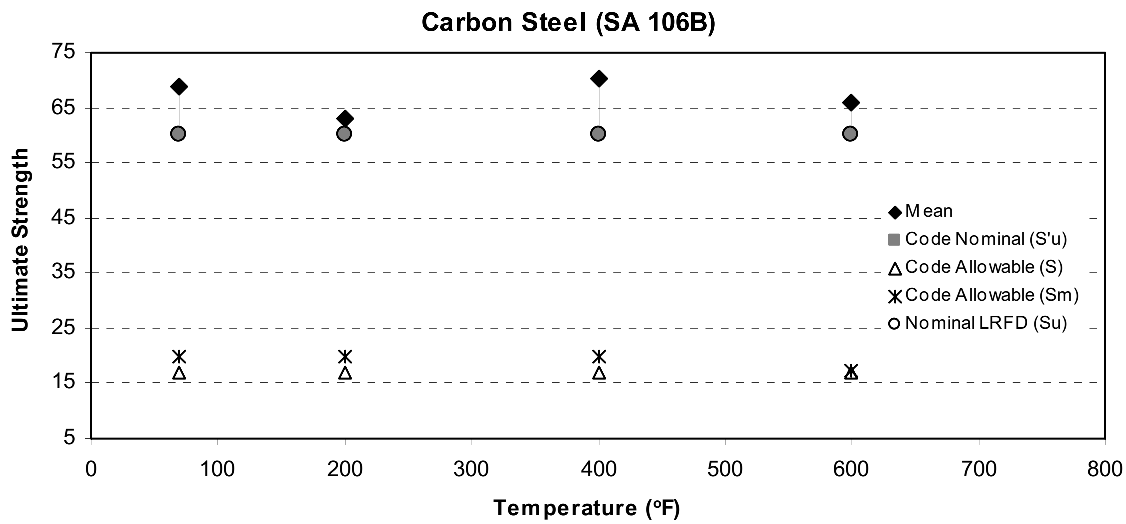


Figure 3-8: Values of Ultimate Strength Used in LRFD and ASME Code for Carbon Steel SA 106B at Different Operating Temperatures

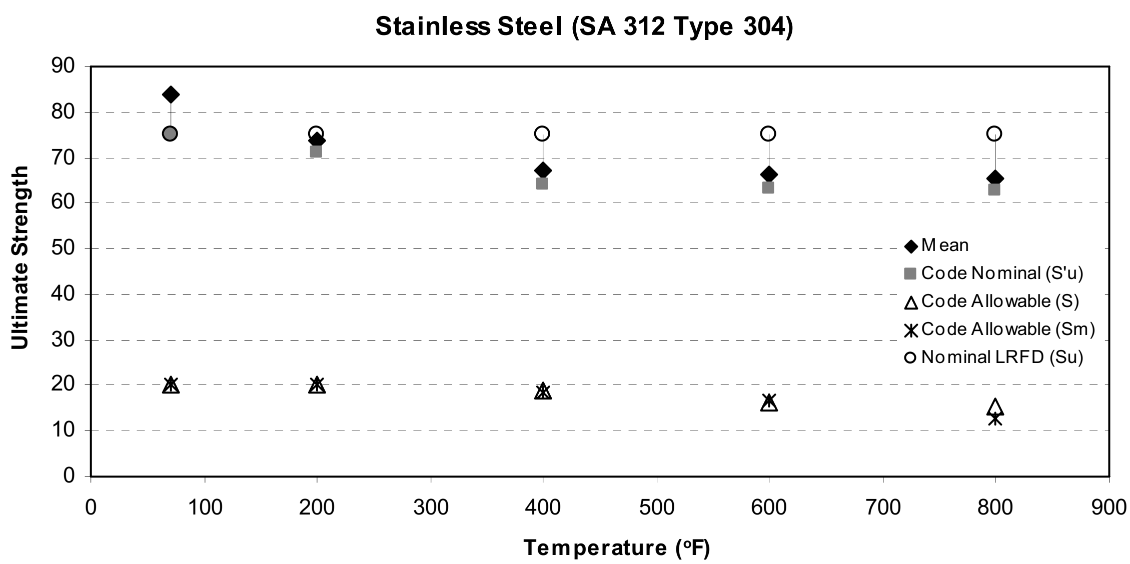


Figure 3-9: Values of Ultimate Strength Used in LRFD and ASME Code for Stainless Steel SA 312 Type 304 at Different Operating Temperatures

Considering Figures 3-6 to 3-9 some inferences can be derived for the criteria used in the ASME B&PV Code that certainly can be assured by examining the properties of more types of steel, which will be included in the LRFD. Thus, for example, by comparing the nominal yield strength cited in the Code (S'_y) with the allowable stresses (S for Classes 2 and 3 and S_m for Class 1), it appears that the Code is more conservative for pipes operating in temperatures less than 200°F. Therefore, calibration of the Code for use in LRFD will result in lower values of β for pipes operating at high temperatures. That is though not the case for the ultimate strength, as Figures 3-8 and 3-9 show.

3.1.4. Geometrical properties

Statistical data on pipe outside diameter, D_o, pipe thickness, t, and the ratio $\theta = D_o/t$ is provided in this section. These variables are investigated under separate headings.

3.1.4.1. External Diameter

In a nuclear power plant pipes of different diameters are used (Zhao, 1994; Crocker, et al., 1967). Dimensional standards (ASME B36.10M and ANSI/ASME B36.19M) provide the diameter, thickness and weight for all piping schedules for both welded and seamless wrought steel as well as stainless steel piping.

Diameter tolerances are quite tight and vary with pipe size, while they are governed by the requirements of ASME B16.9 (2003). For example for a 4 in pipe the tolerance is 1/16 in, while for 24 in pipe the tolerance is 1/8. For straight pipes these diameter tolerances are for the entire pipe, but for fittings, these only apply to the ends. The basic idea is that it must be possible to create good welds between pipes and fittings. In typical probabilistic risk assessment studies conducted for existing plants the statistical characteristics for diameter are considered to follow normal distribution with a value of twice standard deviation = ± tolerance values. Table 3-11 provides the outside diameter variations for various pipe sizes. Based on the assumption that tolerances fall within the 4σ area, the coefficient of variation for the outside diameter in Table 3-11 is estimated.

Table 3-11: Properties of Nominal Pipe Outside Diameter

Nominal Diameter	Diameter Variation (in)	Mean	*COV*	Distribution
D_o	+1/64, -1/32	D_o	$0.012/D_o$	Normal
$2\text{in} \le D_o \le 4\text{in}$	+1/32, -1/32	D_o	$0.016/D_o$	
$5\text{in} \le D_o \le 8\text{in}$	+1/16, -1/32	D_o	$0.023/D_o$	
$10\text{in} \le D_o < 20\text{in}$	+3/32, -1/32	D_o	$0.031/D_o$	
$D_o \ge 20\text{in}$	+1/8, -1/32	D_o	$0.039/D_o$	

3.1.4.2. Thickness

The pipe thickness usually is indicated by a schedule number. The higher the schedule number, the thicker the pipe is. Its value can be approximated by the following equation:

$$Schedule\,number = 1000\,P\,/\,S \tag{3-1}$$

where P=the steam pressure (lb/in^2); and S=the working stress of pipe material (usually taken as 10 to 15 percent of the ultimate strength of steel).

The minimum thickness for fittings and straight pipes is the nominal thickness minus 12.5%. There is no maximum thickness for fittings, but modern fabrication techniques allow manufacturers to create products that do not exceed nominal values by much except, perhaps at points like the intrados of elbows, (Ayyub, et al., 2005). There is an average weight tolerance for straight pipes that, in effect, limits the average thickness tolerances to 5%. In typical probabilistic risk assessment studies conducted for existing plants the statistical characteristics for thickness are considered to follow normal distribution with a value of twice standard deviation = ± tolerance values. A minimum coefficient of variation for the thickness of 0.03 can be used. Table 3-12 summarizes the probabilistic characteristics used for the reliability–based design for onshore and offshore pipelines and dented pipes, and Table 3-13 the estimated coefficient of variation (*COV*) to be used in this study.

Table 3-12: Reported Probabilistic Characteristics for the Thickness of Pipes

Distribution	Mean	*COV*	Reference
Normal	Nominal (mm)	0.25 / Mean	Zimmerman, et al. (1998)
Normal	NA	0.025	Sotberg, et al. (1994)
Normal	NA	0.02	Bai, et al. (1997)
Normal	0.925*(Nominal)	0.03	Stewart, et al. (2002)

NA=Not Available

Table 3-13: Statistical Properties for the Thickness of Pipes

Nominal Pipe Size	Nominal Thickness	Thickness Variation	Mean	*COV*	Distribution
D_o	t	-12.5%	t	$0.035/t$	Normal
$2\text{in} \leq D_o \leq 4\text{in}$	t	-12.5%	t	$0.035/t$	
$5\text{in} \leq D_o \leq 8\text{in}$	t	-12.5%	t	$0.035/t$	
$10\text{in} \leq D_o < 20\text{in}$	t	-12.5%	t	$0.035/t$	
$D_o \geq 20\text{in}$	t	-12.5%	t	$0.035/t$	

3.1.4.3. Section Modulus

The elastic, Z, and plastic, Z_P, section modulus of a pipe were given by Eqs. (2-3) and (2-4), respectively. Monte Carlo simulation was used in order to assess the coefficient of variation and bias for this variable. As a result a lognormal distribution is recommended with a coefficient of variation equal to 0.05 and bias 1.0.

3.1.4.4. Diameter to Thickness Ratio

The diameter to thickness ratio $\theta = D_o/t$ constitutes an indicator for the following:

- The susceptibility of pipes to buckling when the latter are subjected to bending loading. Relative information is provided in Chapter 4.
- The shape factor defined as the ratio of the plastic section modulus to the elastic one, which defines the margin between the first yield moment and the first hinge moment.
- The characterization of a pipe as thin or thick is related with the ratio of the internal diameter, d, to the pipe thickness, t, where $d=D_o-2t$. Thin pipes are considered those having a ratio d/t greater than 20. ASME Code Criteria are based on the assumption of thin pipes, as explained in a previous chapter.

Taking into consideration the tables for standard commercial pipe sizes, it can be noticed that the ratio for pipes made of carbon steel varies between 6 to 100, while for stainless steel has an upper limit of 40.

In order to assess the probabilistic characteristics of θ, Monte Carlo simulation was performed and the following probabilistic characteristics were derived: Coefficient of variation equal to 0.037, while the distribution can be considered either normal or lognormal.

3.2. *Load Variables*

This section gives information and the probabilistic characteristics for the loads impacting nuclear piping.

3.2.1. Sustained Weight

The sustained weight includes the own weight of the pipe, the weight of the attachments or components mounted on it, the insulation, and the weight of the pipe's contents. A description of these loads and the probabilistic characteristics for the sustained weight are provided in the following sections.

3.2.1.1. Self Weight

For the computation of the weight of the pipe, the following equation is proposed (King, 1967).

$$weight\ of\ pipe, (lb/ft) = 10.68\, F\, t\, (D_o - t) \tag{3-2}$$

where F=relative weight factor, t=wall thickness (in), and D_o=outside diameter (in).

The pipe weight calculation in Eq. (3-2) is based on low–carbon steel properties, which weighs 0.2833 lb/in^3 and is extended to other materials through the factor F, which takes the values: 1.02 for austenitic stainless steel, 0.98 for wrought iron, 1.00 for carbon steel, and 0.95 for ferritic stainless steel. Normally, the weight of piping can be found in piping catalogs from vendors, where the same weight for carbon and austenitic stainless steel is used. The weight per foot of steel pipe is subject to tolerances as illustrated in Table 3-14.

Table 3-14: Self-Weight Tolerances of Steel Piping (Crocker, et al., 1967)

Specification	Size	Tolerance	
ASTM A376 and A312	12 in and under	+6.5%	-3.5%
ASTM A106	Sch. 10-120	+6.5%	-3.5%
	Sch. 140-160	+10%	-3.5%
ASTM A53	Std wt and XS wt	+5%	-5%

3.2.1.2. Self Weight of Fittings and Components

Except from the weight of the pipe itself, the sustained weight should include all the fittings and components that are part of the pipe run, including valves, meters and other special equipment. Because of the relative large diameters and wall thickness of the nuclear pipes the accompanying equipment is usually of greater weight than the one mounted on a conventional pipeline, for example valves with motorized or hydraulic actuators (Lamit, 1981).

3.2.1.3. Insulation

All nuclear pipes connecting the nuclear vessel with the steam generator, turbines and condenser require high quality insulation in order to protect surrounding equipment and instrumentation. For these pipes the insulation is never permanently bonded; it can be easily removed and stored during the regular inspection of the pipes. Block insulation, metal insulation and blanket insulation have been used in such cases. Most protective insulation must be clad with stainless steel or aluminum sheets.

For pipes that inspection is not necessary, common commercial and industrial piping insulation materials are used that demonstrate resistance in high temperatures and can reduce heat losses. Such materials are provided in ASTM specifications.

The weight of pipe insulation, *W*, is given by the following relation (Helguero, 1983):

$$W(lb/ft) = 0.0218\,I\,K\,(D_o + K) \qquad (3\text{-}3)$$

where *K*=insulation thickness, D_o=outside diameter of pipe (in), *I*=insulation density (lb/ft^3). Table 3-15 gives values for *I* for some insulation materials.

Table 3-15: Insulation Density, *I* (Helguero, 1983; Kannappan, 1986)

Material	Density, *I* (lb/ft^3)
Calcium Silicate	11, 12.25*
85% Magnesium	10 to 11
Thermobestos	11.53
Kalo	19 to 21
High Temperature	24
Super -X	25
Poly-Urethane	2.3, 2.0*
Mineral Wool	8
Fiber Glass	3.25*
Foam Glass	8.50*
Polystyrene	2.00*

*Values provided by Kannappan, 1986

3.2.1.4. Contents of Pipe

The weight of pipe's contents (lb/ft) is given by the following equation (Crocker, et al., 1967):

$$weight\ of\ contents\ of\ pipe = G\,0.3405\,(D_o - 2t)^2 \qquad (3\text{-}4)$$

where G=specific gravity of contents, t=pipe thickness (in), and D_o=outside diameter of pipe (in).

Different coolants are used for different types of reactors. The density of these coolant materials varies considerably. For example gas cooled reactors have coolant densities below 0.1 lb/ft^3 and water cooled reactors may have coolant densities over 60 lb/ft^3.

3.2.1.5. Probabilistic Characteristics

The uniformly distributed weight, including the insulation and fluid weights, as well as the concentrated weight due to valves, flanges, etc. may vary by ± 20% from the as-analyzed weight (Mikitka, et al., 1988). Typical probabilistic risk assessment studies conducted for existing plants consider the statistical characteristics for dead weight to follow normal distribution with a value of twice standard deviation =± tolerance values, (Ayyub, et al., 2005).

Hwang, et al. (1983) estimate that the coefficient of variation for sustained weight of pipes can be considered as low as 0.05, but since often there are unexpected loads on pipes like cable trays, etc., a value of 0.10 will be used in this study. This coefficient of variation is used also for the own weight of building structures (Ellingwood, 1981).

3.2.2. Internal Pressure

Within each service level there is actually a variation of pressure- indicated although valves are responsible for keeping a constant pressure within the pipes. Table 3-16 gives representative average operating pressure (Service Limit A) and the corresponding operating temperature for different reactors and piping systems (primary and secondary piping). Nevertheless, pressure information for PWR and BWR are of interest for this study.

Table 3-16: Operating Pressure at Operating Temperature (Crocker, et al., 1967; Lamit, 1981)

Reactor Type	Primary Pressure Average (psig)	Steam Pressure (psig)
Pressurized-water (PWR)	2,500 at 514 ^{o}F	453 at 460 ^{o}F
Boiling-water (BWR)	1,000 at 546 ^{o}F	500 at 825 ^{o}F
Sodium-cooled Graphite-moderated Thermal Reactor	atmospheric	800 at 825 ^{o}F
Sodium cooled Fast-breeder Reactor	atmospheric	900 at 780 ^{o}F
Gas-cooled Reactor Systems	360	1,450 at 1,000 ^{o}F
Organic-moderated Reactor-Systems	120	450 at 550 ^{o}F

The probabilistic characteristics in existed studies for internal pressure are tabulated in Tables 3-17 for the operating pressure, while in Table 3-18 characteristics for the accidental pressure are provided, which can be related to the Service Level D pressure. Table 3-19 gives the suggested probabilistic characteristics for the different pressure types encountered in the design of piping in this study.

Table 3-17: Statistical Properties for Pressure Based on Literature Review

Pressure Type	Mean	*COV*	Distribution	Reference
Design	$\overline{P_{DES}}$	0.04	Normal	Bishop, et al. (1993)
P_{max}	1.03 ($\overline{P_A}$)	NA	Weibull	Stancampiano, et al. (1976)
Operating	$\overline{P_A}$	0.05	Normal	Stewart, et al. (2002)
P_{max}	1.07 $\overline{P_{DES}}$	0.02	Extreme I	Sotberg, et al. (1994)
Operating	$\overline{P_A}$	0.10	Lognormal	Saigal (2005)

NA=Not Available

Table 3-18: Statistics on Accidental Pressure

Occurrence		Intensity			Reference
Rate per year	Duration	Mean/Design	*COV*	Distribution	
NA	NA	0.90	0.12	Normal	Hwang, et al. (1983)
$1.7(10^{-3})$	20 min	0.80	0.20	Type I	Ellingwood, et al. (1996)

NA=Not Available

More, specifically the pressure for each service level in this study is considered to have different probabilistic characteristics. This arises from the fact that the different loading conditions for each service level can generate pressure loading (e.g., for accidental, Service Level D, or emergency conditions of Service Level C the *COV* is expected to be higher and the bias less than that for other service levels. Nevertheless, in this study the *COV* for pressure is between 0.10 and 0.20 for all service limits as Table 3-19 shows. Extreme I of the largest values distribution is used for the faulted or accidental conditions (Service Limits C and D) as well as for the maximum (peak) pressure under normal operating conditions. In Table 3-19, P_O and P_S are the pressures coincident with the Operating Basis Earthquake (OBE) and the Safe Shutdown Earthquake (SSE), respectively. These pressures are considered to have the same probabilistic characteristics, since they are generated from the same physical load, namely earthquake. Nevertheless, P_S is expected to attain higher values than the P_O pressure.

Table 3-19: Proposed Probabilistic Characteristics for Internal Pressure for this Study

Pressure	*COV*	Bias	Distribution
Design, P_{Des}	0.10	1.0	Normal
P_A	0.10	1.0	Normal
P_B	0.13	0.95	Normal
P_C	0.15	0.85	Extreme I
P_D	0.20	0.80	Extreme I
P_{max}	0.13	0.90	Extreme I
P_O	0.13	0.95	Lognormal
P_S	0.13	0.95	Lognormal

3.2.3. Earthquake Loading

Seismic loading can be classified as a reversing dynamic loading as shown in Figure 2-1. For Service Limits B and C the pipes should be designed to withstand an Operating Basis Earthquake (OBE), while for Service Limit D pipes should also be designed for the Safe Shutdown Earthquake (SSE). More specifically, a definition for these earthquakes according to the Article N-1000 of the ASME BPV Code, (2001) is provided herein:

The Operating Basis Earthquake (OBE), E_o, is *that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material could be reasonably be expected to affect the plant site during the operating life of the plant.*

This earthquake is typically expected to occur once in one hundred years (Rodabaugh, 1984). The maximum vibratory ground motion of the *OBE* should be at least one-half the maximum vibratory ground motion of the *SSE*, unless a lower *OBE* can be justified on the basis of probability calculations.

The Safe Shutdown Earthquake (SSE), E_S, *is that earthquake, which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is the earthquake which produces the maximum vibratory ground motion for which the pipes should remain functional.*

This earthquake is typically expected to occur once in one thousand years (Rodabaugh, 1984).

The Code requires the moment responses caused by a postulated earthquake loading at the nuclear plant foundation. The seismic loading is transmitted to the piping system through the pipe support connections and the structure that supports it. For the calculation of the maximum response of piping under earthquake loading, many uncertainties arise, and namely:

- The <u>intensity of the peak ground motion at the plant site</u>. The usual approach is to perform a seismic hazard analysis, where a probability distribution of effective peak ground acceleration at the site is determined by considering all possible magnitudes of earthquake, epicenter distances and depths possible for the site under consideration, (Cornell, 1968; Ellingwood, 1994). This way a cumulative distribution function $G_A(x)$ is generated, showing the annual probability of exceeding a specified ground acceleration, x, as a function of x. The peak ground acceleration, A, is supposed to have a Type II distribution of largest values.

- The pipe response, which implicates different uncertainties by itself, such as:
  a) The *method of analysis*. The most precise method but cost prohibitive is to analyze with a time history the piping system together with the other components and the building. As an alternative, the pipes are decoupled from the structure and input load functions are considered at the supports. Some pipes are within rigid containments, and in such case the supports vibration can be considered in phase, but in generally the supports may not be in phase and this way two types of stresses are generated that are considered in the ASME B&PV Code (2001): the primary stresses due to the inertia of mass, and secondary stresses due to relative movement of the supports. Primary stresses are considered in this study. In usual practice the response of piping is obtained by using the Response Spectrum Method.

  b) The *damping* of the pipe. Over the different eras of piping design different response spectra were utilized and values of critical damping between 0.5% and 5% were considered, with the damping for the SSE to be larger than the one considered for the OBE. When the Response Spectrum Method is considered, the variability in the modal frequency of piping systems should also be considered. Discussion about the criteria for seismic piping design is provided in detail by Stephenson (1995, 2003).

For the development of LRFD for buildings (Ellingwood, et al., 1980) and other structures (e.g., dams) the coefficient of variation of the seismic load and its distribution were determined. As in civil engineering structures, where the largest uncertainty comes from the peak ground acceleration since all the other uncertainties mentioned above, (method of analysis, damping, modal frequency) have a smaller coefficient of variation, for pipes also the acceleration determines the characteristics of the seismic load. Table 3-20 summarizes the probabilistic characteristics of seismic loads used in different studies for the development of load and resistance safety factors. For piping also the distribution of the seismic load can be considered as Extreme II of largest values with a coefficient of variation varying between 0.40 and 0.90.

Table 3-20: Probabilistic Characteristics for the Seismic Load

Occurrence		Intensity			Reference
Rate per year	Duration	Mean	*COV*	Distribution	
0.02	30sec	Site-dep.	0.85	Type II	Ellingwood (1995)
0.05	30sec	($0.08E_s$)	0.90	Type II	Ellingwood, et al. (1996)
$\ln F_A(0.05)$/year	10-20sec	NA	0.85	Type II	Hwang & Ellingwood, et al. (1987)
2/year	60sec	NA	0.70	Type I	Casciati (1983)
1 to 4/year	60sec	NA	0.35-0.70	Type I or II	Casciati, et al. (1982)

NA=Not Available

3.2.4. Mechanical Loading

In this study the term "mechanical" loads is used to describe loads such as water hammer or pressure surges. Water hammer refers to shocks sounding like hammer blows produced by a rapid change of fluid flow velocity in a closed pipeline. It can happen due to rapid closure of the valve, where the fluid stops suddenly. The kinetic energy is then converted into pressure energy. The pressure rise causes in turn elastic waves that travel upstream and downstream from the point of origin. These elastic waves cause increases or decreases in pressure that are called water hammer surge or transient pressure. In most cases water hammer occurs during a plant startup or during return of an isolated plant system into service or when safety valves are actuated. The discharge piping is more susceptible to transient hydrodynamic loads, since the opening time of safety valves is very fast and can induce large hydrodynamic loads on the downstream piping, especially when loop seals are present.

The pressure rise, P, for instantaneous valve closure is given in the following equation (AWWA Manual, 2004).

$$P = \frac{a W V}{144 g} \tag{3-5}$$

where W is the weight of fluid (lb/ft^3), V is the velocity of flow (fps), g=32.2 fps/sec, and α is the magnitude of the surge wave velocity, which is independent of the length of the pipe and for steel is equal to:

$$a = \frac{4660}{\sqrt{(1 + (D_i / 100t))}} \text{ fps} \tag{3-6}$$

where, D_i is the inside diameter of the pipe and t its thickness.

The pressure rise exert a force to the pipe which is equal to the pressure times the cross-sectional area of the pipe. The water hammer mechanism can be also generally described by Joukowsky's Law as follows:

$$\Delta p = \rho \, \alpha \, \Delta u \tag{3-7}$$

where Δp=the dynamic pressure change resulting from the change of the flow velocity in the pipe by an amount Δu, ρ=the density of the fluid, α=the speed of a pressure wave in the fluid flowing in the pipe.

Table 3-21 presents the statistics on Safety Relief Valve (SRV) discharge loads as presented in the consensus estimation studies of Hwang, et al. (1983), and Table 3-22 shows the statistical properties of Safety Relief Valve (SRV) discharge loads, presented in other studies. SRV loads occur mostly in BWR plants. McGeorge (1974) refers that in most cases of steam flow in main steam lines, the fluctuation of pressure following a valve closure is of the order of 10-20% of the normal operating pressure.

Table 3-21: Statistics on Safety Relief Valve (SRV) Discharge Loads, (Hwang, et al., 1983)

Property	Load Case			
	A	B	C	D
Design Value (psi d)	13.49	17.40	16.46	28.23
Design Value (bar d)	0.93	1.20	1.14	1.95
Predicted Value (bar d)	0.60	0.79	0.74	1.11
Mean/Design Value	0.65	0.66	0.65	0.57
Variance	0.00357	0.00407	0.00363	0.0154
Standard Deviation	0.0597	0.0638	0.0602	0.124
COV	0.10	0.08	0.08	0.11
Number of Occurrence in 40 years	271	1313	NA	1620
Occurrence Rate per year	6.775	32.825	NA	40.5

A: First actuation of one or two valves (100^{o}F suppression pool)
B: First actuation of three or more adjacent valves (100^{o}F suppression pool)
C: First actuation of an ADS valve (120^{o}F suppression pool)
D: Subsequent actuation of a single valve (120^{o}F suppression pool)

Table 3-22: Statistics on Safety Relief Valve (SRV)

Occurrence		Intensity			Reference
Rate per year	Duration	Mean	*COV*	Distribution	
N/A	1sec	$0.8P_{SRV}$	0.14	Normal	Ellingwood, et al. (1996)

N/A=Not Available

Mechanical loads such as water hammer except from the overpressure listed in the above tables result also in out-of balance forces developed at areas of piping such as elbows, tees, etc. The time varying force develops a dynamic excitation of the piping system and the development of moments, which are considered for the piping design for Service Limits B and C.

3.2.5. Thermal Loading

Thermal loading is considered in the Code for Class 2 and 3 piping only as a cause for fatigue, while for Class 1 pipes both for fatigue and ratcheting. More specifically, for Classes 2 and 3 the range of expansion moment loading resulting from a temperature difference (expansion or contraction) at locations where the pipe is restraint to move are taken into consideration. More discussion is provided in Chapter 7.

Nevertheless, as a result of accidental temperature, which is not a repeated load, moments can be developed, too. Probabilistic characteristics of accidental temperature are suggested for containments by Hwang, et al. (1983), namely a coefficient of variation equal to 0.12 and bias (ratio of mean to design value) equal to 0.90.

The temperature differences, ΔT, produce also axial forces, $F=E\,\alpha\,\Delta T$, where E is the modulus of elasticity and, α, the thermal expansion coefficient. These forces were not considered herein.

3.2.6. LOCA Loading

Loss Of Coolant Accident (LOCA), as water hammer, leads to an increase in the pressure boundary and dynamic loading on the piping. LOCA loading is characterized as small or large depending on what pipe breaks and the effects of the pipe's failure. Its cause is that low pressure piping gets over-pressurized. This type of loading is accidental and therefore is considered only for Service Limit D conditions. Moreover, it is mostly usual for Class 1 piping.

3.3. Generated Random Variables

The variables used in the performance functions are stresses. The basic loading random variables on the other hand, as presented previously, are different types of loadings. Using Monte Carlo simulation in order to approximate the characteristics of stresses, it was inferred that the loading has the greatest impact such as the stresses can also be approximated to have the same probabilistic characteristics as the loads themselves.

CHAPTER 4: STRENGTH MODELS UNCERTAINTY

In this chapter initially a brief discussion about the bias and the factors applied to mean and nominal values of variables is provided. Then, the procedure for the estimation of the uncertainty introduced by the design strength models for yield or burst of pipes due to internal pressure and ultimate moment capacity is discussed. Moreover, the bias of the resistance for the previously mentioned failure modes is assessed.

4.1. Definition of Bias

The determined in the previous chapter probabilistic characteristics of the design variables are used for the calculation of partial safety factors applicable to the mean value of variables, R, L_i, as Eq. (4-1) shows. For convenience these factors are called mean partial factors. Since engineers use the nominal values, R_n, L_{ni}, in structural design, the partial load and resistance factors, φ, γ_i applicable to the mean values of variables are converted to factors applicable to nominal values, φ_n, γ_{ni}, by using the ratio shown in Eq. (4-2) also called bias, a statistical term usually used to express deviation from reality. These factors are called nominal factors. Hence, Eq. (4-1) yields Eq. (4-3) by using Eq. (4-2).

$$\varphi R \geq \sum_{i=1}^{k} \gamma_i L_i \tag{4-1}$$

$$\text{Bias} = b = \frac{\text{True mean value}}{\text{Nominal value}} \tag{4-2}$$

$$\varphi b_R R_n \geq \sum_{i=1}^{k} \gamma_i b_{Li} L_{ni}$$

or

$$\varphi_n R_n \geq \sum_{i=1}^{k} \gamma_{ni} L_{ni} \tag{4-3}$$

where, $b_R = R/R_n$ and $b_{Li} = L_i/L_{ni}$ are the bias for the resistance and loads, respectively.

The calculation of bias for the resistance of piping for burst or yielding due to internal pressure and ultimate bending capacity is calculated according to Eq. (4-2). The true mean value in that equation is obtained as:

$$\text{True mean value} = X_M \text{ (Simulated mean value)} \tag{4-4}$$

where the simulated mean value is the mean value obtained from a variety of pipes strengths and dimensions, considering, moreover, the probabilistic characteristics of the basic random variables given in Chapter 3, and using Monte Carlo simulation. X_M is a variable, which introduces the uncertainty of the strength model used to obtain the nominal value of the resistance.

4.2. Strength Model Uncertainty

Detailed description for the determination of the uncertainty generated by the use of strength models in order to obtain the resistance of structural elements is encountered and discussed for different structures (Galambos, 1973; MacGregor, 1976; Ellingwood, et al., 1980; Assakkaf, 1998). The strength model uncertainty or strength model bias is the result of simplifications and assumptions made for the derivation of the model.

Initially, by comparing experimental results with the model predictions and using representative mean values of variables, the total bias shown in Eq. (4-5) is computed.

$$\text{Total Bias} = \frac{\text{Experimental value}}{\text{Representative mean value}} = X_E \; X_M \; X_V \tag{4-5}$$

The mean of total bias, μ_{TB}, can be therefore expressed as:

$$\mu_{TB} = \mu_E \; \mu_M \; \mu_V \tag{4-6}$$

and the coefficient of variation, V_{TB}, (considering X_E, X_M, X_V as uncorrelated variables and neglecting terms higher than second order), as:

$$V_{TB} = \sqrt{V_E^{\,2} + V_V^{\,2} + V_M^{\,2}} \tag{4-7}$$

The variables X_E, X_V, and X_M in Eq. (4-5) are defined as:

$$X_E = \frac{\text{Experimental value}}{\text{True mean value}} \tag{4-8a}$$

which is a variable with mean value, μ_E equal to 1 and coefficient of variation, V_E, that includes uncertainties arising from erroneous readings, inaccuracies of the gages and small errors in the setting of the experiments. Ellingwood, et al. (1980) proposes a value between 0.02-0.04 for V_E.

$$X_V = \frac{\text{Simulated mean value}}{\text{Representative mean value}} \tag{4-8b}$$

which is a variable with mean value μ_V=1.0 and coefficient of variation, V_V, which considers the uncertainties introduced by the basic variables such as the dimensions, and the strength of steel, and

$$X_M = \frac{\text{True mean value}}{\text{Simulated mean value}} \tag{4-8c}$$

which is the variable that as mentioned previously represents the uncertainty of the strength model alone. From the previous discussion and Eq. (4-6), it is evident that it has a mean value equal to that of total bias and coefficient of variation given as:

$$V_M = \sqrt{V_{TB}^{\ 2} - V_V^{\ 2} - V_E^{\ 2}} \tag{4-9}$$

In what follows, the total bias (mean and coefficient of variation) for strength models predicting the burst and yielding pressure of piping and their ultimate moment capacity is calculated. Moreover, the bias of the resistance, b_R, according to Eq. (4-2), for each case is estimated.

4.3. Piping Burst and Yielding Due to Internal Pressure

Piping burst is a brittle failure highly undesirable in all engineering designs. Yielding starts at the inner surface of the pipe and progress towards the outside surface. As the internal pressure in the pipe arises to a bursting point, the generated tension by the circumferential or hoop stress expands the walls of the pipe, creates thinning of the wall and finally causes a split along a longitudinal line, which usually is not an existing longitudinal joint. As yielding precedes the burst of the pipe, it is usual demand in the design codes that pipes should resist yielding and therefore permanent deformations under normal operating conditions. The following sections describe criteria, models and assumptions for the design against burst and yielding of piping due to internal pressure.

4.3.1. Strength Models

The models analytically examined here are the ones usually used in the ASME codes. They are based on the maximum principal stress criterion, on the Tresca criterion or are arbitrary approximations like the Barlow model. The models are simple, facilitating hence hand calculations, since their use goes back almost six decades and are based on elastic prediction of strength. In other words, the yield strength, S_y, is substituted by the ultimate strength, S_u, in order to predict the burst pressure.

Table 4-1 presents these models. It also shows two models, 6 and 7, based on elastic perfectly plastic behavior of the material, using the Tresca and the Von Mises Criterion, respectively. From these two criteria the Tresca is more conservative but favorites the calculations, since unlike the Von Mises criterion it does not consider the longitudinal stress, f_L, and therefore is invariant for the different boundary conditions of the pipe (Szabó, 1972; Benham, et al., 1996). Nevertheless, the most common case is to consider pipes in closed end conditions.

There are also models that consider the strain hardening of the material, when burst is examined. In such cases the material is selected to follow a law, usually the power law stress-strain relationship, where the strengthening coefficient, n, is calculated as a ratio of the ultimate strain. Such models are presented in Table 4-2.

Burrows, et al. (1954) describe a great variety of models for the design of pipes for bursting. They group the models that give similar results and suggest the Boardman model, also used in the ASME B&PV Code, Section III (2001), for the prediction of burst pressure of pipes, operating at room as well as at elevated temperatures.

Table 4-1: Models Examined for Use in LRFD

		Model	Description
1	Lamé	$f = f_H = P\dfrac{0.5\left(\dfrac{D_o}{t}\right)^2 - \dfrac{D_o}{t} + 1}{\left(\dfrac{D_o}{t} - 1\right)}$	Maximum principal stress criterion
2	Boardman	$f_H = P\dfrac{D_o - 2yt}{2t}$ y=0.4 and for $D_o/t<6$, $y=d/(D_o+d)$	Approximation of model 1
3	Thin Theory	$f_H = P\dfrac{d}{2t}$	Tresca criterion with $f_R = 0$ based on internal diameter
4	Average Diameter	$f_H = P\dfrac{D_m}{2t}$	Pseudo-average hoop stress based on the average diameter
5	Barlow	$f_H = P\dfrac{D_o}{2t}$	Pseudo-average hoop stress based on the outer diameter
6		$f = P\dfrac{1}{\ln\dfrac{D_o}{d}}$	Tresca criterion for perfectly plastic behavior of the material
7		$f = P\dfrac{\sqrt{3}}{2}\dfrac{1}{\ln\dfrac{D_o}{d}}$	Von Mises criterion for perfectly plastic behavior of the material, considering end caps and $f_L = 0.5f_H$

D_o=external diameter, d=internal diameter, f=equivalent stress, f_H=hoop stress, f_R=radial stress, f_L=longitudinal stress, P=internal pressure, t=thickness

Table 4-2: Models for Burst Pressure and Strain Hardening Steel

Criterion	Strain Hardening Material	Reference
Tresca	$P_u = \frac{1}{2^n}\frac{2t}{D_m}S_u$ with corresponding ultimate strain $\varepsilon_u = \frac{n}{2}$ Based on pure power-law curve	Zhu, et al. (2005); Steward, et al. (1994)
Von Mises	<u>*Closed-End Cylinders*</u> $P_u = \frac{1}{\left(\sqrt{3}\right)^{n+1}}\frac{4t}{D_m}S_u$ where the strengthening coefficient *n* is $n = 0.239\left(\frac{S_u}{S_y} - 1\right)^{0.596}$ with corresponding ultimate strain $\varepsilon_u = \frac{n}{\sqrt{3}}$	Zhu, et al. (2005); Steward, et al. (1994); Cooper (1957); Svensson (1958)
	<u>*Closed-End Cylinders*</u> $P_u = \left(\frac{2}{\sqrt{3}}\right)\left(\frac{2\,t\,S_u}{D_o}\right)\left(\frac{1}{\sqrt{3}}\right)^n$ with corresponding ultimate strain $\varepsilon_u = \frac{n}{2}$ <u>*Open-End Cylinders*</u> $P_u = \left(\frac{2}{\sqrt{3}}\right)\left(\frac{2\,t\,S_u}{D_o}\right)$ with corresponding ultimate strain $\varepsilon_u = \frac{2\,n}{3}$	Gerdeen (1976)
	<u>*Closed-End Cylinders*</u> $P_u = \left(\frac{4}{\sqrt{3}}\right)\left(\frac{S_u + S_y}{2.075}\right)\left(\frac{t}{D_o - t}\right)$ Material follows the Ramberg-Osgood power law	Kirkemo (2001)

D_m=average diameter, D_o=external diameter, n=strength hardening coefficient, P_u=burst pressure, S_y=yield strength of steel, S_u=ultimate strength of steel, t=thickness of steel, ε_u=ultimate strain

4.3.2. Total Bias Estimation for Yield and Burst Internal Pressure

The nominal value of yield or burst pressure can be estimated, as mentioned previously by using a variety of models, when the hoop stress, f_H or equivalent stress, f is substituted by the either the yield strength of steel, S_y, or the ultimate strength of steel, S_u. The test data and the predicted by the models pressure are given in Tables 4-3a, and 4-3b for burst and yielding of pipes, respectively. Criteria for the selection of tests are that the pipes are straight, without defects and remote from discontinuities. The data include different categories of pipes, both thin ($d/t \leq 20$) and thick pipes. It should be nonetheless mentioned that in some cases (e.g. yielding of stainless or carbon steel pipes) data is either not available or very limited and uniform in order to pursue the statistical analysis described in Section 4.2. In such cases the trend of the results is only considered and assumptions are made in order to evaluate the bias for the resistance of pipes, except for the yielding of pipes made of stainless steel, where no data at all are available.

The coefficient of variation V_E, as described in Section 4.2, is the same for all the models and assumed to be 0.02. V_V is estimated, using Monte Carlo simulation and the statistical properties of the basic random variables presented in Chapter 3. V_{TB} is the coefficient of variation of the total bias derived from the experimental results and lastly V_M is calculated, using Eq. (4-9) with respect to the measured, experimental burst or yielding pressure. The mean value and coefficient of variation of the total bias are summarized in Tables 4-4a and 4-4b for burst and yielding pressure, respectively, while a distinction between thick and thin pipes is also mad

Table 4-3a: Experimental Data Used for the Estimation of Total Bias for Burst of Pipes

d (mm)	d/t	f_y† (MPa)	f_u† (MPa)	P_{burst} (MPa)	Model 1*	2*	3*	4*	5*	6*	7*	Reference
80.9	20.2	238	391	47	36.76	36.50	38.67	36.84	35.19	36.87	42.57	Wellinger, et al. (1971)
80.9	20.2			42	36.76	36.50	38.67	36.84	35.19	36.87	42.57	(C)
71.3	8.1			94.2	84.89	84.07	96.52	85.91	77.41	86.26	99.61	
71.3	8.1			100.6	84.89	84.07	96.52	85.91	77.41	86.26	99.61	
81.6	8.2			97.6	84.37	83.55	95.83	85.37	76.97	85.71	98.97	
114.7	9.2			73.5	76.11	75.37	85.22	76.85	69.97	77.10	89.02	
114.7	9.2			76	76.11	75.37	85.22	76.85	69.97	77.10	89.02	
80.9	20.2	512	642	57.9	60.36	59.93	63.49	60.49	57.77	60.54	69.91	
80.9	20.2			61.8	60.36	59.93	63.49	60.49	57.77	60.54	69.91	
35.7	29.8	239	557	41.41	36.19	35.99	37.45	36.23	35.09	36.24	41.85	Pretorius, et al. (1996)
34.9	21.8			55.86	48.74	48.41	51.07	48.83	46.78	48.86	56.42	(S)
48.4	40.3			29.5	26.94	26.82	27.62	26.95	26.31	26.96	31.13	
47.6	29.8			39	36.19	35.99	37.45	36.23	35.09	36.24	41.85	
61.1	50.9			23.5	21.45	21.38	21.88	21.46	21.05	21.46	24.78	
60.3	37.7			33.4	28.78	28.65	29.56	28.79	28.07	28.80	33.26	
73.8	61.5			18.9	17.82	17.77	18.11	17.82	17.54	17.83	20.58	
73	45.6			26.7	23.88	23.79	24.42	23.89	23.39	23.90	27.59	
573.6	31.5	635	733	41.76	45.04	44.81	46.52	45.08	43.74	45.10	52.08	Maxey (1986)
572.3	30.3	556	667	37.86	42.60	42.38	44.05	42.65	41.33	42.66	49.26	(C)
572.3	30.3			40.79	42.60	42.38	44.05	42.65	41.33	42.66	49.26	
871.1	38.7	476	610	27.93	30.70	30.56	31.51	30.72	29.96	30.72	35.48	Stewart, et al. (1994)
152.4	15.6	635	733	86.6	88.25	87.52	97.24	88.57	83.53	88.68	102.4	(C)
384	28.4	290	549	36.5	37.25	37.04	38.60	37.29	36.07	37.30	43.08	Royer, et al. (1974)
378	29.5	793	935	59.6	61.18	60.85	63.32	61.25	59.31	61.27	70.75	(C)
492.15	62.1	476	610	18.73	19.33	19.27	19.65	19.33	19.03	19.34	22.33	Nakai, et al. (1982)
493.73	69.2	413	536.9	16.97	15.30	15.26	15.52	15.30	15.09	15.30	17.67	(C)
596.9	94.0			11.77	11.30	11.28	11.42	11.30	11.19	11.30	13.05	
595.33	83.4	515.2	626.6	15.1	14.84	14.81	15.02	14.85	14.67	14.85	17.14	
590.55	62.0	444	578.2	17.95	18.35	18.30	18.65	18.36	18.07	18.36	21.20	

*: Refer to Table 4-1, †: Representative mean value for steel and not measured, (C): Carbon Steel, (S): Stainless Steel

Table 4-3b: Experimental Data Used for the Estimation of Total Bias for Yielding of Pipes

d (mm)	d/t	f_y† (MPa)	P_{yield} (MPa)	Model							Reference
				1*	2*	3*	4*	5*	6*	7*	
492.15	62.1	476	15.1	15.08	15.04	15.33	15.09	14.85	15.09	17.42	Nakai, et al.(1982) (C)
493.73	69.2	413	14.02	11.77	11.74	11.94	11.77	11.60	11.77	13.59	
596.9	94.0		10.2	8.69	8.68	8.79	8.69	8.60	8.70	10.04	
595.33	83.4	515.2	12.94	12.20	12.18	12.35	12.21	12.06	12.21	14.10	
590.55	62.0	444	15.59	14.09	14.05	14.32	14.10	13.88	14.10	16.28	
71.3	8.1	238	58.9	51.67	51.17	58.75	52.29	47.12	52.51	60.63	Wellinger, et al. (1971) (C)
80.9	20.2		25.5	22.38	22.22	23.54	22.43	21.42	22.44	25.91	

*: Refer to Table 4-1, †: Representative mean value for steel and not measured, (C): Carbon steel

Table 4-4a: Probabilistic Characteristics of Total Bias for Burst Pressure

Model*	Ratio internal diameter-thickness, (d/t)					
	Any		≤ 20		>20	
	Mean (μ_{TB})	Coef. Var. (V_{TB})	Mean (μ_{TB})	Coef. Var. (V_{TB})	Mean (μ_{TB})	Coef. Var. (V_{TB})
1	1.050	0.091	1.066	0.090	1.046	0.092
2	1.056	0.091	1.076	0.090	1.051	0.093
3	1.002	0.090	0.951	0.075	1.015	0.090
4	1.047	0.090	1.055	0.088	1.045	0.092
5	1.092	0.100	1.159	0.100	1.075	0.096
6	1.046	0.090	1.052	0.087	1.044	0.092
7	0.906	0.090	0.911	0.087	0.905	0.092

*: Refer to Table 4-1

Table 4-4b: Probabilistic Characteristics of Total Bias for Yield Pressure and Carbon Steel

Model*	Ratio internal diameter-thickness, (d/t)					
	Any		≤ 20		>20	
	Mean (μ_{TB})	Coef. Var. (V_{TB})	Mean (μ_{TB})	Coef. Var. (V_{TB})	Mean (μ_{TB})	Coef. Var. (V_{TB})
1	1.116	0.060	NA	NA	1.112	0.065
2	1.121	0.060	NA	NA	1.116	0.065
3	1.077	0.067	NA	NA	1.090	0.065
4	1.114	0.059	NA	NA	1.111	0.065
5	1.150	0.072	NA	NA	1.133	0.067
6	1.113	0.059	NA	NA	1.111	0.064
7	0.964	0.059	NA	NA	0.962	0.064

*: Refer to Table 4-1, NA=Not Available, since only one test is available

Figures 4-1a to 4-1g show the histograms of the estimated total bias for all seven models for burst and Figures 4-2a to 4-2g those for yielding of pipes. Normal and lognormal distributions are moreover fitted in the histograms.

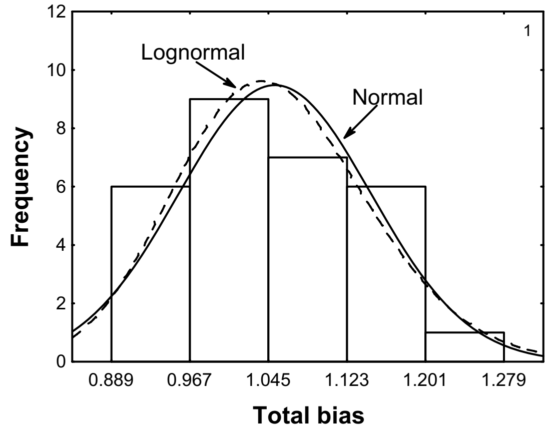


Figure 4-1a: Total Bias of Burst Pressure for Model 1

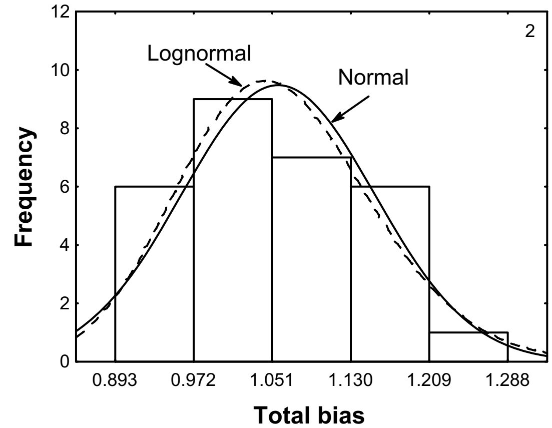


Figure 4-1b: Total Bias of Burst Pressure for Model 2

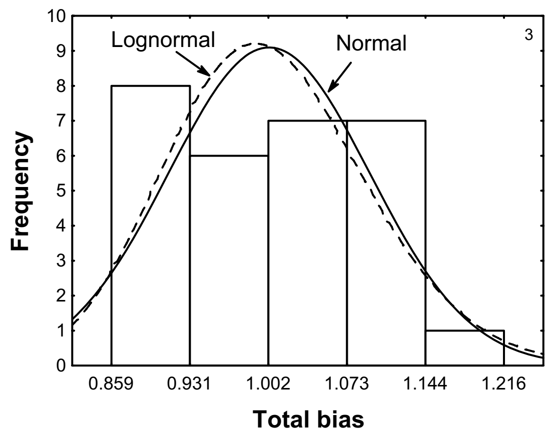


Figure 4-1c: Total Bias of Burst Pressure for Model 3

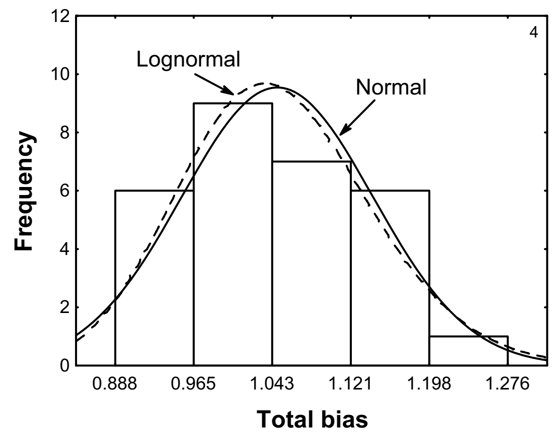


Figure 4-1d: Total Bias of Burst Pressure for Model 4

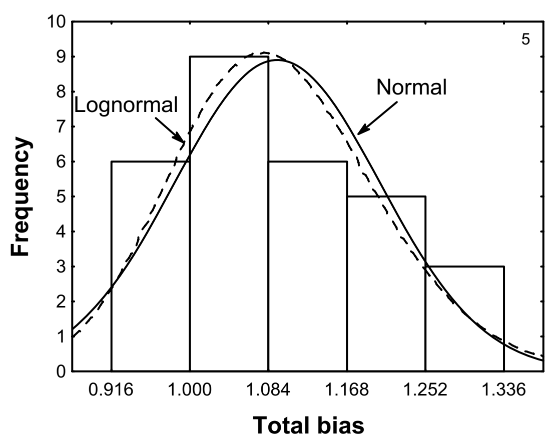


Figure 4-1e: Total Bias of Burst Pressure for Model 5

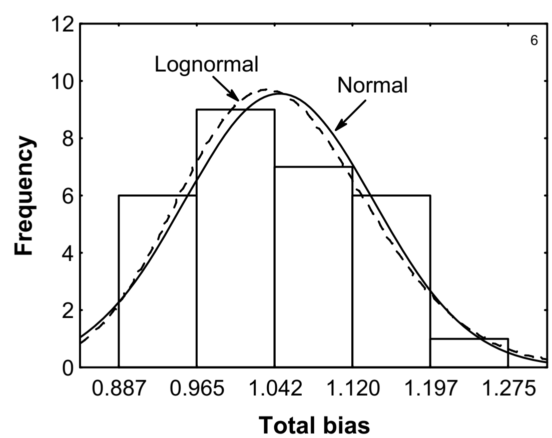


Figure 4-1f: Total Bias of Burst Pressure for Model 6

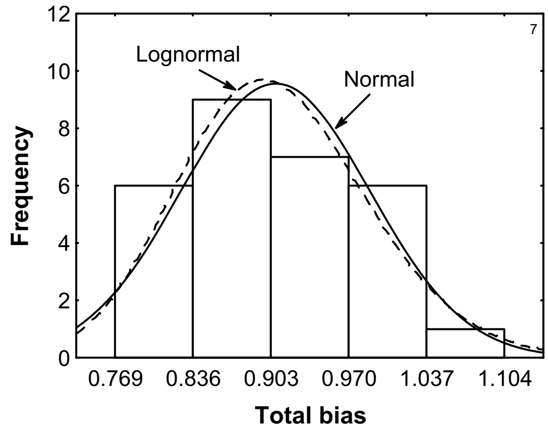


Figure 4-1g: Total Bias of Burst Pressure for Model 7

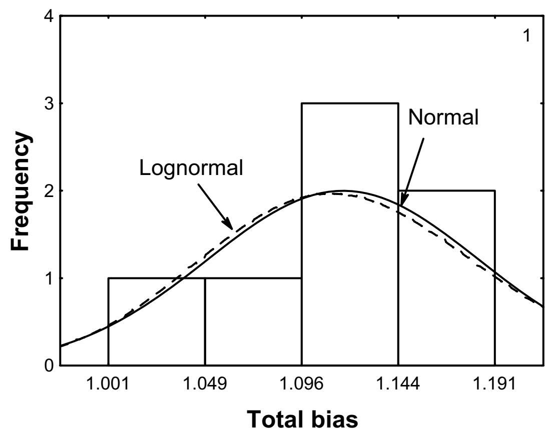


Figure 4-2a: Total Bias of Yield Pressure for Model 1 and Carbon Steel

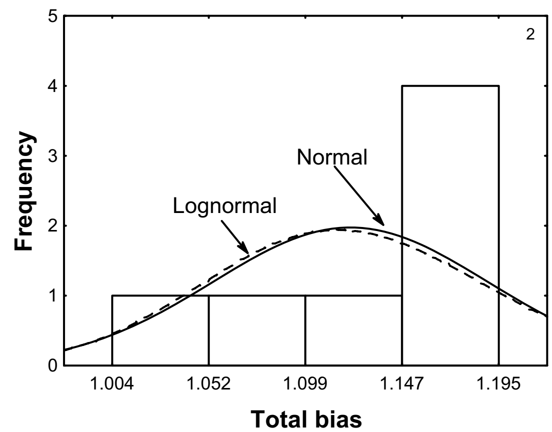


Figure 4-2b: Total Bias of Yield Pressure for Model 2 and Carbon Steel

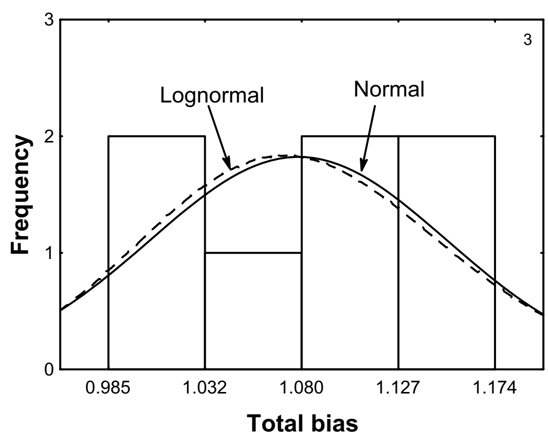


Figure 4-2c: Total Bias of Yield Pressure for Model 3 and Carbon Steel

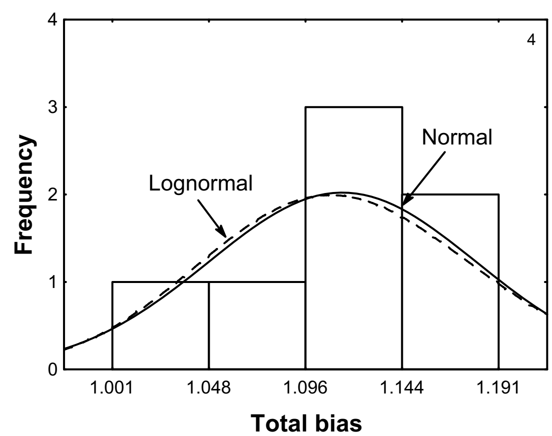


Figure 4-2d: Total Bias of Yield Pressure for Model 4 and Carbon Steel

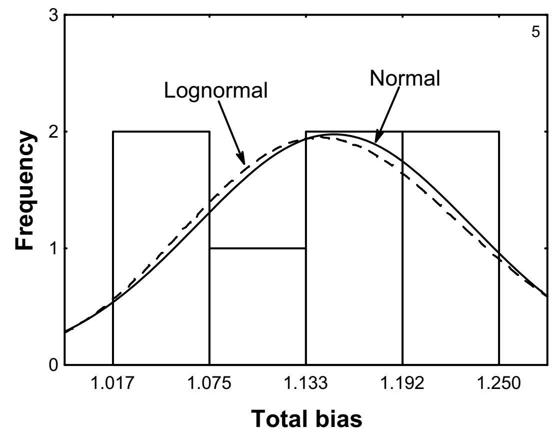


Figure 4-2e: Total Bias of Yield Pressure for Model 5 and Carbon Steel

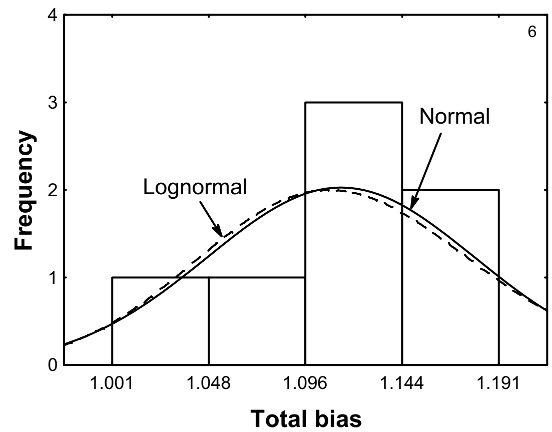


Figure 4-2f: Total Bias of Yield Pressure for Model 6 and Carbon Steel

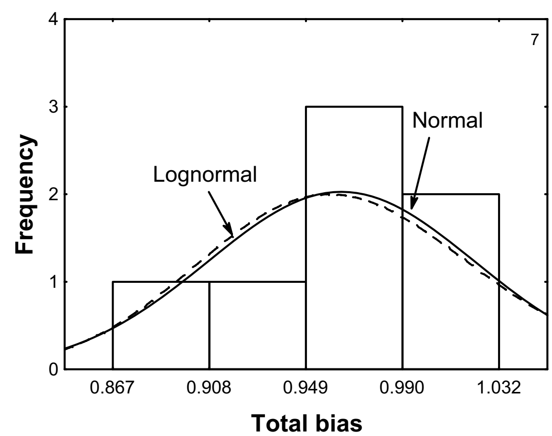


Figure 4-2g: Total Bias of Yield Pressure for Model 7 and Carbon Steel

Table 4-5 shows that all models, except from model 7, give similar results, when burst is considered. More specifically, model 7 gives a value of total bias less than one, and therefore is not recommended to be used for the prediction of burst or yield pressure. Model 3 based on the thin theory yields a mean value equal to unity, when burst is considered. As shown in Table 4-4a, the model is not conservative for thick pipes and therefore it is also unsuitable since it underestimates the burst pressure for thick pipes.

Table 4-5: Models Examined and Parameters Calculated for the Prediction of Burst Pressure

Model*	Mean (μ_{TB})	Coefficient of Variation (V_{TB})	(V_V)	(V_M)	(V_E)
1	1.050	0.091	0.072	0.052	0.02
2	1.056	0.091	0.072	0.052	0.02
3	1.002	0.090	0.073	0.049	0.02
4	1.047	0.090	0.072	0.050	0.02
5	1.092	0.100	0.071	0.068	0.02
6	1.046	0.090	0.072	0.050	0.02
7	0.906	0.090	0.072	0.050	0.02

*: Refer to Table 4-1

4.3.3. Bias of Burst and Yield Pressure

Tables 4-6a and 4-6b give the calculated bias of burst and yield pressure for the models discussed herein, respectively. For carbon steel and yielding, a column is moreover added showing an assumed coefficient of variation for the model uncertainty variable, X_M, since it could not be derived according to the procedure of Section 4.2 due to a uniform and small sample that gives an unrealistic small coefficient of variation. Nonetheless, as mentioned earlier, no estimation is provided for the yielding of pipes made of stainless steel, since for these pipes there is no information at all.

Table 4-6a: Probabilistic Characteristics of Bias of Burst Pressure for Carbon and Stainless Steel

Model*	Stainless Steel		Carbon Steel	
	Mean	Coef. of Variation	Mean	Coef. of Variation
1	1.184	0.091	1.205	0.091
2	1.190	0.091	1.211	0.091
3	1.130	0.094	1.150	0.094
4	1.180	0.091	1.201	0.091
5	1.230	0.101	1.252	0.101
6	1.179	0.091	1.200	0.091
7	1.021	0.091	1.040	0.091

*: Refer to Table 4-1

Table 4-6b: Probabilistic Characteristics of Bias of Yield Pressure for Carbon Steel

Model*	Assumed Coefficient of Variation for X_M	Carbon Steel	
		Mean	Coefficient of Variation
1	0.05	1.257	0.104
2	0.05	1.263	0.105
3	0.06	1.214	0.110
4	0.05	1.255	0.106
5	0.06	1.295	0.109
6	0.05	1.200	0.104
7	0.05	1.086	0.105

*: Refer to Table 4-1

4.4. Ultimate Moment Capacity of Piping

A failure due to excessive bending is of principal interest for the design of piping. Moreover, the equations in the ASME Code, as discussed in Chapter 2, are based on the assumption that pipes are subjected to large bending moments compared to other loading e.g., shear or axial forces. Bending moments result from a variety of loading such as own weight, seismic, other reversing or not reversing dynamic loadings and thermal loads, when free expansion is restraint. A failure due to excessive bending can be visualized as local buckling, ovalization of the cross-section or collapse. The following sections describe design strength models for the ultimate moment capacity and calculate the total bias and bias for the ultimate flexural strength of straight pipes, operating at room temperature.

4.4.1. Strength Models for Failure Moment

Nuclear pipes, as explained in Chapter 3, are principally made of carbon (e.g., SA 106 Gr. B) or stainless austenitic steel (e.g., Types 304, 316, and 347) that show corrosion resistance and good performance under high temperatures. These materials are ductile and their behavior can be considered as linear elastic–perfectly plastic, as Figure

4-3 shows. Given this fact, limit theory is considered for the analysis of pipes. More specifically, as load increases a hinge is formatted and then a redistribution of moments occurs until the number of hinges exceeds by one the degree of indeterminacy of the pipe and hence a collapse mechanism is formed. For limit theory small deformations of pipes are considered and the failure moment equals:

$$M_f = M_P = S_y Z_p \tag{4-10}$$

where S_y is the yield strength and Z_p is the plastic section modulus.

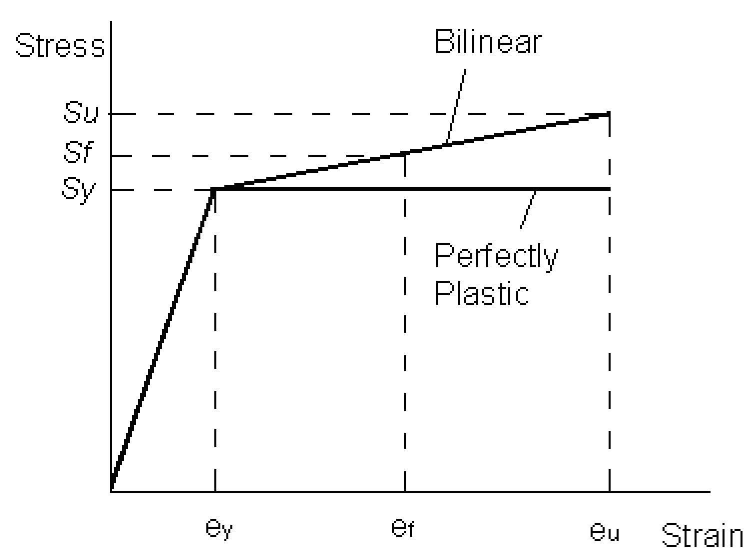


Figure 4-3: Perfectly Plastic and Bilinear Approximations of Steel Behavior

Sherman (1976) examined if the above theory is applicable to straight pipes by conducting experiments for simply supported, fixed ends and cantilever pipes of different ratios of external diameter to thickness, D_o/t. He concluded that pipes actually develop a collapse mechanism, whereas pipes of D_o/t approximately equal to 100 fail due to buckling, without even being able to form a hinge first.

If the material is also considered work-hardening, the failure moment has the following upper bound:

$$M_f = M_u = S_u Z_p \qquad (4\text{-}11)$$

where S_u is the ultimate strength of the material. Should now a bilinear approximation of work hardening material is considered, as shown in Figure 4-3, the failure moment, M_f, is given as:

$$M_f = S_y Z_p + (S_f - S_y) Z \qquad (4\text{-}12)$$

where Z_p is the plastic and Z is the elastic cross-section modulus.

In Eq. (4-12) S_f is the stress that corresponds to a predefined failure strain, e_f, different from the ultimate, e_u, as shown in Figure 4-3. If the stress–strain curve is not available, S_f can be considered equal to the ultimate strength, S_u (Belke, 1983).

In the following sections the total bias for excessive bending is estimated according to Eq. (4-5). The experimental results of bending tests on straight pipes without and with internal pressure are considered and are based on bibliographical data (Rodabaugh, 1978; Belke, 1983). Rodabaugh (1978) summarizes experimental data from other researchers (Schroeder, et al., 1974; Ellyin, et al., 1976, 1977; Franzen, et al., 1972; Gerber, 1974; Sherman, 1974; Jirsa, 1972; and Sorenson, 1970), and graphically calculates the experimental failure moment as that, which causes a deformation equal to two times the elastic deformation. As explained by Ayyub, et al. (2005), there are also other ways to define the failure moment of a pipe. Belke (2003) does not refer to the way experimentally the collapse failure moment is estimated. Simply supported, clamped and cantilevered pipes are examined. The models evaluated are these of Eqs. (4-10) and (4-

11) because are more suitable, due to their simplicity, to be used in an LRFD format.

The data used for the analysis are summarized in Tables 4-7a and 4-7b for bending without and with internal pressure, respectively. The mean value of steel shown in these tables is again the representative mean of the material, and where not available, a mean of the reported data was considered. As in the case of burst and yielding of pipes, data for bending are also limited and in some cases not available.

Table 4-7a: Experimental Data Used for the Estimation of Total Bias for Bending of Pipes

D_o (mm)	D_o/t	f_y† (MPa)	f_u† (MPa)	M_p(Eq. 4-10) (kN m)	M_u (Eq. 4-11) (kN m)	M_{exp} (kN m)	Reference
33.7	12	264	600	0.71	1.61	1.24	Belke (1984) (S)
33.7	12			0.71	1.61	1.19	
33.7	12			0.71	1.61	1.31	
33.7	12			0.71	1.61	1.25	
32.3	17			0.46	1.06	0.68	
32.3	17			0.46	1.06	0.71	
32.3	17			0.46	1.06	0.66	
32.3	17			0.46	1.06	0.62	
29.8	33			0.20	0.45	0.28	
29.8	33			0.20	0.45	0.27	
29.8	33			0.20	0.45	0.27	
29.8	33			0.20	0.45	0.24	
27.13	14.8	259.94	579.17	0.34	0.68	0.28	Franzen, et al. (1972), (S)
27.13	14.8			0.34	0.68	0.40	
105.66	12.3	259.94	579.17	21.02	46.89	29.38	Gerber (1974) (S)
81.03	25.3			5.08	11.19	4.52	
106.43	25.1			11.53	25.65	11.30	
160.78	24.1			41.24	91.97	63.27	
106.43	25.1			11.53	25.65	11.30	
80.01	21	194.44		4.29		4.18	Schroeder, et al. (1974), (C)
90.68	51			2.71		2.82	
108.20	18	277.52	488.16	17.51	30.72	23.73	Gerber (1974) (C)
108.20	18			17.51	30.72	22.60	
105.66	12.3			22.48	39.50	29.38	
108.20	18			17.51	30.72	24.86	
108.20	18			17.51	30.72	22.56	
100.84	7.5			28.81	50.64	39.55	
111.25	36.5			9.94	17.42	15.82	
111.25	36.5			9.94	17.42	18.08	
111.25	36.5			9.94	17.42	19.21	
67.56	21.3	592.27		7.80		8.59	Ellyin, et al. (1976) (C)
117.60	30.7	277.52	488.16	13.78	24.29	14.69	Ellyin, et al. (1977) (C)
146.56	46.2			18.08	31.86	18.98	
258.32	17.4	277.52	488.16	244.73	430.48	259.87	Sherman (1974) (C)
265.94	33.6			146.43	257.61	135.58	
273.05	107.5			51.64	90.73	39.55	
273.05	46.1	365.43		154.34		158.18	Jirsa, et al. (1972) (C)
273.05	30.7			226.76		192.08	
406.4	61.5			385.74		361.56	
508	78.4			692.38		576.23	

Table 4-7a (Continued)

D_o (mm)	D_o/t	f_y† (MPa)	f_u† (MPa)	M_p (Eq. 4-10) (kN m)	M_u (Eq. 4-11) (kN m)	M_{exp} (kN m)	Reference
32.56	39.4	586.06		0.45		0.46	Sorenson (1970) (C)
500.13	63.1	360.60		692.38		796.56	
32.08	94	586.06		0.23		0.15	
32.08	99			0.23		0.17	
273.05	108	309.58		57.51		39.55	
32.05	101	586.06		0.23		0.14	
32.03	115			0.11		0.11	
32.03	112			0.23		0.12	
32.05	103			0.23		0.14	
32.08	100.2			0.19		0.17	

(C): Carbon steel, (S): Stainless steel, †: Representative mean value for steel and not measured

Table 4-7b: Experimental Data Used for the Estimation of Total Bias for Bending of Pipes with Internal Pressure

D_o (mm)	D_o/t	f_y† (MPa)	f_u† (MPa)	P (MPa)	M_p (Eq. 4-10) (kN m)	M_u (Eq. 4-11) (kN m)	M_{exp} (kN m)	Reference
33.7	41.26	194.44		5.18	3.40		3.16	Schroeder, et al. (1974), (C)
27.13	14.83	277.52	488.16	13.48	0.31	0.68	0.24	Franzen, et al. (1974), (S)
27.13	14.83			20.68	0.31	0.68	0.21	
27.13	14.83			27.58	0.31	0.68	0.16	
27.13	14.83			20.64	0.31	0.68	0.34	
27.13	14.83			27.58	0.31	0.68	0.32	
27.13	14.83			15.15	0.31	0.68	0.33	
27.13	14.83			18.97	0.31	0.68	0.28	
27.13	14.83			24.13	0.31	0.68	0.21	

(C): Carbon steel, (S): Stainless steel, †: Representative mean value for steel and not measured

4.4.2. Total Bias for Pure Bending

From the examined experimental results it is evident that the failure moment (ultimate bending resistance) is dependent on the ratio of the external diameter to the thickness of the pipe, D_o/t. More specifically, for the model of Eq. (4-10), pipes with $D_o/t>75$ are susceptible to failure due to buckling and ovalization of the cross-section and therefore are expected not to reach the limit pressure, M_P, as shown in Figure 4-4, for carbon steel. For D_o/t<50 the failure moment either exceeds the moment calculated by Eq. (4-10) or approaches it. Computation results are shown in Figure 4-5 for both stainless and carbon steel. In addition, in Table 4-8a the statistical properties of the total bias for Eq. (4-10) are given, where moreover the coefficient of variation for the model, V_M, is derived.

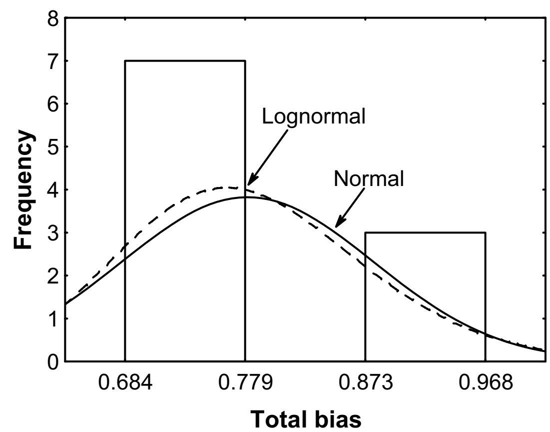
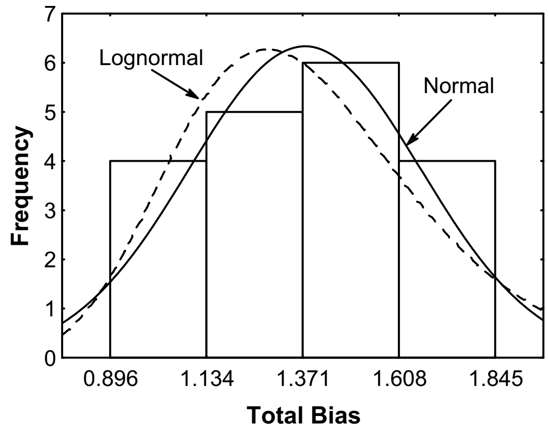
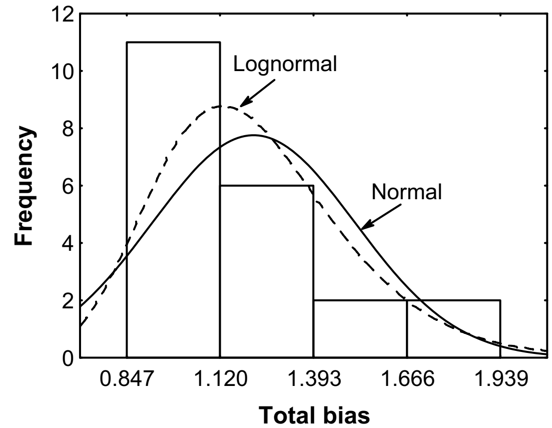


Figure 4-4: Total Bias for the Bending Resistance According to Eq. (4-10) for D_o/t>75 and Carbon Steel



(a)



(b)

Figure 4-5: Total Bias for the Bending Resistance According to Eq. (4-10), (a) Stainless Steel for D_o/t<50, (b) Carbon Steel for D_o/t<65

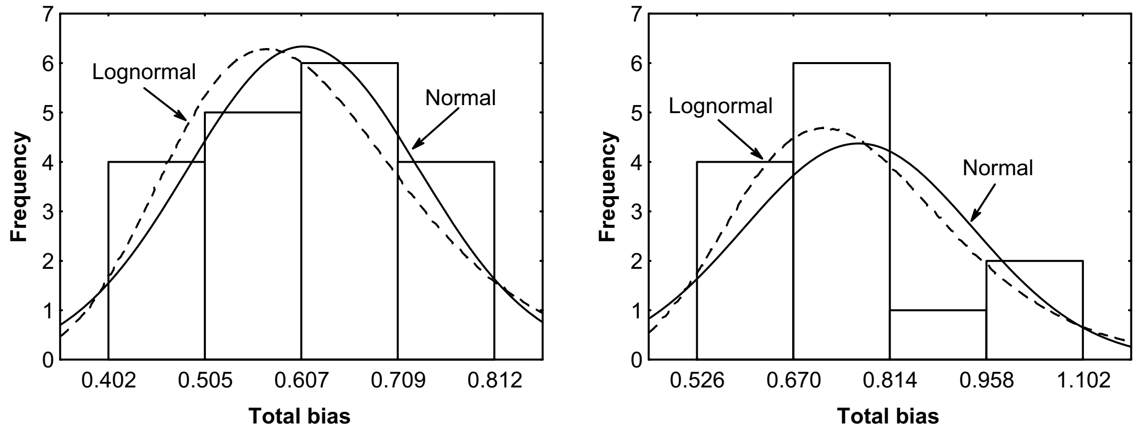
Table 4-8a: Statistical Descriptive of Total Bias for Eq. (4-10) and Pure Bending, and Derivation of V_M

Properties		Mean	Coefficient of Variation			
D_o/t	Steel	(μ_{TB})	(V_{TB})	(V_V)	(V_M)	(V_E)
<50	Stainless	1.373	0.207	0.16	0.13	0.02
≤ 65	Carbon	1.216	0.242	0.10	0.22	0.02
≥ 75	Carbon	0.780	0.126	0.10	0.07	0.02

The model of Eq. (4-11) gives always values of total bias less than one and as expected is not conservative. Figure 4-6 shows histograms of the total bias with fitted distributions for D_o/t<50 for both stainless and carbon steel. Table 4-8b shows further the statistical properties of the model and the derivation of the coefficient of variation, V_M.

Table 4-8b: Statistical Descriptive of Total Bias for Eq. (4-11) and Pure Bending, and Derivation of V_M

Properties		Mean	Coefficient of Variation			
D_o/t	Steel	(μ_{TB})	(V_{TB})	(V_V)	(V_M)	(V_E)
<50	Stainless	0.608	0.202	0.08	0.18	0.02
<50	Carbon	0.766	0.223	0.08	0.21	0.02

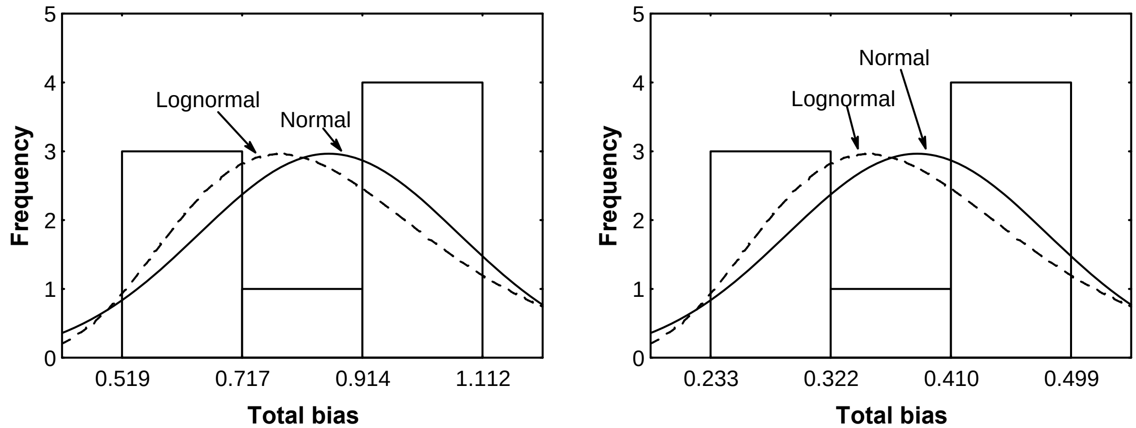


(a) (b)

Figure 4-6: Total Bias for the Bending Resistance According to Eq. (4-11) for D_o/t<50, (a) Stainless Steel, (b) Carbon Steel

4.4.3. Total Bias for Bending with Internal Pressure

As presented by Rodabaugh, et al. (1978) and as expected by theory, internal pressure reduces the moment capacity of straight pipes. Experimental results were evaluated for data summarized by Rodabaugh, et al. (1978) and the total bias was estimated. Figure 4-7 shows histograms of calculated total bias for stainless steel for both models of Eqs. (4-10) and (4-11). Moreover, Tables 4-9a and 4-9b give the statistical properties for the total bias and the derivation of the coefficient of variation for the models of Eqs. (4-10) and (4-11), respectively.



(a) (b)

Figure 4-7: Total Bias for the Bending Resistance with Internal Pressure for Stainless Steel and D_o/t<50, (a) According to Eq. (4-10), (b) According to Eq. (4-11)

Table 4-9a: Statistical Descriptive of Total Bias for Eq. (4-10) and Bending with Internal Pressure, and Derivation of V_M

Properties		Mean	Coefficient of variation			
D_o/t	Steel	(μ_{TB})	(V_{TB})	(V_V)	(V_M)	(V_E)
<50	Stainless	0.857	0.248	0.16	0.19	0.02

Table 4-9b: Statistical Descriptive of Total Bias for Eq. (4-11) and Bending with Internal Pressure and Derivation of V_M

Properties		Mean	Coefficient of variation			
D_o/t	Steel	(μ_{TB})	(V_{TB})	(V_V)	(V_M)	(V_E)
<50	Stainless	0.385	0.248	0.16	0.19	0.02

4.4.4. Bias of Flexural Strength for Straight Pipes

Considering the probabilistic properties of the variables in Chapter 3 and the derived model uncertainty, the bias for the bending resistance is estimated according to Eqs. (4-2) and (4-4). Results are shown comprehensively in Table 4-10 for all the examined cases.

Table 4-10: Bias for Bending Resistance and All Examined Cases

Steel	D_o/t	Bias (Eq. 4-10)		Bias (Eq. 4-11)	
		Mean	*COV*	Mean	*COV*
Bending					
Stainless	<50	1.71	0.21	0.68	0.20
Carbon	≤ 65	1.37	0.24	0.87	0.23
	≥ 75	0.88	0.12	NA	NA
Bending with internal pressure					
Stainless	<50	1.07	0.25	0.43	0.21

NA: Not Available

4.5. Conclusions

A definitive step for the development of Load and Resistance Factor Design (LRFD) for nuclear pipes is the quantification of the uncertainties introduced by the design strength models. The methodology for that quantification was described, and in addition, models for the burst or yielding due to internal pressure and for the flexural resistance of pipes were evaluated. Further the bias of the piping resistance was estimated for these cases.

The collected data for the analysis are limited and moreover the provided information concerns only straight pipes operating at room temperature. Therefore, results and assumptions can be further expanded by the acquisition of additional data. Moreover, in this section the bias was estimated only from experimental data, whereas the use of advanced finite element analysis of pipes can also provide useful data for the bias of the resistance.

CHAPTER 5: LOAD COMBINATIONS AND PERFORMANCE FUNCTIONS FOR PIPING

This chapter presents load combinations and the resultant performance functions necessary for the LRFD for piping, as explained in Chapter 2. The partial load and resistance factors corresponding to the performance functions are summarized in Chapter 6, while analytical calculations are provided in Appendix C. Performance functions for fatigue are given separately in Chapter 7.

5.1. Performance Functions

The performance functions for the LRFD are based on the criteria and format used in the ASME B&PV Code, Section III. This is judged necessary, since a propable transition- even in the form of a code case - from the current Allowable Stress Design to the LRFD, should provide the familiar formats to the designers such as it will be easier for them to understand the philosophy of the LRFD. In consequence, the Boardman model is used for the design for internal pressure, and the Tresca criterion with the assumption of large moments for the combination of primary loads. As it has already been mentioned, LRFD favorites future changes in models and characteristics in variables. Therefore the amelioration of the current design criteria will be easier accomplished by using the LRFD rather than the ASD.

The performance functions are given in the following section based on combination of loads that coincide in time. The Design and Service Levels A and B equations have the steel yield strength as the resistance variable. Service Level D has the ultimate steel strength, since larger displacements are expected in order for strength hardening to develop and having in consequence an expansion of the Tresca yield surface.

For the development of the performance functions for Service Level C there is actually a challenge. By examining the allowable stresses of the Code given in Table 2-2 of Section 2.1.4.1 for the combination of primary loads, it can be inferred that the yield strength of steel is exceeded more than an approximated value of the shape factor. Hence, the use of the ultimate strength seems reasonable such as calibration of the current Code equations will not lead in extremely low values for the target reliability index, β, which can be unusual for a structural design.

Nevertheless, in design examples with arbitrary chosen load intensities the use of the yield strength of steel permitted reasonable safety margins, but since calibration of a great range of real piping design calculations is necessary to confirm this inference, the ultimate strength is selected as the resistance variable for Service Level C performance functions. Should the yield strength of steel is used in the performance functions of Service Level C, a lower value of the target reliability index is to be expected compared to that for performance functions of Service Level B.

In Table 5-2 of the following section, it can be seen that the performance functions g_9, g_{14}, and g_{19} include a factor E that is applied to the sum of dynamic loads. Since no analytical coputations were made in order to evaluate its value, for the calculation of the partial load and resistance factors *E* is considered as constant equal to one. Nevertheless, its mean value is expected to be less than one and its physical meaning is that by summing the individual stress quantities of dynamic loading may result in conservative values as by combining the dynamic loading before the calculation of stresses.

5.2. Load Combinations

In this chapter primary loads/stresses are considered as described in Chapter 3, (secondary stresses cause fatigue or ratcheting) and are summarized below:

- The sustained weight
- Internal Pressure
- Earthquake load (OBE, SSE)
- Mechanical loading (e.g. sudden valve closure, water hammer)
- Accidental loading (LOCA)

Loads that coincide in time are combined and moreover the Turkstra's Rule is considered, which simply states that when combining loads, it is logical to assume that only one load can attain its maximum value for the specified design life of the component, whereas the other loads attain an arbitrary-point-in-time value. Other rules for combining loads are the Borges model (Borges, et al., 1971) and the combination of loads by considering them as Poisson pulse processes (Wen, 1990).

Table 5-1 presents the loads to be combined. Also secondary loads (thermal) are shown, although as mentioned earlier these loads are considered only in fatigue evaluations. The performance functions arising from these load combinations are provided in Table 5-2.

Table 5-1: Loads to Be Combined for Different Service Levels

Service Limit	Weight	Pressure	Mechanical*	OBE	SSE	LOCA	Thermal
Design	✓						
		✓					
	✓	✓					
A	✓	✓					
	✓	✓					✓
							✓
B & C		✓					
	✓	✓	✓				
	✓	✓		✓			
	✓			✓			
	✓	✓	✓	✓			
D		✓					
	✓					✓	
	✓				✓		
	✓		✓			✓	
	✓	✓			✓		

*Dynamic loadings other than earthquake

Table 5-2: Recommended Performance Functions for Straight Pipes

Service Level	Performance Function	Definition of Variables
Design	$g_1 = S_y - S_H$ $g_2 = S_y - S_A$ $g_3 = S_y - S_A - S_{PDes}$	$S_H = \frac{P_{Des}(D_o - 2yt)}{2t}$ $S_A = \frac{M_A}{Z}$ $S_{PDes} = \frac{P_{Des} D_o}{4t}$
A (Operating Condition)	$g_4 = S_y - S_A - S_{P_{max}}$	$S_P = \frac{P_{max} D_o}{4t}$ $S_A = \frac{M_A}{Z}$
B (Upset Loading Condition)	$g_5 = S_y - S_H$ $g_6 = S_y - S_{PB} - S_A - S_M$ $g_7 = S_y - S_A - S_O$ $g_8 = S_y - S_A - S_{PO} - S_O$ $g_9 = S_y - S_{PO} - S_A - E(S_M + S_O)$	$S_{PB} = \frac{P_B D_o}{4t}$ $S_{PO} = \frac{P_O D_o}{4t}$ $S_H = \frac{P_B(D_o - 2yt)}{2t}$ $S_O = \frac{M_O}{Z_P}$ $S_A = \frac{M_A}{Z_P}$ $S_M = \frac{M_M}{Z_P}$
C (Emergency Loading Condition)	$g_{10} = S_u - S_H$ $g_{11} = S_u - S_A - S_O$ $g_{12} = S_u - S_{PO} - S_A - S_O$ $g_{13} = S_u - S_{PC} - S_A - S_M$ $g_{14} = S_u - S_{PO} - S_A - E(S_M + S_O)$	$S_{PO} = \frac{P_O D_o}{4t}$ $S_{PC} = \frac{P_C D_o}{4t}$ $S_H = \frac{P_C(D_o - 2yt)}{2t}$ $S_A = \frac{M_A}{Z_P}$ $S_O = \frac{M_O}{Z_P}$

Table 5-2: (Continued)

Service Level	Performance Function	Definition of Variables
D (Faulted Loading Condition)	$g_{15} = S_u - S_H$ $g_{16} = S_u - S_A - S_S$ $g_{17} = S_u - S_{PS} - S_A - S_S$ $g_{18} = S_u - S_A - S_{PD} - S_L$ $g_{19} = S_u - S_A - E(S_S + S_L) - S_{PS}$	$S_{PD} = \frac{P_D D_o}{4t}$ $S_H = \frac{P_D (D_o - 2yt)}{2t}$ $S_S = \frac{M_S}{Z_P}$ $S_A = \frac{M_A}{Z_P}$ $S_L = \frac{M_L}{Z_P}$ $S_{PS} = \frac{P_S D_o}{4t}$
Nomenclature	S_y=Nominal Yield Strength of Steel, S_u=Nominal Ultimate Strength of Steel, S_H =Hoop Stress, $S_{i,}$ i=P_{Des}, P_{max}, P_C , P_D, $P_{O,}$ P_S= Stress due to Normal Operating Pressure, Maximum Operating Pressure, Pressure Coincident with Service Limit C Conditions, Pressure Coincident with Service D Conditions, Pressure coincident with OBE, Pressure coincident with SSE S_L. S_M = Stresses Due to Mechanical Loading, S_L=stress due to LOCA loadind, y = 0.4, Z = Elastic Section Modulus, Z_P = Plastic Section Modulus, S_O= Stress Due to OBE, S_S = Stress Due to SSE, M = Moment, E=Factor for Combining Dynamic Loading	

5.3. Normalization of Stresses with Respect to Sustained Weight

For the calculation of the partial load and resistance factors the performance functions listed in Table 5-2, except from the performance functions g_1, g_5, g_{10}, and g_{15}, are normalized with respect to the stress due to sustained weight. All the stresses noted as S_i in that table, therefore become f_i as follows:

$$f_i = \frac{S_i}{\mu_{SA}} \tag{5-1}$$

where S_i is the stress due the load of origin, i, and μ_{SA} the mean stress due to sustained weight. The normalized stress f_i becomes a new variable with the following characteristics:

$$\mu_{f_i} = \frac{\mu_{S_i}}{\mu_{S_A}} \tag{5-2a}$$

$$COV \text{ of } S_i = COV \text{ of } f_i \tag{5-2b}$$

$$\text{PDF of } S_i = \text{PDF of } f_i \tag{5-2c}$$

where μ_{fi}, μ_{Si}, μ_{SA} are the mean values of variables f_i, S_i, and S_A, respectively. The acronyms *COV* and PDF stand for Coefficient Of Variation and Probability Density Function, respectively. This procedure is necessary in order to be able to consider different magnitude of loading for the pipes under consideration. The sustained weight was selected to be used for the normalization of other stresses, for uniformity reasons, since it is present in all the performance functions. Of course, other variables could have been used in order to normalize the stresses.

The proposed LRFD equations intend to serve as an alternative to the equations of the ASME Code, Section III and namely the ***design by rule*** part, and therefore should take into consideration a representative range of the loading magnitude for piping. This makes necessary the normalization of stresses. Below, in addition, some explanation is provided in order to demonstrate the great variability of loading that piping is subjected to. Hence:

- Nuclear pipes come with different sizes, especially those complying with the design rules of Classes 2 and 3, which constitute the majority of piping, and are part of different sections of the nuclear plants.
- The earthquake loading not only varies between different territories in U.S. (west-east), but significantly varies within close regions where special tectonic characteristics define the subsoil's behavior to seismic excitations. Even in the same plant the pipes can be differently impacted, depending on the floor they are mounted on, the characteristics of the building structure, and their own properties (flexibility, mass).
- Pressure differs highly depending on the size of the pipe and the operating temperature. The produced longitudinal stresses attain diverse values and if they are to be compared with the stresses due to sustained weight, diverse values are obtained for light or heavy pipes pressurized at different levels.
- Generally, values of loading being accepted as Service Limit B for some pipes, for others can be loading characterized as Service Limit C, etc. This fact may also lead to small and large load ratios for all service levels.
- The sustained weight can vary significantly even for the same schedule pipes depending on the sustained weight (superimposed valves, etc.).

This method of analysis was also considered for the development of LRFD equations for other structures, buildings, ships, etc., too. In order to obtain values for the ratio of Eq. (5-2a) calculations for simple pipes-beams were considered and the ranges were extended such as to include feasible quantities for the variables under consideration.

These ranges and the summary of the probabilistic characteristics of normalized variables are given in Chapter 6.

5.4. The Target Reliability Index, β, for Piping

The use of a probabilistic based approach for the design of nuclear components necessitates that a target probability of failure be established before the design proceeds. This probability refers to the design life of the structure, which in the case of nuclear plants and components is 40 years, with a possibility of extension for another 20 years. The target probability of failure sometimes may also be expressed as probability of failure per year or for example for pipelines as a probability of failure per year and kilometer.

Although the actual probability of failure can also be estimated, using Monte Carlo simulation or by collecting historical data on relevant, reported failures of pipes, when selecting the reliability index and in consequence assigning the probability of failure to pipes, the following factors should be considered:

a. *The consequences that a failure can cause* e.g., deaths, injuries, economic losses, environmental damage, etc. and the cost for increasing the reliability of piping. Accordingly, a cost-benefit analysis can be performed for finding an optimal design. Nevertheless, this method of analysis necessitates the use of higher level reliability methods.

b. The probability of occurrence of the loading event. Loading such as weight and pressure are associated with smaller probabilities of failure compared to loads with smaller probability of occurrence, such as earthquake loading or a shock wave from a pipe that breaks. Consequently, in case of similar performance functions, higher reliability indices are expected for Service Limits A and B, where the loading is operational or occasional as compared to Service Limits C and D, where in the case of the latter, the occurrence of loading might as well not be within the service life of the component.

c. *The probabilities of failure, which are implicit in the current design***.** This procedure, known also as code calibration, quantifies the probabilities of failure for the design of piping according to the ASME B&PV Code, Section III. The results from calibration are expecting to give a range of probabilities of failures. This way, the probability of failure actually becomes a variable, where a histogram can be created and a corresponding value -often in the upper percentile of the distribution- can be considered as the target reliability index for future designs for piping according to LRFD. Therefore, LRFD will become more consistent as compared to Allowable Stress Design and the probability of failure for the component will not only be more consistent but also known.

d. Assignment of an initial probability of failure for the whole plant. Schwartz, et al. (1981) suggest that the acceptable probability of failure or β for certain categories of pipes can be assigned by considering an initial acceptable probability of failure for the whole plant that by using risk analysis methods can break down to a suggested value of β for the pipes under consideration in a system's framework.

As an example for suggested probabilities of failure for nuclear structures of Category I, such as containments, etc. are given for different load combinations in Table 5-3 by Schuëller, et al. (1992).

Table 5-3: Lifetime Limit State Probabilities for Nuclear Structures (for 40 years)

Load Combination	Limit State Probability	β
$D+L$	<E-15	8
$D+L+E$	7.23E-04	4
$D+L+E+P_L$	2.20E-09	5.5
Overall	7.92E-04	4
Nomenclature:	D=Dead Load, L=Live Load, E=Earthquake Load, P_L=Pressure due to LOCA	

Solving Eq. (2-20) for β, Eq. (5-3) is obtained according to which the values of β in Table 3-2 are derived:

$$\beta = \Phi^{-1}\left[1 - P(L.S.)\right] \tag{5-3}$$

where $P(L.S.)$=the limit state probability.

A pilot project was successful in calculating probability of piping failures based upon deterministic Code rules (Barnes, et al., 2000). Phase I investigations found that pipe cross-section failure probabilities are generally below 10^{-6} per year, when credit is taken for the probability of the seismic event occurring. Phase II analysis used the example from Phase I modified to account for cyclic stresses in hot piping. In this instance, the cumulative leak probabilities were computed to be quite high, as high as $3\text{x}10^{-3}$ per year. The double-ended pipe break probabilities were several orders of magnitude lower.

In this study, calculations will address a range of reliability indices that are judged suitable for each performance function, understanding that in order to estimate the target reliability index for each performance function the above criteria should be considered.

The Code calibration, which is the procedure of determining the target (desired) reliability index for each load combination based on inconsistent probabilities of failure that exist in the current Code and stochastic analysis of loads (Schwartz, et al., 1981) is out of the scope of this work. Nonetheless, only in some example calculations presented in Chapter 6, calibration is attempted in order, for the specific examples, to quantify for illustration purposes the implied reliability indices of the ASME Code design equations.

Table 5-4 presents values of β and the corresponding probability of failure, P_f, addressing the design life of piping calculated according to Eq. (2-20).

Table 5-4: Reliability Index β and Corresponding Probability of Failure, P_f

Reliability Index, β	Probability of failure, P_f
1.5	6.68E-02
2.0	2.28E-02
2.5	6.21E-03
3	1.35E-03
3.5	2.33E-04
4.5	3.40E-06
5.5	1.90E-08
6	9.87E-10
7	1.82E-12
8	<E-15

However, the derived equations according to LRFD will correspond to a reliability index slightly different from the quantified target reliability index used for the calculation of partial safety factors. This is inevitable for the following reasons:

- The partial load factors should be applicable to a big range of magnitude of applied loads. This fact often results in ranges, and not a single value, of a nominal resistance factor for a given set of nominal load factors. It is therefore necessary to select a representative value for the resistance factor and subsequently accept a controlled difference (conservative for some pipes and non conservative for others) for the value of β for some categories of piping.

- The same can occur when it is desired to have the same load and resistance factors for the same failure modes. Values of β slightly conservative or not conservative may result.
- Deviations may also arise from the selection of the probabilistic characteristics of variables. Taking as an example the steel resistance, it is recommended to group materials in categories with similar probabilistic characteristics. Nevertheless, small deviations still may exist in an effort to minimize the different categories and evaluate common statistical properties, etc.

In conclusion, it can be said that the need to provide uniform and simple criteria for the design of structural or mechanical elements results in deviations from the target reliability index, which nevertheless are known and controlled by the Code writers.

CHAPTER 6: CALCULATION OF PARTIAL SAFETY FACTORS

In this chapter for all of the performance functions listed in Table 5-2, the partial safety load and resistance factors are evaluated. Details for the computations as well as for the criteria used are presented in Section 6.1. Further, the chapter is divided into two parts. Part I presents the computation of safety factors for limit states expressing the failure of the pressure boundary (burst or yielding due to internal pressure) and more specifically the performance functions, g_1, g_5, g_{10}, $g_{15,}$ presented in the previous chapter. Part II gives the partial safety factors for the remaining performance functions, expressing combinations of acting loads. A sensitivity analysis is performed in cases that the influence of different parameters (type of distribution or coefficient of variation for some variables) is judged to be examined. The statistical properties of steel are not presented for each performance function in this chapter, since the values used are the recommended ones that were presented in Tables 3-5 and 3-10 for different operating temperatures and steel properties.

6.1. Computations

In Chapter 2, and particularly in Section 2.2.1.4, the procedure for the calculation of factors applied to the mean values of variables was presented. Since the factors applied to nominal values of variables are used in the design, these factors should be ultimately evaluated.

Having evaluated the mean factors (γ'_i and φ') for a performance function, Eq. (6-1), the bias can be used, as described in Chapter 4, in order to obtain the nominal partial safety factors.

$$\sum_{i=1}^{k} \gamma'_i X_i' = \varphi' R' \tag{6-1}$$

where,
φ'=safety factor applied to the mean strength of steel
γ_i'=safety factor applied to the mean value of the load i
X_i'=mean value of load i
R'=converged mean value of the steel strength (resistance)
k=number of loads

Taking into consideration,moreover, that for a code's development the nominal load factors attain predetermined values, γ_i for i=1,…, k, such as for each load to have the same partial safety factor applied to all load combinations, an adjusted nominal resistance factor, φ, can be derived, using Eq. (6-2).

$$\varphi = \frac{\sum_{i=1}^{k} \frac{\gamma_i X_i'}{b_i}}{R'} b_R \tag{6-2}$$

where,
φ=adjusted nominal resistance factor
X_i'=mean value of load i
R'=converged mean value of the steel resistance, derived from the calculation of mean factors.
b_i=bias for load i
b_R=bias of the resistance (steel strength)
γ_i=predefined nominal safety factor for load i
k=number of loads

Therefore, the designers will use design equations like the one given by Eq. (6-3).

$$\sum_{i=1}^{k} \gamma_i X_i \leq \varphi R_n \tag{6-3}$$

where,
X_i=nominal value of load i
R_n=nominal value of the steel strength (resistance)
γ_i=predefined nominal safety factor for load i
φ=adjusted nominal resistance factor

The adjusted nominal resistance factor, φ, further, is used for the analysis and understanding of the computation results. Since different values of the reliability index are used for each performance function and by keeping the same load factors, a relation between β and the adjusted nominal resistance factor can be derived that changes from performance function to performance function and even for the different loading categories of the same performance function. In this study, a criterion for the analysis of results is that the proposed adjusted resistance factor can have an impact on the value of the target reliability index, β, approximately $\pm$ 0.25. In cases that this is not possible, more categories are considered in order to keep β in the above predefined space.

Computational results are extensive, since several values of the target reliability index, β, are used for the calculations for each performance function. Nonetheless, it should be clarified that the design equations according to LRFD will ultimately correspond to a selected value of β, according to the criteria discussed in Section 5.4. This procedure is not included in this study and therefore a summary of the adjusted nominal resistance factors for a predefined set of load factors and different values of β is provided for each performance function. In parenthesis the range of the adjusted nominal factor is shown, whereas the recommended values are in bold face. Diagrams of selected categories of mean partial safety factors for some performance functions are also provided in this chapter. The calculated mean values of the partial safety factors as well as the calculated adjusted nominal resistance factor for predefined load factors are provided in detail in Appendix C.

6.2. Part I: Design for Internal Pressure

Initially, the proposed performance functions and the probabilistic characteristics of the implicated variables are presented. The hoop stress, S_H, is evaluated according to the Boardman model, Eq. (6-4), which, as explained in Chapter 5, is an approximation of the Lamé model, considering in addition a linear elastic behavior of steel. The value of y in the equation depends on the ratio θ of the external diameter to the thickness of the pipe. In other ASME Codes (e.g., B31.1, 2001), y is dependent on the design temperature, when the latter is greater than 900°F, and accounts for the creep behavior of steel. The Boardman model is selected for the computations, since engineers are familiar with it and use it for many decades.

$$S_H = P\frac{D_o - 2yt}{2t} \tag{6-4}$$

where, y=0.4 and for $\theta = D_o/t < 6$, y=$d/(D_o+d)$

6.2.1. Performance Functions and Probabilistic Characteristics of Variables

As explained in Section 5.1 the selection of the performance functions was aided by the current design practice. More specifically, since the current Code for Service Limits C and D permits the yielding of the pipe (Table 2-5), that is, it allows some permanent deformation before burst occurs, the performance function is expressed with respect to the variable S_u. In other words, the performance functions ensure that a pipe will not burst. On the other hand, for Service Limits A and B the performance functions ensure that neither burst nor permanent deformation of the pipe is allowed. In the case that the ultimate stress was to be used also for Service Levels A and B, β would have been greater than the one used for Service Levels C and D.

The derived performance functions control the design for internal pressure for all piping components. The same holds in the present Code, where the computation of the piping thickness or of the allowable pressure for piping is evaluated with respect to straight pipes. The performance functions can be used for all classes piping, considering moreover the appropriate value of the target reliability index, β. The performance functions for the different service limits are as follows:

Design and Service Limit A:

$$g_1 = S_y - X_M P_{Des} (0.5\theta - 0.4) = 0 \text{ for } \theta = D_o/t \geq 6 \quad (6\text{-}5a)$$

or

$$g_1 = S_y - X_M P_{Des} \{0.5\theta - [(0.5\theta - 1)/(\theta - 1)]\} = 0 \text{ for } \theta = D_o/t < 6 \quad (6\text{-}5b)$$

Service Limit B:

$$g_5 = S_y - X_M P_B (0.5\theta - 0.4) = 0 \text{ for } \theta = D_o/t \geq 6 \quad (6\text{-}6a)$$

or

$$g_5 = S_y - X_M P_B \{0.5\theta - [(0.5\theta - 1)/(\theta - 1)]\} = 0 \text{ for } \theta = D_o/t < 6 \quad (6\text{-}6b)$$

Service Limit C:

$$g_{10} = S_u - X_M P_C (0.5\theta - 0.4) = 0 \text{ for } \theta = D_o/t \geq 6 \quad (6\text{-}7a)$$

or

$$g_{10} = S_u - X_M\, P_C\, \{0.5\theta - [(0.5\theta - 1)/(\theta - 1)]\} = 0 \text{ for } \theta = D_o/t < 6 \qquad (6\text{-}7b)$$

Service Limit D:

$$g_{15} = S_u - X_M\, P_D\, (0.5\theta - 0.4) = 0 \text{ for } \theta = D_o/t \geq 6 \qquad (6\text{-}8a)$$

or

$$g_{15} = S_u - X_M\, P_D\, \{0.5\theta - [(0.5\theta - 1)/(\theta - 1)]\} = 0 \text{ for } \theta = D_o/t < 6 \qquad (6\text{-}8b)$$

where S_u, S_y the ultimate and yield strength of steel, θ is the ratio of external diameter to thickness of pipe (D_o/t), and X_M is a variable that considers the uncertainty introduced in the design by the use of the Boardman model.

The probabilistic characteristics of pressure for different Service Levels are given in Table 6-1 together with the considered ranges of mean values of the steel strength S_y and S_u. Table 6-2 presents the characteristics of the model uncertainty variable, X_M, used in the analysis.

Table 6-1: Probabilistic Characteristics of Variables Used for the Calculation of Partial Factors for g_1, g_5, g_{10}, and g_{15}

Variable		Mean (psi)	*COV*	Bias = Mean / Nominal[(a)]	Distribution
P_{Des}		50-3,000	0.10	1.00	Normal
P_A			0.10	1.00	Normal
P_B			0.13	0.95	Normal
P_C			0.15	0.85	Extr. I (Largest)
P_D			0.20	0.80	Extr. I (Largest)
S_y(b)	carbon	25,000-50,000	0.08	1.13	Lognormal
	stainless		0.15	1.26	Lognormal
S_u(b)	carbon	40,000-90,000	0.06	1.15	Lognormal
	stainless		0.06	1.13	Lognormal
$\theta=D_o/t$		na	na	1.00	Deterministic

(a)=Nominal value at room temperature for the properties of steel, (b)=Properties at room temperature, na=not applicable

Table 6-2: Probabilistic Properties of Variable X_M

Failure mode	Steel	Mean	*COV*	Bias
Bursting	Carbon & Stainless	1.05	0.05	1.00
Yielding	Carbon	1.12	0.05*	1.00
Yielding	Stainless	1.12*	0.05*	1.00

*Assumed values due to lack or limited data

6.2.2. Partial Safety Factors

The AFOSM method, as described in Chapter 2, is used for the calculation of the mean partial safety factors, and convergence of the iterations is achieved with respect to the deterministic value of θ. Computations were made for the ranges of values of pressure, yield, and ultimate strength of steel shown in Table 6-1. The factors obtained considering different mean values for the pressure and resistance of steel are the same, showing that the performance functions are insensitive to the relative amount of pressure and strength of steel for the examined or similar quantities. Moreover, in all cases the same factors are obtained from the performance functions of Eqs. (a) and (b), where in the latter case a distinction is made for pipes of θ<6. Only the converged value of the deterministic θ does change.

Factors were evaluated for values of β equal to 1.5, 2.0, 2.5, 3.0, and 4.5. The factors applied to mean values of variables (mean factors) are presented in Tables C-1 to C-4 of Appendix C for the different Service Levels, types of steel, and operating temperatures. Figures 6-1 to 6-4 show how the calculated mean resistance and load factors vary with the reliability index for operation at room temperature and different properties of steel. It can be seen that approximated values of partial safety factors can be obtained, using linear interpolation for other values of the target reliability index, β.

Table C-5 gives the adjusted nominal resistance factor, φ. The model uncertainty variable itself, X_M, and the partial safety factors for the pressure, γ_P, and for the model uncertainty variable, γ_M, are incorporated in one nominal load factor namely γ, which has the predefined selected value of 1.2. This way, the derived equation to be used for the calculation of thickness or of the permissible internal pressure attains the form of Eq. (6-9)

$$\varphi f^* = \gamma P \frac{D_O - 2yt}{2t} \tag{6-9}$$

where f^* in the above equation is S_u for Service Levels C and D and S_y for the other cases, γ is the total pressure load factor always equal to 1.2, and P is the pressure for the service level under consideration.

The values listed in Table C-5 are plotted in order to show how the adjusted nominal resistance safety factor, φ, changes for different temperatures or values of the target reliability index. Hence, Figures 6-5 to 6-8 show all the examined cases. Table 6-

3 presents the suggested values for the adjusted nominal resistance factor. Values were modified such as the criterion of $\beta \pm 0.25$ holds, and in order to obtain rounded numbers.

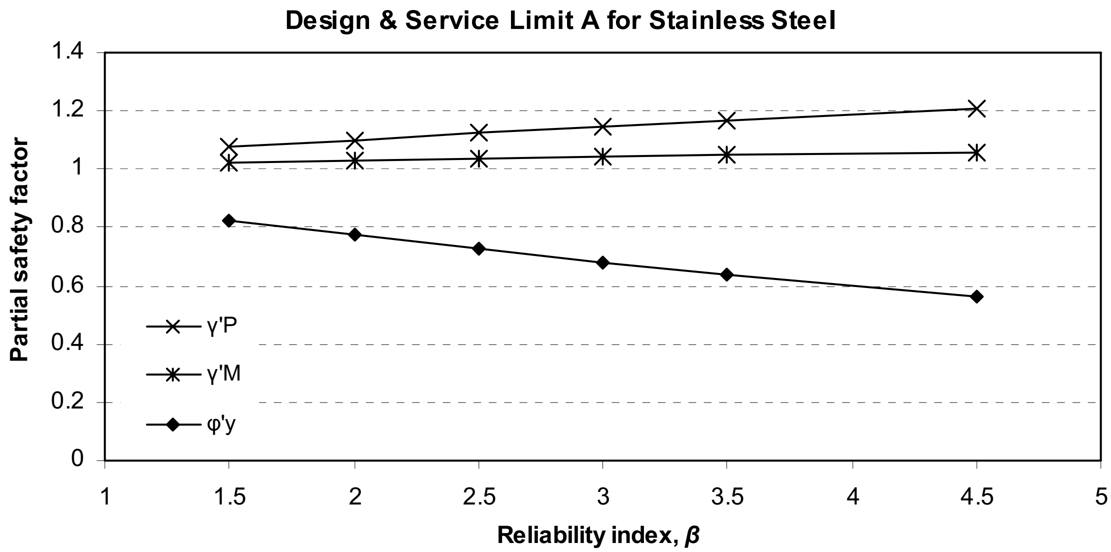


Figure 6-1a: Mean Partial Safety Factors φ'_y for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Design and Service Limit A and Stainless Steel

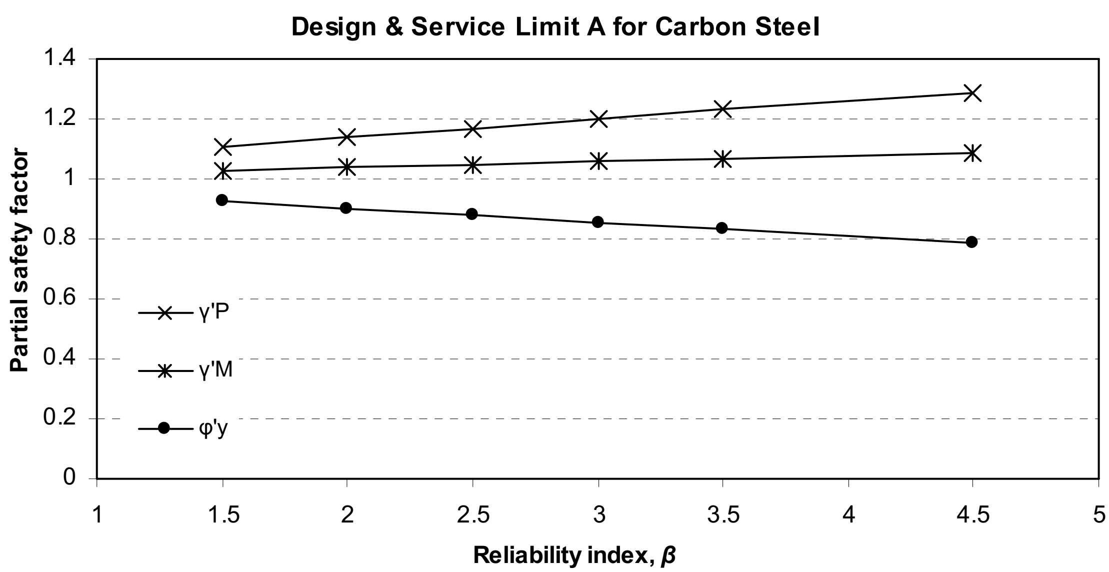


Figure 6-1b: Mean Partial Safety Factors φ'_y for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Design and Service Limit A and Carbon Steel

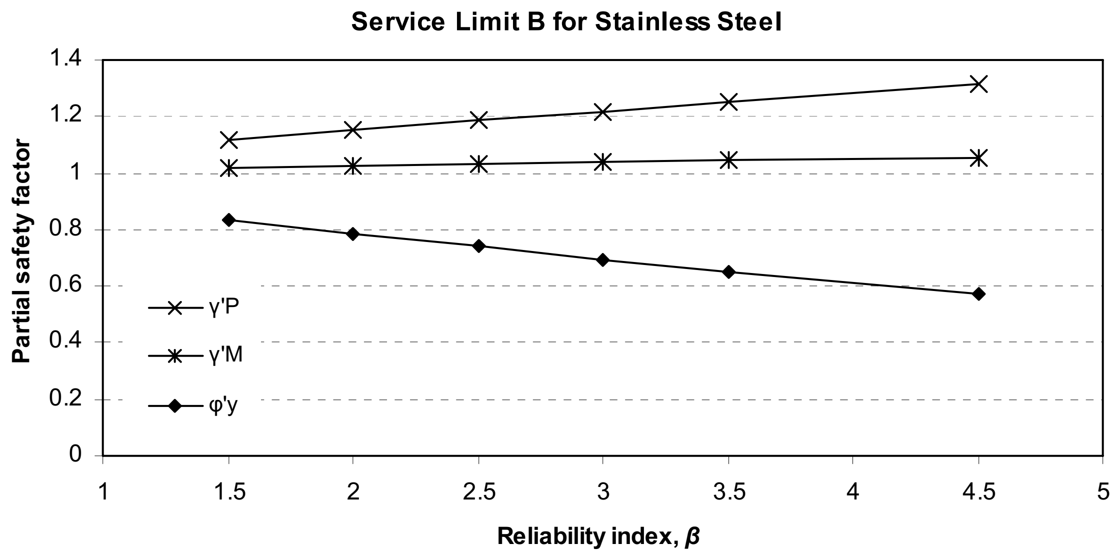


Figure 6-2a: Mean Partial Safety Factors φ'_y for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Service Limit B and Stainless Steel

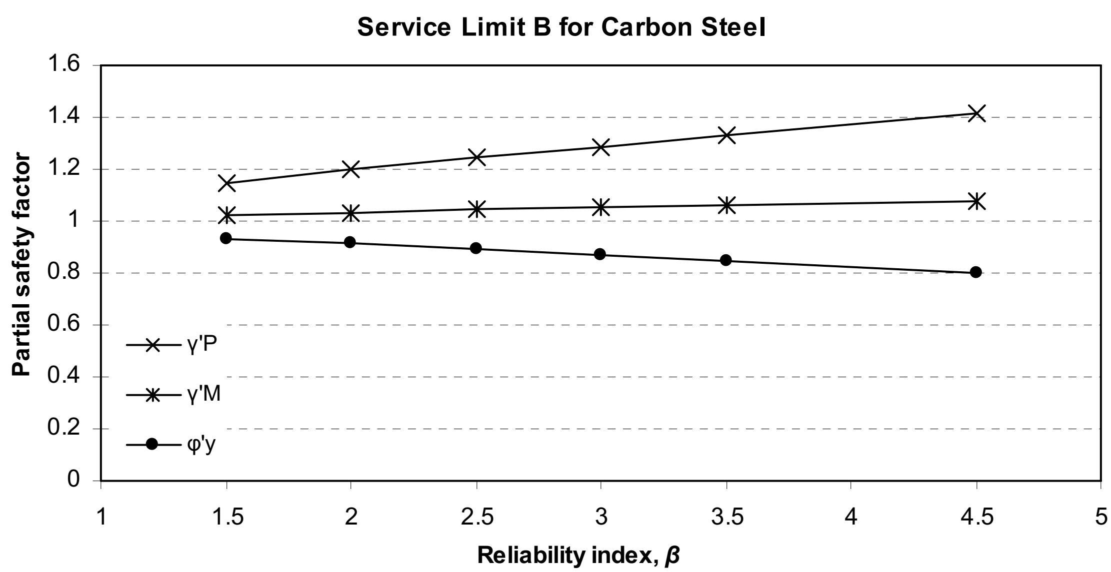


Figure 6-2b: Mean Partial Safety Factors φ'_y for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Service Limit B and Carbon Steel

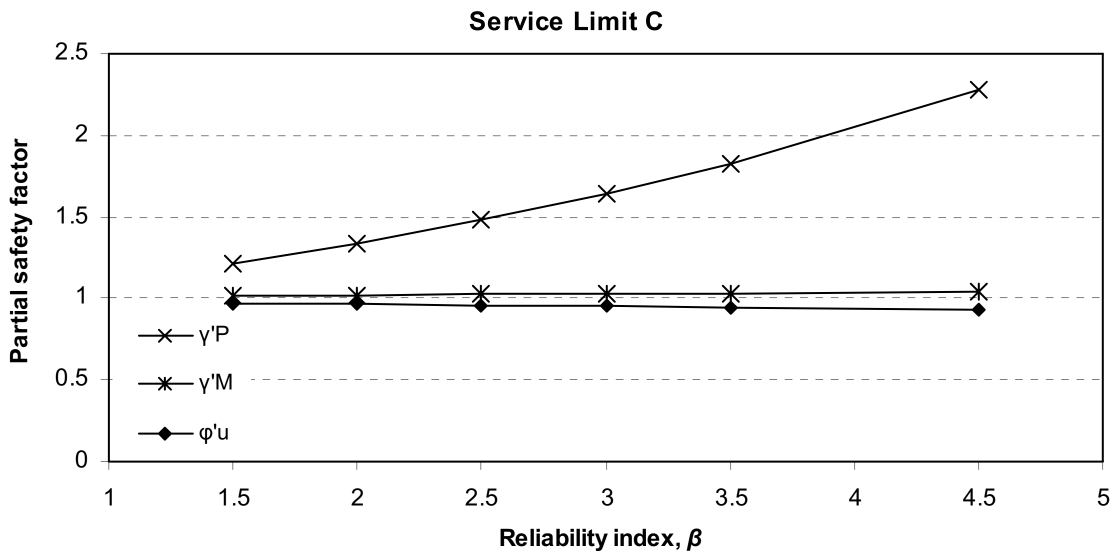


Figure 6-3: Mean Partial Safety Factors φ'_u for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Service Limit C and Both Stainless and Carbon Steel

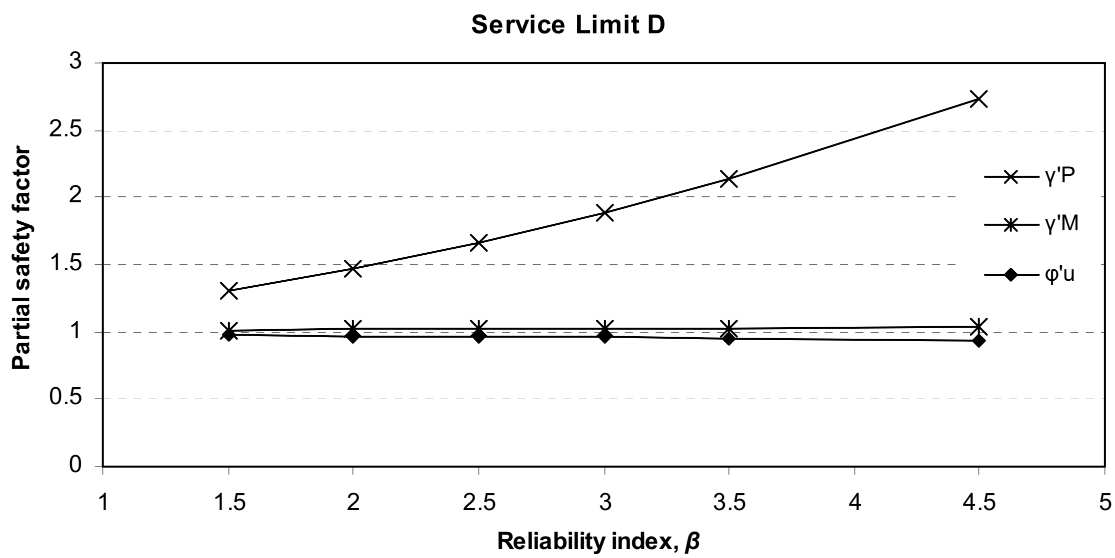


Figure 6-4: Mean Partial Safety Factors φ'_u for the Resistance, γ'_P for the Pressure, and γ'_M for the Model Uncertainty Variable versus β for Service Limit D and Both Carbon and Stainless Steel

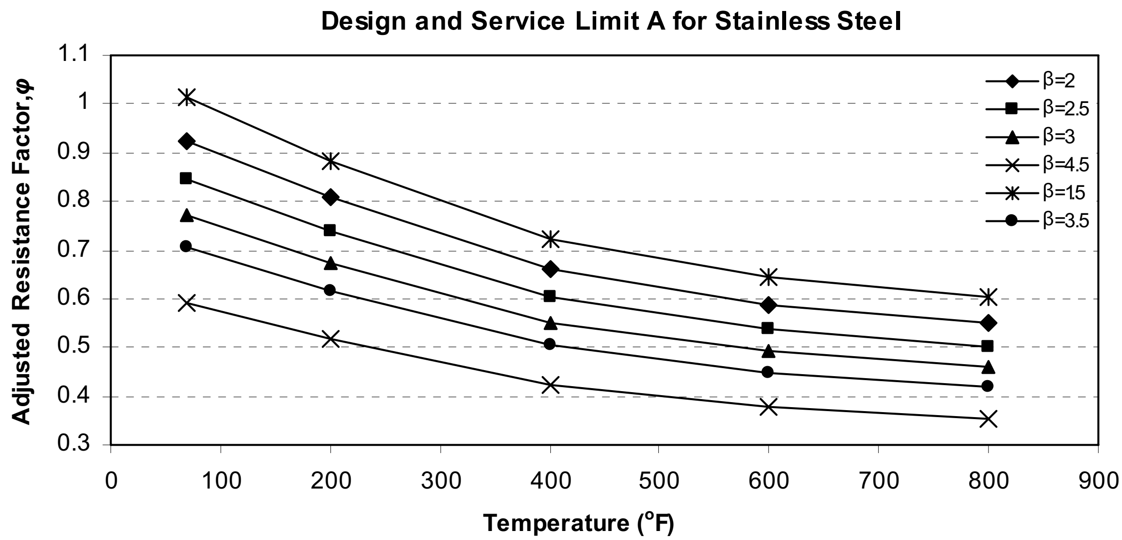


Figure 6-5a: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit A and Stainless Steel

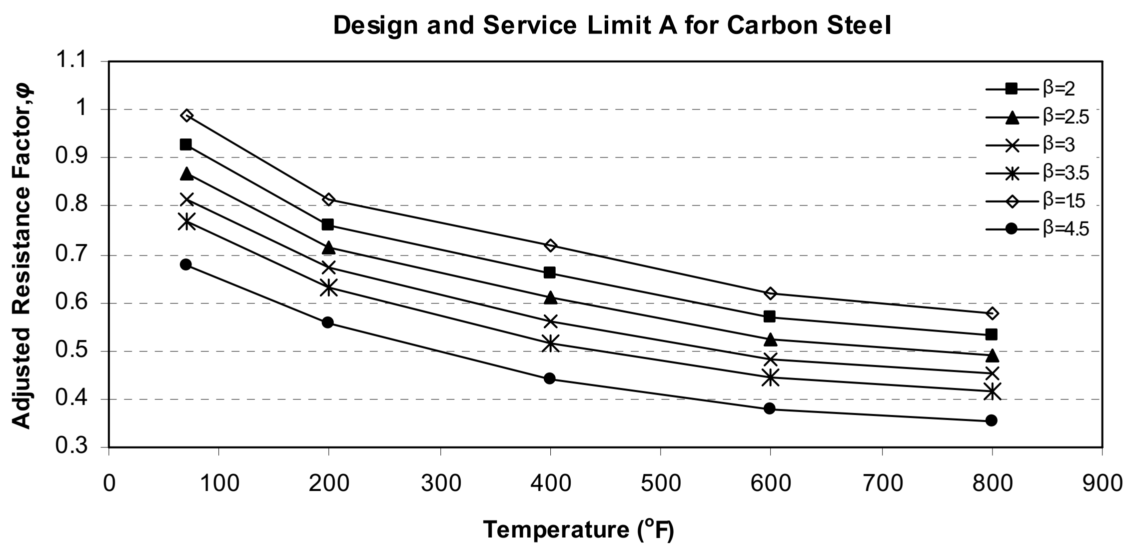


Figure 6-5b: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit A and Carbon Steel

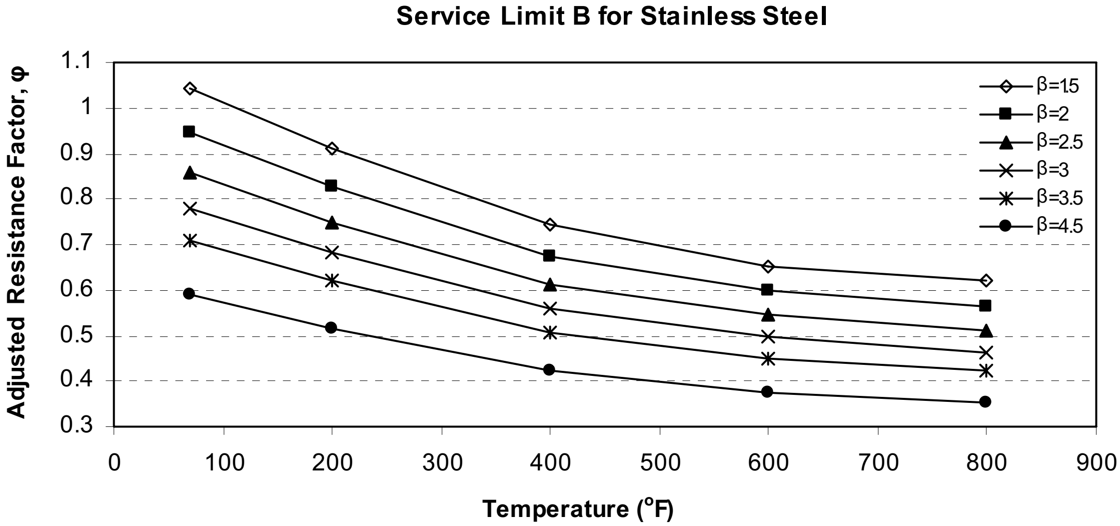


Figure 6-6a: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit B and Stainless Steel

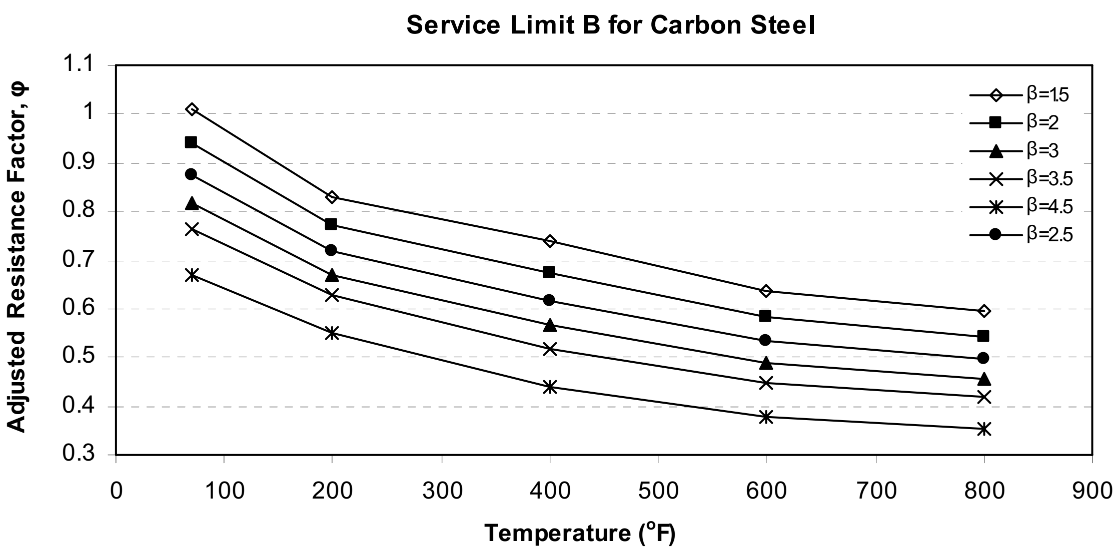


Figure 6-6b: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Different Operating Temperatures and Values of β, for Service Limit B and Carbon Steel

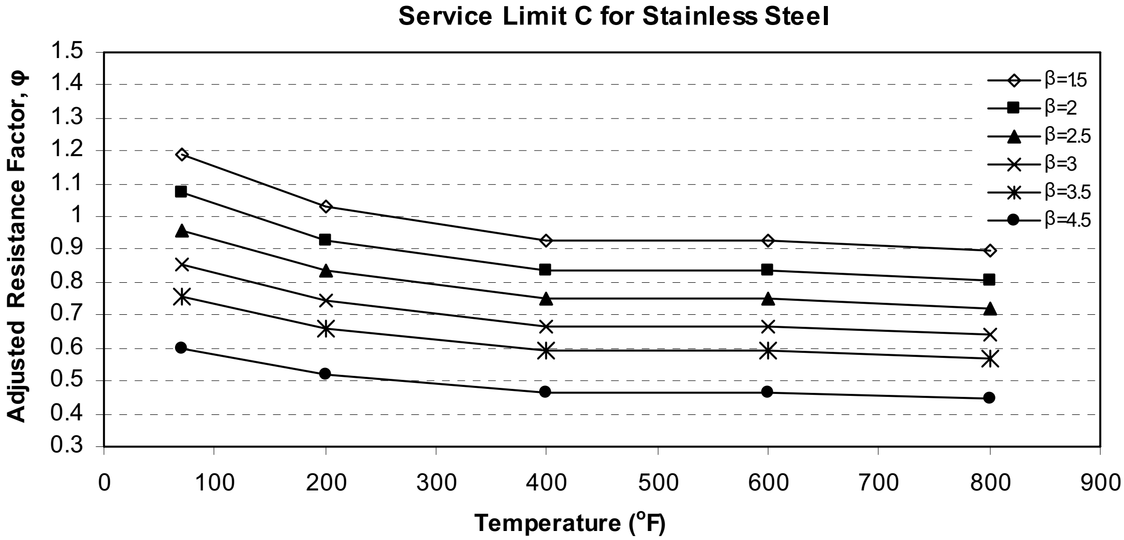


Figure 6-7a: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit C and Stainless Steel

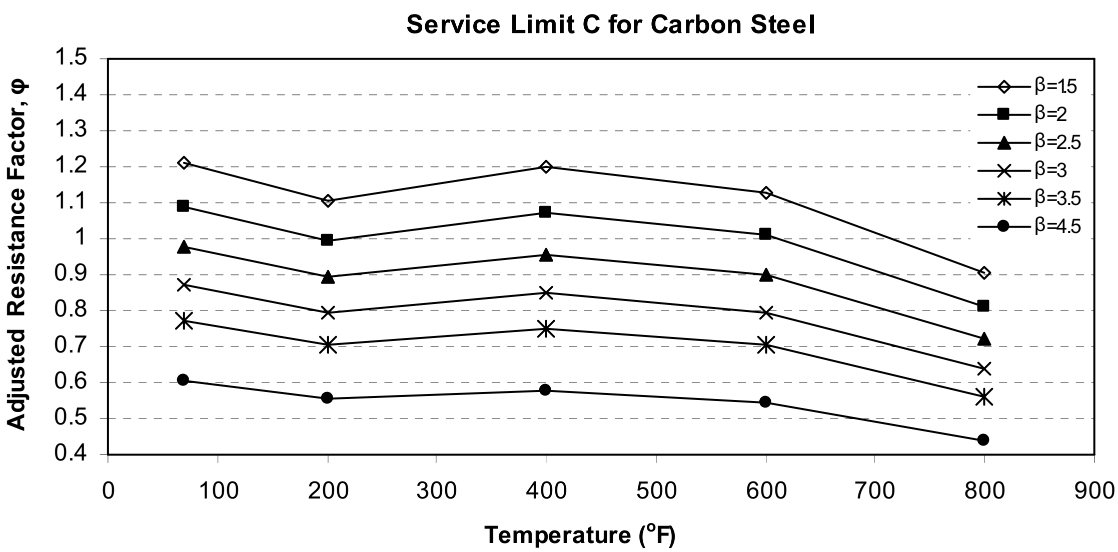


Figure 6-7b: Adjusted Nominal Resistance Ractor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit C and Carbon Steel

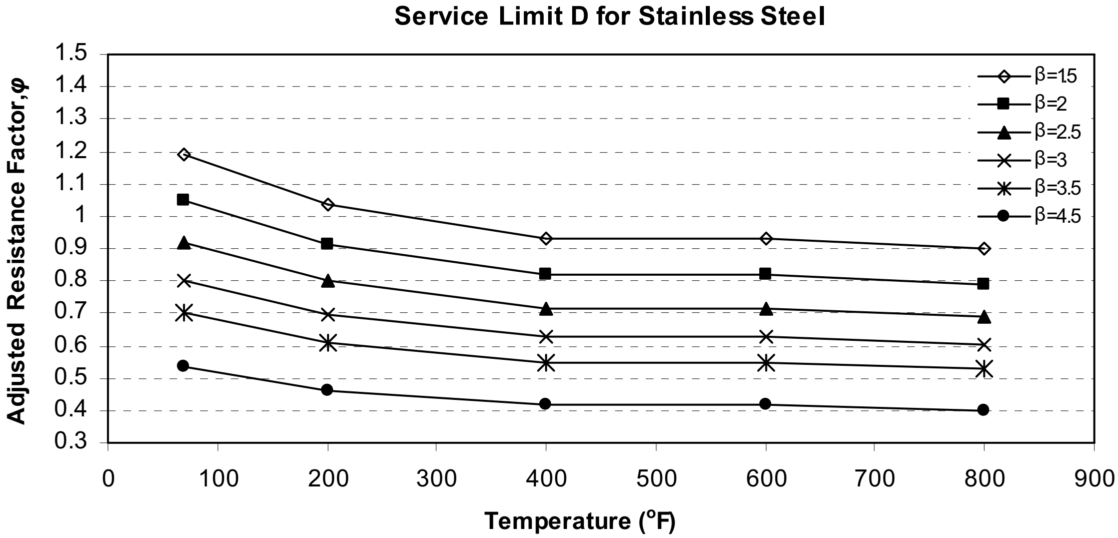


Figure 6-8a: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit D and Stainless Steel

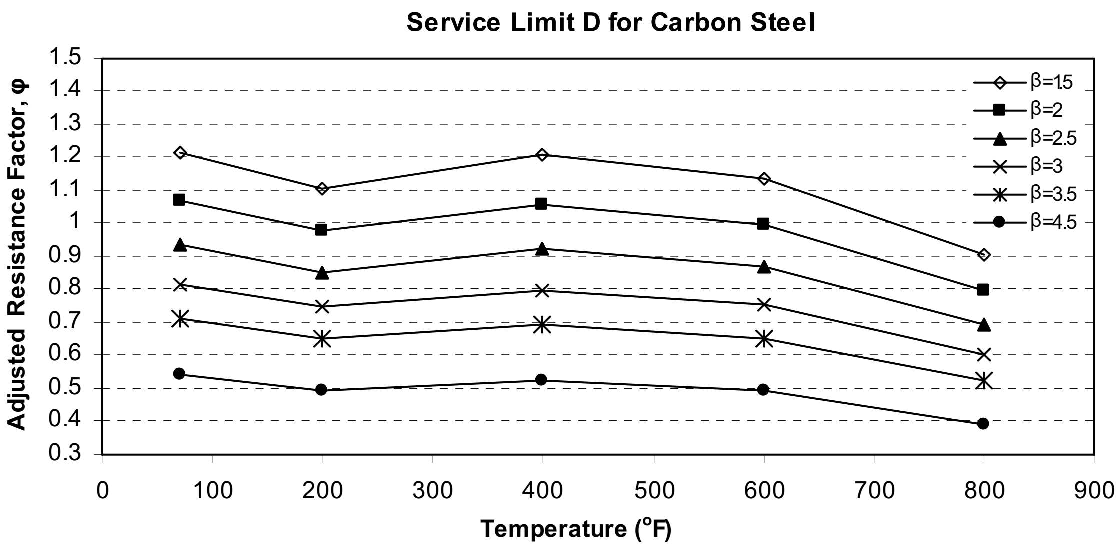


Figure 6-8b: Adjusted Nominal Resistance Factor φ in Eq. (6-9) for γ=1.2, Various Operating Temperatures and Values of β, for Service Limit D and Carbon Steel

Table 6-3a: Recommended Adjusted Nominal Resistance Factor, φ, for Total Load Factor γ=1.2 and Carbon Steel.

Service Level	Temperature (^{o}F)	Adjusted Value of φ for β: 1.5	2	2.5	3	3.5	4.5
Design and A	70	1.00	0.95	0.85	0.80	0.75	0.70
	200	0.80	0.75	0.70	0.65	0.65	0.55
	400	0.70	0.65	0.60	0.55	0.50	0.50
	600	0.60	0.55	0.50	0.50	0.45	0.45
	800	0.60	0.55	0.50	0.45	0.40	0.40
B	70	1.00	0.95	0.85	0.80	0.75	0.65
	200	0.85	0.75	0.72	0.65	0.65	0.55
	400	0.75	0.65	0.60	0.55	0.50	0.45
	600	0.65	0.60	0.55	0.50	0.45	0.40
	800	0.60	0.55	0.50	0.45	0.40	0.35
C	70	1.20	1.10	0.95	0.85	0.75	0.60
	200	1.10	1.00	0.90	0.80	0.70	0.55
	400	1.20	1.05	0.95	0.85	0.75	0.60
	600	1.10	1.00	0.90	0.80	0.70	0.55
	800	0.90	0.80	0.70	0.65	0.55	0.45
D	70	1.20	1.05	0.95	0.80	0.70	0.55
	200	1.10	0.95	0.85	0.75	0.65	0.50
	400	1.20	1.05	0.90	0.80	0.70	0.50
	600	1.15	1.00	0.85	0.75	0.65	0.50
	800	0.90	0.80	0.70	0.60	0.50	0.40

Table 6-3b: Recommended Adjusted Nominal Resistance Factor, φ, for Total Load Factor γ=1.2 and Stainless Steel

Service Level	Temper. (°F)	Adjusted Value of φ for β: 1.5	2	2.5	3	3.5	4.5
Design and A	70	1.00	0.90	0.85	0.75	0.70	0.60
	200	0.90	0.80	0.75	0.65	0.60	0.50
	400	0.70	0.65	0.60	0.55	0.50	0.40
	600	0.65	0.60	0.55	0.50	0.45	0.40
	800	0.60	0.55	0.50	0.45	0.40	0.35
B	70	1.05	0.95	0.85	0.80	0.70	0.60
	200	0.90	0.85	0.75	0.65	0.60	0.50
	400	0.75	0.65	0.60	0.55	0.50	0.40
	600	0.65	0.60	0.55	0.50	0.45	0.35
	800	0.60	0.55	0.50	0.45	0.40	0.35
C	70	1.20	1.05	0.95	0.85	0.75	0.60
	200	1.00	0.95	0.85	0.75	0.65	0.50
	≥400	0.90	0.80	0.75	0.65	0.60	0.45
D	70	1.20	1.05	0.90	0.80	0.70	0.55
	200	1.05	0.90	0.80	0.70	0.60	0.45
	≥400	0.90	0.80	0.70	0.60	0.55	0.40

6.2.3. Sensitivity Analysis

In this section, the effect of considering a lognormal distribution instead of normal for the internal pressure is examined. Both distributions are reported in studies (Table 3-17). Comparison of the adjusted nominal resistance factor for Service Level A is shown in Figure 6-9a for stainless steel and Figure 6-9b for carbon steel, for a combined load factor γ=1.2. It can be noticed that for low values of β, there is actually no difference for the obtained values and the cases examined. Actually, only for β>2.5 there is a slight difference for carbon steel. The higher difference is noticed for β=4.5 and carbon steel to be 3.24% with an impact on β of 0.02. Nevertheless, the use of either distribution is recommended, since there is no significant impact on the value of the target reliability index, β.

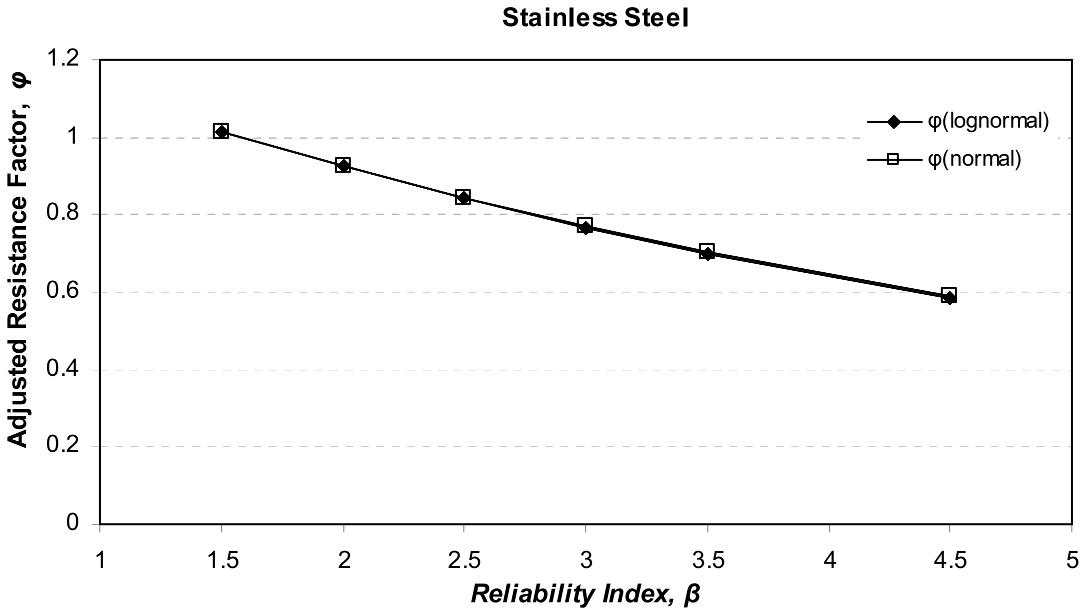


Figure 6-9a: Adjusted Nominal Resistance Factor for the Internal Pressure having Normal and Lognormal Distribution for Service Limit A and Stainless Steel

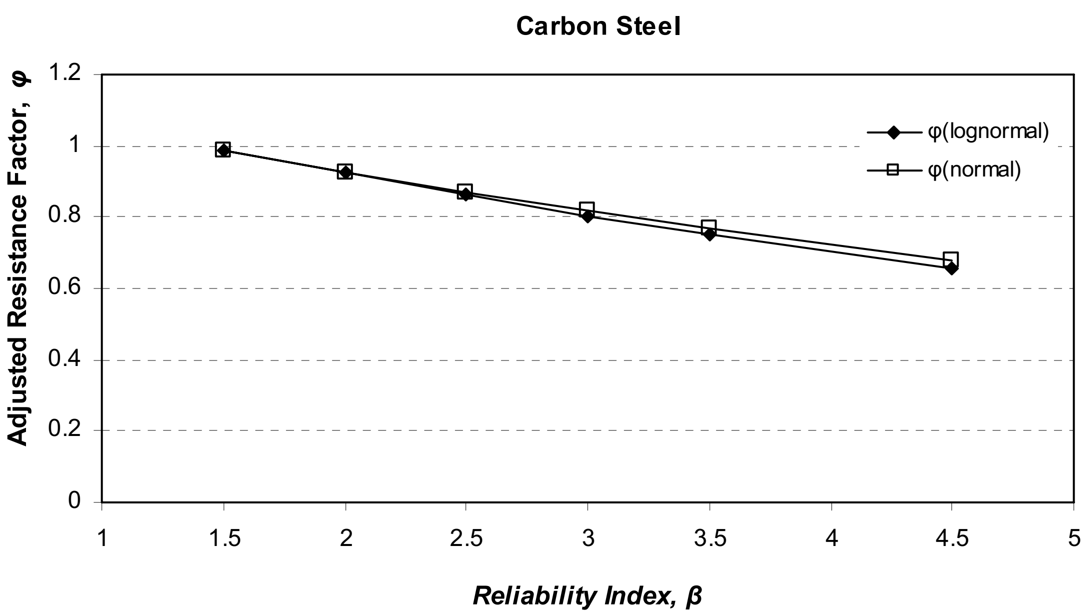


Figure 6-9b: Adjusted Nominal Resistance Factor for the Internal Pressure having Normal and Lognormal Distribution, for Service Limit A and Carbon Steel

6.2.4. Computational Example

This section provides a computational example, where for two pipes made of stainless and carbon steel the required minimum thickness is first estimated. Then, the maximum pressure for all service limits is computed according to the ASME B&PV Code, Section III. Calibration is performed, that is the partial safety factors and the corresponding reliability index, are calculated such as the LRFD equations will give the same results as the ones obtained from the Code equations. Nevertheless, in order to derive the implied reliability indices for the design for internal pressure according to the Code, a large number of calculations are needed, which as previously mentioned are above the scope of this work.

Hence, a Class 1 pipe made of carbon steel A106 B and a pipe made of austenitic steel Type 304 are designed for operation at room temperature and operation at 400^{o}F. The pipe's outside diameter is D_o=12.75 in and the design pressure, P_{Des}, assumed to be 800psi for all cases. The thickness of the pipe and the allowable (maximum) pressure for all service limits are to be estimated. Table 6-4 shows the mechanical properties of the considered materials such as the nominal yield and ultimate strength of steel, namely the minimum specified yield or ultimate strength of steel, as well as the allowable stresses, all given in the ASME B&PV Code, II**,** Table 2-a. Table 6-5 presents the computations. In the LRFD column the derived reliability index, β, and the partial factors are provided, in order to obtain the same thickness and maximum pressure as the ASME Code equations. The additional thickness, A, which is added and accounts for corrosion-erosion effects, is not considered in the calculations since no new recommendations are provided for its value.

Table 6-4: Properties of Steel

Steel	S_y ksi (MPa)	S_u ksi (MPa)	S_{RT} ksi (MPa)	S_{400} ksi (MPa)
Carbon: A106B	35 (241.32)	60 (413.69)	20 (137.90)	20 (137.90)
Stainless: Type 304	30 (206.85)	75 (517.12)	20 (137.90)	18.7 (128.93)

Table 6-5a: Sample Computations for a Pipe Made of Carbon Steel

ASME	LRFD

For Design at Room Temperature

ASME

Design:

$$t_{min} = \frac{P_{Des}\, D_o}{2\,(S + P\,y)} = \frac{800\,(12.75)}{2(20000 + 0.4 * 800)} =$$

0.25in (6.37mm)

***Service Limit A*:**
Selecting t=0.28in (7.14mm)
P_a=P_A=897.39 psi (6.19MPa)

***Service Limit B*:**
P_B=1.1 P_a=987.13 psi (6.81MPa)

***Service Limit C*:**
P_C=1.5 P_a=1346.09 psi (9.28MPa)

***Service Limit D*:**
P_D=2 P_a=1794.78 psi (12.38MPa)

LRFD

$$\dagger\, \varphi\, S^* = \gamma\, P \frac{D_o - 2\,y\,t}{2\,t} \qquad \text{(a)}$$

***Design*:**
For φ=0.68, γ=1.2 and solving (a) for t, yields t_{min}=0.25 in (6.37mm) **(β=4.42)**

Service Limit A:
For φ=0.68, γ=1.2 and by selecting t=0.28 in (7.14mm) and solving (a) for P, P_a=P_A=897.39 psi (6.19MPa) **(β=4.42)**

***Service Limit B*:**
For φ=0.75, γ=1.2 and solving (a) for P produces P=P_B=987.13 psi (6.81MPa) **(β=3.58)**

***Service Limit C*:**
For φ=0.60, γ=1.2 and solving (a) for P produces P=P_C=1346.09 psi (9.28MPa) **(β=4.54)**

***Service Limit D*:**
For φ=0.80, γ=1.2 and solving (a) for P produces P=P_D=1794.78 psi (12.38MPa) **(β=3.08)**

For Design Temperature 400^{o}F

ASME

Design:

$$t_{min} = \frac{P_{Des}\, D_o}{2\,(S + P\,y)} = \frac{800\,(12.75)}{2(20000 + 0.4 * 800)}$$

= 0.25in (6.37mm)

Selecting t=0.28in (7.14mm)

***Service Limit A*:**
P_a=897.39 psi (6.19MPa)

***Service Limit B*:**
P_B=1.1 P_a=987.13 psi (6.81MPa)

***Service Limit C*:**
P_C=1.5 P_a=1346.09 psi (9.28MPa)

***Service Limit D*:**
P_D=2 P_a=1794.78 psi (12.38MPa)

LRFD

***Design*:**
For φ=0.68, γ=1.2 and solving (a) for t produces t_{min}=0.25in (6.37mm) **(β=1.78)**

Service Limit A:
Using t=0.28 in (7.14mm) and for φ=0.68, γ=1.2 , produces P=897.39 psi (6.19MPa) **(β=1.78)**

***Service Limit B*:**
For φ=0.75, γ=1.2 and solving (a) for P produces P_B=987.13 psi (6.81MPa) **(β=1.37)**

***Service Limit C*:**
For φ=0.60, γ=1.2 and solving (a) for P produces P_C=1346.09 psi (9.28MPa) **(β=4.37)**

***Service Limit D*:**
For φ=0.80, γ=1.2 and solving (a) for P produces P=P_D=1794.78 psi (12.38MPa) **(β=3.01)**

†S^*=S_y or S_u depending on the Service Limit

Table 6-5b: Sample Computations for a Pipe Made of Stainless, Austenitic Steel

ASME	LRFD
For Design at Room Temperature	
	† $\varphi S^* = \gamma P \frac{D_o - 2yt}{2t}$ (a)
Design: $t_{min} = \frac{P_{Des} D_o}{2(S + P y)} = \frac{800(12.75)}{2(20000 + 0.4 * 800)} =$ 0.25in (6.37mm)	***Design*:** For φ=0.80, γ=1.2 and solving (a) for t, it is t_{min}=0.25 in (6.37mm) **(β=2.80)**
Service Limit A: Selecting t=0.28in (7.14 mm) P_a=P_A=897.39psi (6.19 MPa)	***Service Limit A:*** Selecting here also t= 0.28in (7.14mm) and for φ=0.80, γ=1.2 and solving (a) for P_a=P_A=897.39 psi (6.19MPa)**(β=2.80)**
***Service Limit B*:** P_B=1.1 P_a=987.13psi (6.81 MPa)	***Service Limit B*:** For φ=0.88, γ=1.2 and solving (a) for P, produces P=P_B=987.13 psi (6.81MPa) **(β=2.37)**
***Service Limit C*:** P_C=1.5 P_a=1346.09psi (9.28 MPa)	***Service Limit C*:** For φ=0.48, γ=1.2 and solving (a) for P, produces P=P_C=1346.09 psi (9.28 MPa), **(β=5.40)**
***Service Limit D*:** P_D=2 P_a=1794.78psi (12.38MPa)	***Service Limit D*:** For φ=0.64, γ=1.2 and solving (a) for P, produces P_D=1567.67 psi (12.38MPa) **(β=3.82)**

ASME	LRFD
For Design Temperature 400^{o}F	
Design: $t_{min} = \frac{P_{Des} D_o}{2(S + P y)} = \frac{800(12.75)}{2(18700 + 0.4 * 800)} =$ 0.27in (6.8mm)	***Design*:** For φ=0.75, γ=1.2 Solving (a) for t, produces t=0.27in (6.8mm) **(β=1.32)**
Service Limit A: Selecting t=0.28in (7.14mm) P_a=839.06 psi (5.79MPa)	***Service Limit A:*** Selecting here also t=0.28in (7.14mm) and solving (a) for P=P_A=839.06psi (5.79MPa) **(β=1.32)**
***Service Limit B*:** P_B=1.1 P_a=922.67psi (6.36MPa)	***Service Limit B*:** For φ=0.82, γ=1.2 Solving (a) for P, produces P_B=922.67psi (6.36MPa) **(β=0.99)**
***Service Limit C*:** P_C=1.5 P_a=1258.59psi (8.68MPa)	***Service Limit C*:** For φ =0.45, γ=1.2 and solving (a) for P, produces P_C=1258.59psi (8.68MPa) **(β=4.64)**
***Service Limit D*:** P_D=2 P_a=1678.21psi (11.57MPa)	***Service Limit D*:** For φ=0.60, γ=1.2 and solving (a) for P, produces P_D=1678.21 psi (11.57MPa) **(β=3.16)**
	†*S= S_y or S_u depending on the Service Limit

6.3. Part II: Design for Combined Loading

In this part, the partial safety factors for the performance functions combining primary stresses such as pressure, earthquake, and moments generated by alternating or not mechanical loads (e.g., sudden valve closure, water-hammer) are evaluated. The following analysis may address pipes with a ratio of external diameter to thickness, θ, approximately less than 75. Since, as explained in Chapter 4, limit theory and the development of plastic hinges are possible for pipes with θ about less than 75. In Table NB-3681(a)-1 of the Code, where the values for the primary indices B_1, B_2 are proposed, for the calculation of bending stresses, the ratio θ is limited to values less than 50. Nevertheless, for values of θ greater than approximately 75 the failure mode is buckling and in this study performance functions especially for buckling are not provided.

Part II is separated in five subsections where the partial safety factors for the performance functions of the five service levels (Design, A, B, C, and D) are presented, respectively. A simple design example, using the derived LRFD equations, is provided at the end of the chapter together with the computation conclusions.

6.3.1. Design

The partial safety factors for the performance functions g_2 and g_3 in Table 5-2 are evaluated herein. The following sections summarize the considered probabilistic characteristics of variables and the results of the computations. Stresses for these performance functions are evaluated considering the elastic section modulus of the pipe's cross-section.

6.3.1.1. Performance Function g_2

For this performance function (P.F.) the partial safety factors are calculated for β=6, 7, 8, therefore for a low probability of failure, in order to show that a failure of a pipe due to its sustained weight should be impossible. The normalized performance function is given by Eq. (6-10).

$$g_2 = f_y - f_A = 0 \tag{6-10}$$

where, f_y is the normalized yield strength of steel and f_A the normalized stress due to sustained weight, all with respect to the stress due to sustained weight.

Table 6-6 gives the parameters for the calculation of safety factors and Table C-6 presents the calculated mean partial safety factors (ϕ'_y, γ'_A for the yield strength and sustained weight, respectively). Table C-7 gives the calculated adjusted nominal resistance factor, ϕ_y, for a load factor γ_A=1.2 for all cases. Figure 6-10, in addition, shows the computed, adjusted nominal resistance factor for different operating temperatures and the considered values of the reliability index, β. Table 6-7 gives recommended (rounded) values for the nominal resistance factors.

Table 6-6: Parameters for the Calculations for g_2

Parameter		Range	Recommended Value	Distribution
β		na	6, 7 ,8	na
f_A	Mean	NA	1	Normal
	COV	0.05 to 0.10	0.10	
	Bias	1.0-1.05	1.0	
f_y	Mean	NA	NA	Lognormal
	COV	Table 3-5	Table 3-5	
	Bias	Table 3-5	Table 3-5	

NA=Not Available, na=not applicable

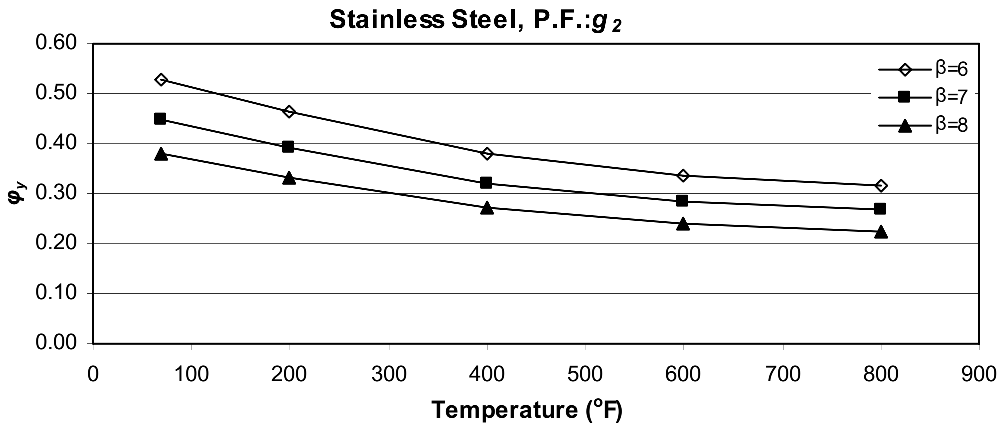


Figure 6-10a: Adjusted Nominal Resistance Factor for g_2 and Stainless Steel

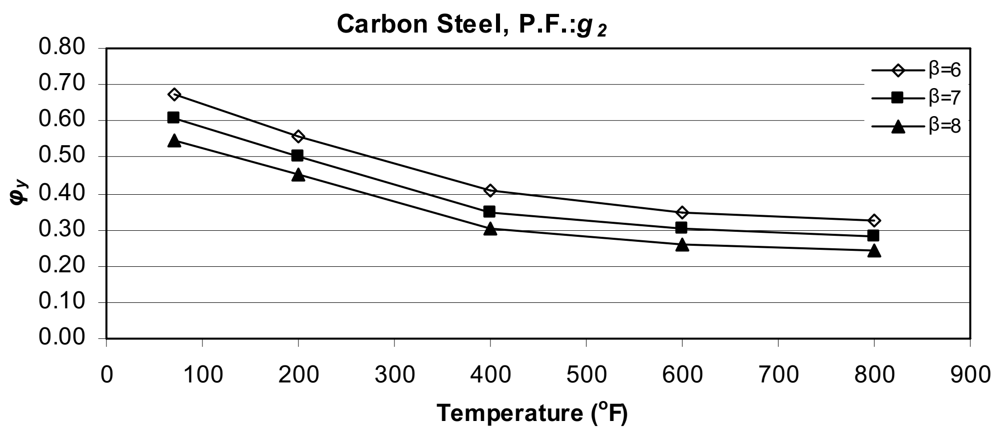


Figure 6-10b: Adjusted Nominal Resistance Factor for g_2 and Carbon Steel

Table 6-7: Recommended Nominal Load and Resistance Factors for g_2

Temperature T (°F)	β	Carbon Steel		Stainless Steel	
		ϕ_y	γ_A	ϕ_y	γ_A
Room Temperature	6	0.68	1.2	0.53	1.2
200		0.55	1.2	0.45	1.2
400		0.40	1.2	0.38	1.2
≥600		0.35	1.2	0.33	1.2
Room Temperature	7	0.60	1.2	0.45	1.2
200		0.50	1.2	0.40	1.2
400		0.35	1.2	0.32	1.2
≥600		0.30	1.2	0.30	1.2
Room Temperature	8	0.55	1.2	0.38	1.2
200		0.45	1.2	0.33	1.2
400		0.30	1.2	0.27	1.2
≥600		0.25	1.2	0.23	1.2

6.3.1.2. Performance Function g_3

For this performance function the partial safety factors are calculated for various values of the target reliability index, β. As the previous performance function, this one is also used for designing the pipe, which then can be checked for other service levels, too. The normalized performance function is given by Eq. (6-11). The parameters of the calculations are given in Table 6-8. Table C-8 presents the mean partial safety factors. Figure 6-11 shows, for selected values of β, how the mean factors (φ'_y, γ'_A, γ'_{PDes} for the yield strength, sustained weight, and design internal pressure, respectively) vary with respect to the normalized stress due to the design pressure.

$$g_3 = f_y - f_A - f_{P\,Des} \tag{6-11}$$

Table 6-8: Parameters for the Calculations for g_3

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	2, 3, 3.5, 4.5, 5.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PDes}	Mean *COV* Bias	0.5 to 50* 0.04 to 0.10 NA	0.5, 1, 5, 10, 50 0.10 1	Lognormal
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained for values greater than 50

The adjusted nominal resistance factors are evaluated for representative values of the normalized pressure with respect to the sustained weight stress, and for nominal factors γ_A=1.1 and γ_{PDes}=1.2 for the sustained weight and design internal pressure, respectively. The adjusted nominal resistance factors are shown in Table C-9. Table 6-9 presents the recommended nominal values for the adjusted resistance factor by grouping the results of Table C-9.

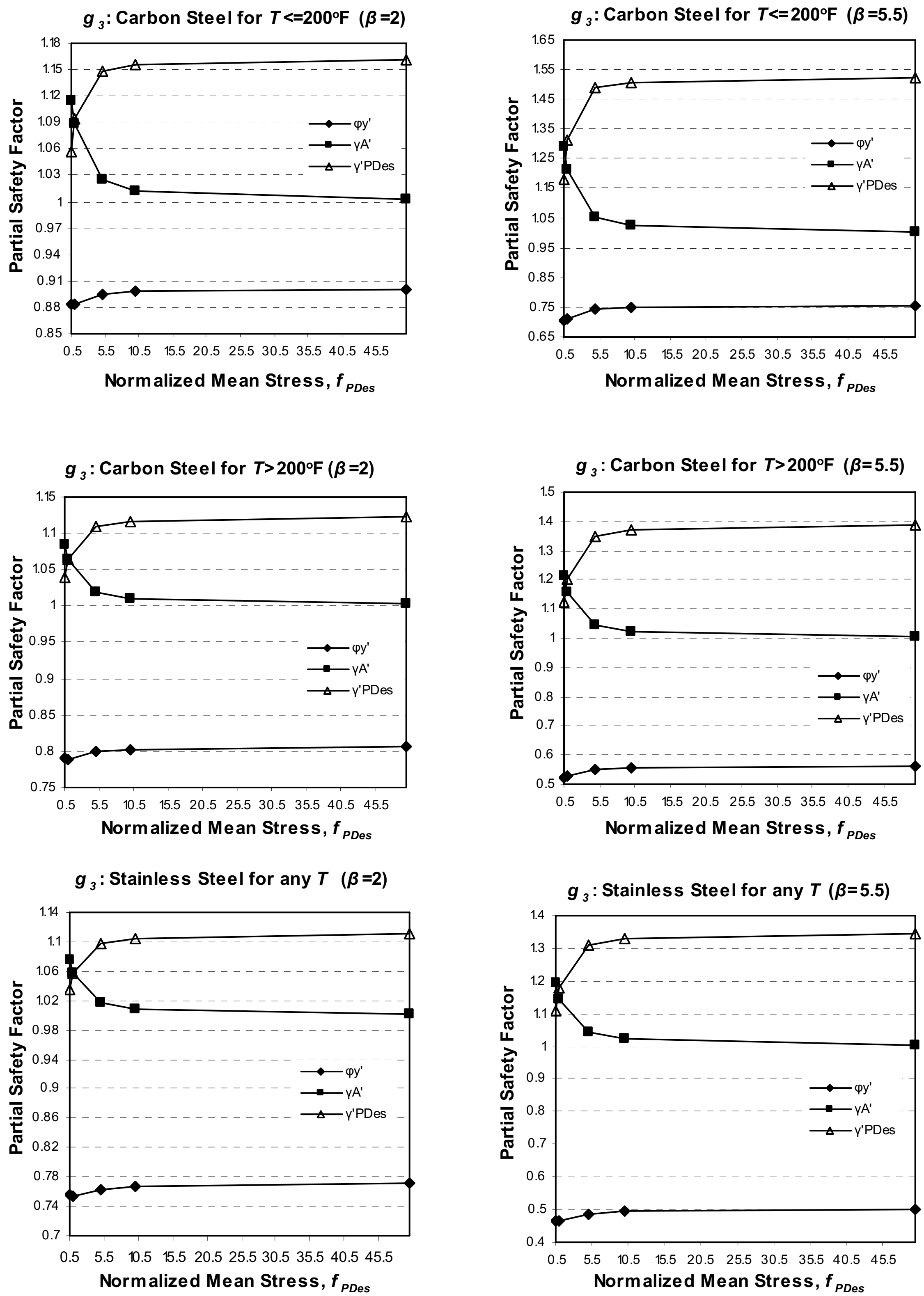


Figure 6-11: Variation of Mean Partial Safety Factors with Respect to Normalized Stress due to Design Internal Pressure for Boundary Values of β=2 and 5.5

Table 6-9: Ranges and Recommended[1] Adjusted Nominal Resistance Factors for g_3

β	φ_y for γ_A=1.1 & γ_{PDes}=1.2 CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2	**0.95** (0.94 to 0.97)[2]	**0.95** (0.93 to 0.96)[2]
3	**0.93** (0.93 to 0.94)	**0.87** (0.86 to 0.88)
3.5	**0.88** (0.87 to 0.89)	**0.80** (0.79 to 0.81)
4.5	**0.78** (0.77 to 0.80)	**0.68** (0.67 to 0.69)
5.5	**0.70** (0.68 to 0.73)	**0.57** (0.56 to 0.58)
	200°F	***200°F***
2	**0.86** (0.85 to 0.87)	**0.91** (0.89 to 0.92)
3	**0.77** (0.76 to 0.78)	**0.76** (0.75 to 0.77)
3.5	**0.73** (0.72 to 0.74)	**0.70** (0.69 to 0.71)
4.5	**0.65** (0.63 to 0.67)	**0.59** (0.59 to 0.60)
5.5	**0.58** (0.56 to 0.60)	**0.50** (0.49 to 0.51)
	400°F	***400°F***
2	**0.74** (0.73 to 0.75)	**0.74** (0.73 to 0.75)
3	**0.63** (0.63 to 0.64)	**0.62** (0.61 to 0.63)
3.5	**0.59** (0.58 to 0.60)	**0.58** (0.57 to 0.58)
4.5	**0.50** (0.50 to 0.51)	**0.48** (0.48 to 0.49)
5.5	**0.43** (0.43 to 0.44)	**0.41** (0.40 to 0.42)
	600°F	***600°F***
2	**0.64** (0.63 to 0.65)	**0.66** (0.64 to 0.67)
3	**0.54** (0.54 to 0.55)	**0.55** (0.55 to 0.56)
3.5	**0.50** (0.50 to 0.51)	**0.50** (0.50 to 0.51)
4.5	**0.43** (0.43 to 0.44)	**0.43** (0.43 to 0.44)
5.5	**0.37** (0.37 to 0.38)	**0.36** (0.36 to 0.37)
	800°F	***800°F***
2	**0.62** (0.62 to 0.63)	**0.62** (0.60 to 0.63)
3	**0.51** (0.51 to 0.52)	**0.52** (0.51 to 0.53)
3.5	**0.47** (0.47 to 0.48)	**0.47** (0.47 to 0.48)
4.5	**0.41** (0.40 to 0.41)	**0.40** (0.40 to 0.41)
5.5	**0.35** (0.34 to 0.36)	**0.34** (0.33 to 0.35)

(1) Recommended values are in bold face, (2) γ_A=1.0 and γ_{PDes}=1.1

6.3.2. Service Level A

In this section only the partial safety factors for the performance function g_4 are evaluated. The probabilistic characteristics for the computations are provided in Table 6-10. The normalized performance function is given by Eq. (6-12), where f_y is the normalized yield strength, f_A the normalized stress due to sustained weight, and f_{Pmax} the normalized stress due to peak pressure. For Service Level (Limit) A stresses are evaluated considering the elastic section modulus of the pipe's cross-section. Table C-10 presents the calculated mean partial safety factors for different values of β and properties of steel. Table C-11 gives the calculated nominal resistance factors, considering a given set of load partial safety factors, and Table 6-11 the recommended adjusted nominal resistance factors derived by summarizing and grouping in categories the results of Table C-11. In Figure 6-12 some cases are plotted, showing how the mean partial safety factors (φ'_y, γ'_A, γ'_{Pmax} for the yield strength, sustained weight, and peak internal pressure, respectively) vary with respect to the normalized maximum pressure.

$$g_4 = f_y - f_A - f_{P_{\max}} = 0 \qquad (6\text{-}12)$$

Table 6-10: Parameters for the Calculations for g_4

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	2, 3, 3.5, 4.5, 5.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{Pmax}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Extr. I (Largest)
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

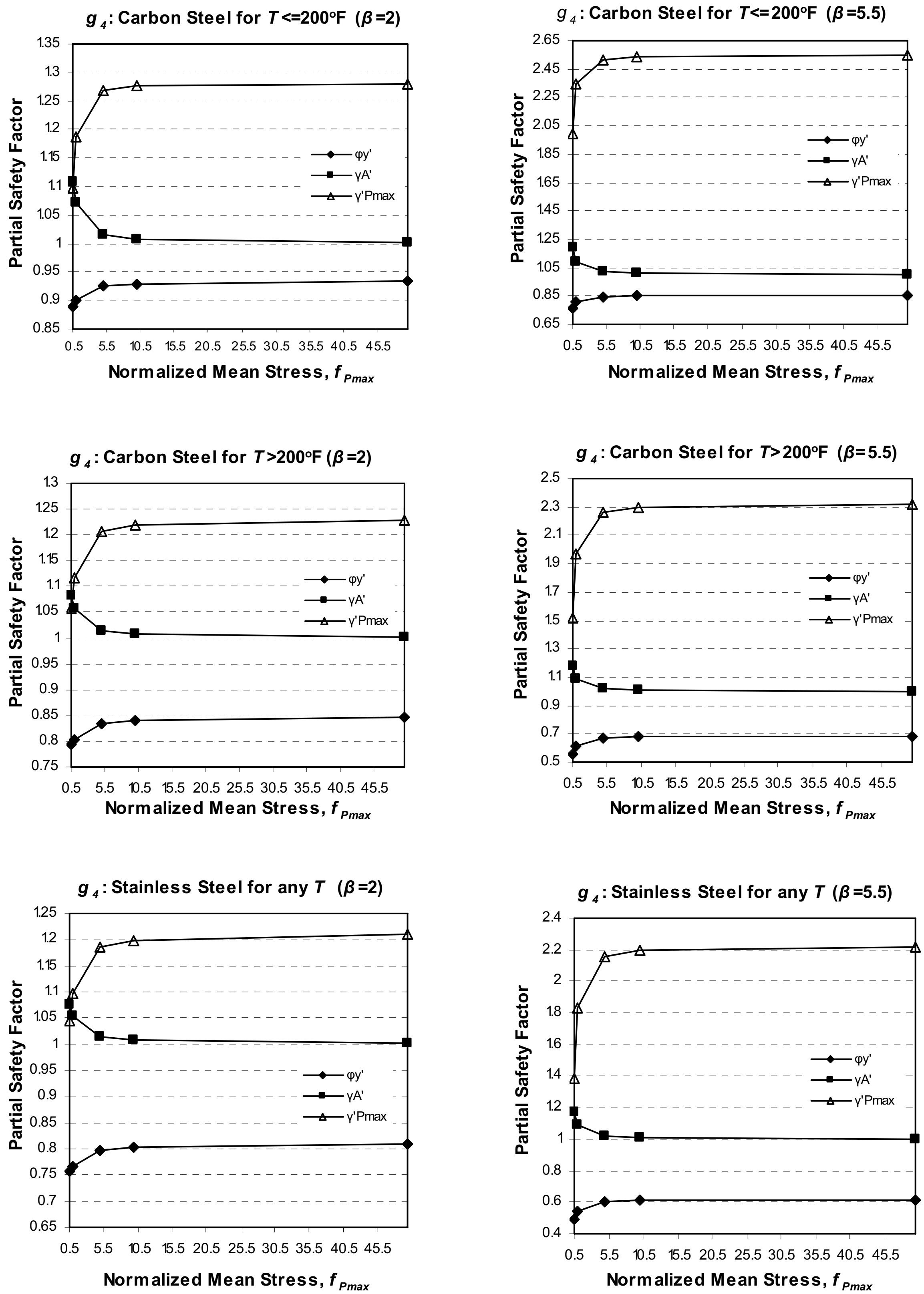


Figure 6-12: Variation of Mean Partial Safety Factors with Respect to Normalized Stress due to Maximum Internal Pressure for Boundary Values of β=2 and 5.5

Table 6-11: Ranges and Recommended[1] Adjusted Nominal Resistance Factors for g_4

β	**φ_y for γ_A=1.1 & γ_{Pmax}=1.2**	
	CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2	**0.96**[2] (0.95 to 0.97)	**0.96**[2] (0.94 to 0.98)
3	For $f_{Pmax}\leq1$, **0.93** (0.93 to 0.94) For $f_{Pmax}>1$, **0.87** (0.85 to 0.89)	**0.86** (0.84 to 0.88)
3.5	For $f_{Pmax}\leq1$, **0.88** (0.87 to 0.89) For $f_{Pmax}>1$, **0.77** (0.76 to 0.79)	For $f_{Pmax}\leq1$, **0.81** For $f_{Pmax}>1$, **0.76** (0.75 to 0.77)
4.5	For $f_{Pmax}\leq1$, **0.72** (0.74 to 0.78) For $f_{Pmax}>1$, **0.62** (0.61 to 0.64)	For $f_{Pmax}\leq1$, **0.67** (0.67 to 0.68) For $f_{Pmax}>1$, **0.59** (0.58 to 0.61)
	200^{o}F	***200^{o}F***
2	**0.87** (0.86 to 0.88)	**0.92** (0.90 to 0.94)
3	For $f_P\leq1$, **0.77** For $f_{Pmax}\geq1$, **0.72** (0.70 to 0.73)	**0.76** (0.74 to 0.78)
3.5	For $f_{Pmax}\leq1$, **0.72** (0.71 to 0.73) For $f_{Pmax}>1$, **0.65** (0.63 to 0.67)	For $f_{Pmax}\leq5$, **0.69** (0.67 to 0.71) For $f_{Pmax}>5$, **0.66** (0.65 to 0.67)
4.5	For $3\leq f_{Pmax}\leq5$ **0.54** (0.53 to 0.64) For $f_{Pmax}<3$ **0.62** (0.61 to 0.64) For $f_{Pmax}>5$, **0.51** (0.50 to 0.53)	For $f_P\leq1$, **0.59** For $f_{Pmax}>1$, **0.53** (0.51 to 0.55)
	400^{o}F	***400^{o}F***
2	**0.75** (0.74 to 0.76)	**0.75** (0.74 to 0.77)
3	**0.62** (0.61 to 0.64)	**0.62** (0.60 to 0.63)
3.5	**0.56** (0.54 to 0.59)	For $f_{Pmax}\leq1$, **0.58** For $f_{Pmax}\geq1$, **0.54** (0.53 to 0.56)
4.5	For $f_{Pmax}\leq1$, **0.50** (0.50 to 0.51) For $f_{Pmax}>1$, **0.44** (0.42 to 0.46)	For $f_{Pmax}\leq1$, **0.48** (0.48 to 0.49) For $f_{Pmax}>1$, **0.43** (0.41 to 0.45)
	600^{o}F	***600^{o}F***
2	**0.65** (0.64 to 0.66)	**0.67** (0.66 to 0.68)
3	**0.54** (0.52 to 0.56)	**0.55** (0.54 to 0.56)
3.5	For $f_{Pmax}\leq1$, **0.51** For $f_{Pmax}>1$, **0.47** (0.46 to 0.49)	**0.49** (0.47 to 0.51)
4.5	For $f_{Pmax}\leq1$, **0.43** (0.43 to 0.44) For $f_{Pmax}>1$, **0.37** (0.36 to 0.39)	For $f_{Pmax}\leq1$, **0.43** For $f_{Pmax}>1$, **0.38** (0.37 to 0.40)
	800^{o}F	***800^{o}F***
2	**0.60** (0.60 to 0.61)	**0.62** (0.61 to 0.64)
3	**0.50** (0.49 to 0.52)	**0.51** (0.50 to 0.52)
3.5	**0.45** (0.43 to 0.48)	**0.46** (0.44 to 0.48)
4.5	For $f_{Pmax}\leq1$, **0.40** (0.40 to 0.41) For $f_{Pmax}>1$, **0.35** (0.34 to 0.37)	For $f_{Pmax}\leq1$, **0.40** For $f_{Pmax}>1$, **0.35** (0.34 to 0.36)

(1) Recommended values are in bold face, (2) γ_A=1.0 and γ_{Des}=1.1

6.3.3. Service Level B

For Service Level B the partial safety factors are calculated for four performance functions, namely g_6, g_7 g_8, and g_9 in Table 5-2, under separate headings. Stresses are evaluated using the plastic section modulus of the pipe's cross-section.

6.3.3.1. Performance Function g_6

The normalized performance function is given by Eq. (6-13), where f_y is the normalized yield strength, f_A the normalized stress due to sustained weight, f_{PB} the normalized pressure stress for Service Level B, and f_M the normalized stress due to dynamic mechanical loading (e.g., generation of moments due to sudden valve closure, etc.).

$$g_6 = f_y - f_A - f_{PB} - f_M \tag{6-13}$$

Table 6-12 provides the probabilistic characteristics for the variables under consideration and recommended values for the computation of the mean partial safety factors. Table C-12 provides the calculated mean safety factors for all cases examined. Table C-13 provides the adjusted nominal resistance factors for different operating temperatures for piping and a predefined set of load factors. A summary of the results and recommended values for the adjusted nominal resistance factors are provided in Table 6-13.

Figure 6-13 presents how the mean partial loads (φ'_y, γ'_A, γ'_{PB}, γ'_M, for the yield strength, sustained weight, pressure under Service Level B conditions, and mechanical loading, respectively) vary with respect to the normalized stress due to internal pressure for preselected values of β=3.5 and f_M=0.5. Figure 6-14 shows how the mean partial loads vary with respect to the normalized stress due to the mechanical loading for preselected values of β=3.5 and f_{PB}=5.

Table 6-12: Parameters for the Computations for g_6

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3, 3.5, 4.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PB}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_M	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.15 1	Lognormal
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

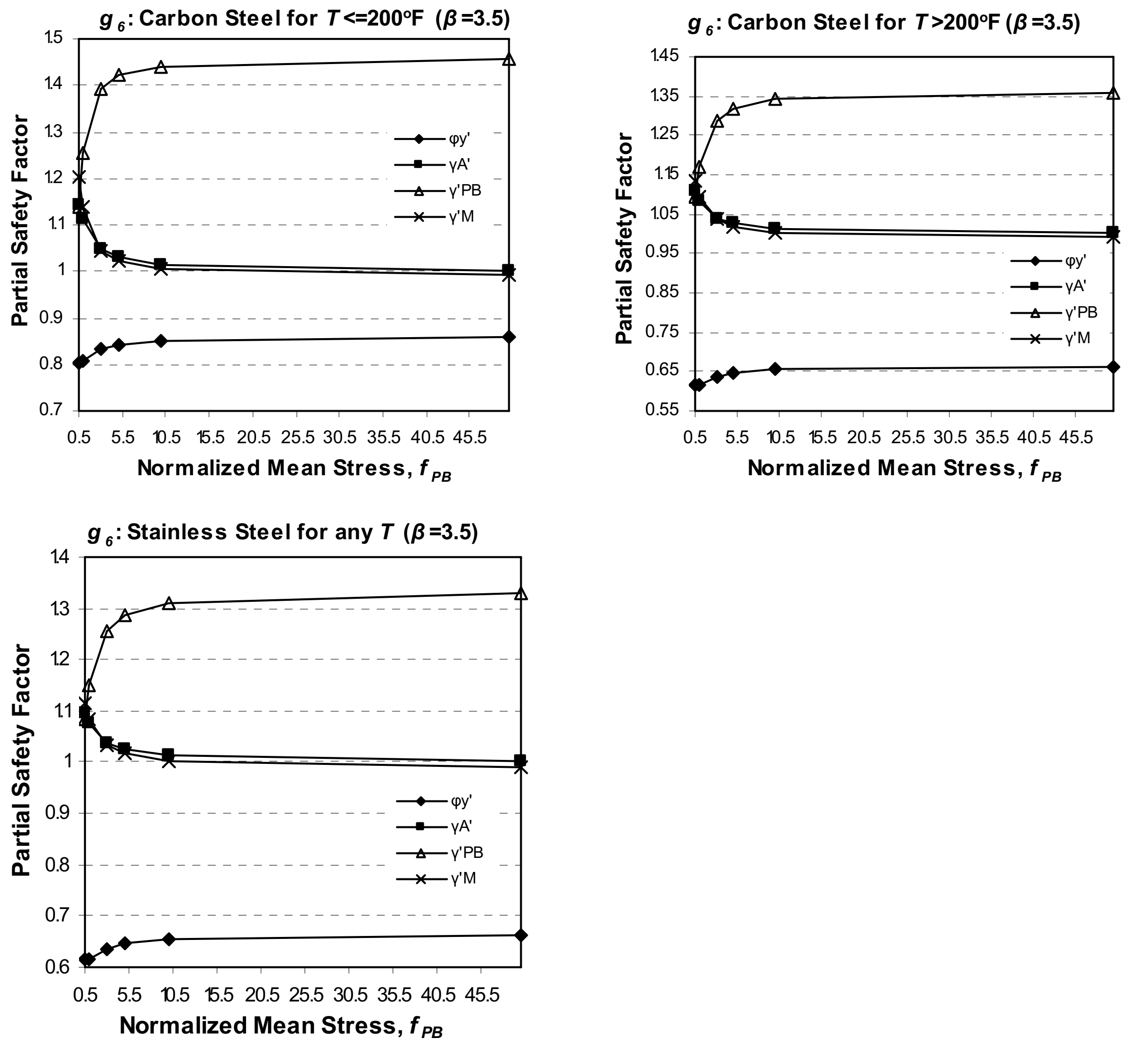


Figure 6-13: Mean Partial Safety Factors with Respect to the Normalized Stress due to Internal Pressure for Preselected Value of β=3.5 and f_M=0.5 for g_6

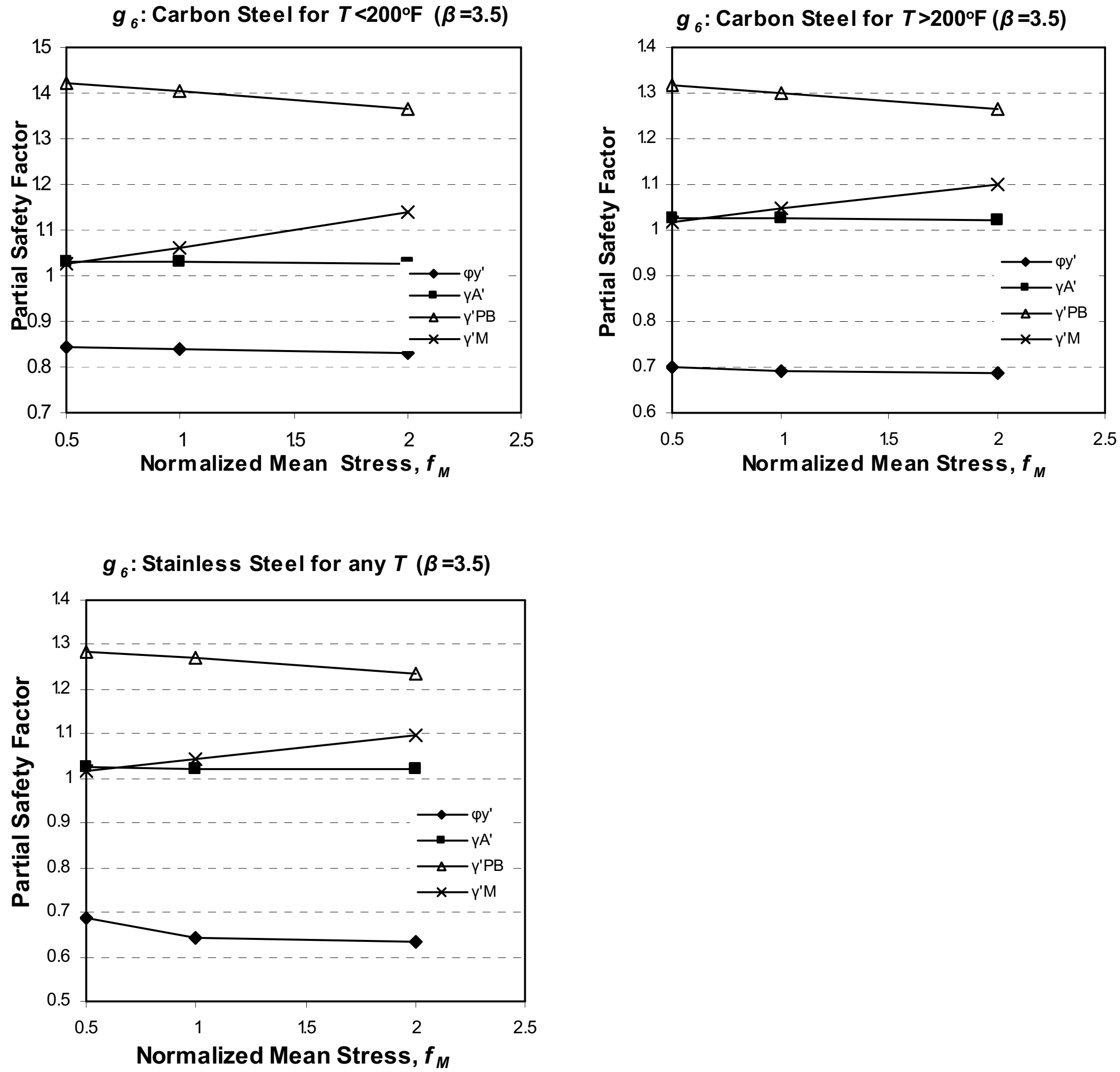


Figure 6-14: Mean Partial Safety Factors with Respect to the Normalized Mechanical Load for Preselected Value of β=3.5 and f_{PB}=5 for g_6

Table 6-13: Ranges and Recommended[1] Values for Adjusted Nominal Resistance Factors for g_6

β	φ_y for γ_A=1.1, γ_M=1.2, and γ_{PB}=1.2 CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2	**0.91**[2] (0.89 to 0.94)	**0.91**[2] (0.89 to 0.93)
3	For f_{PB}≤5, **0.97** (0.95 to 0.99) For f_{PB}>5, **0.93** (0.91 to 0.96)	**0.90** (0.88 to 0.93)
3.5	For f_{PB}≤5, **0.91** (0.89 to 0.94) For f_{PB}>5, **0.87** (0.85 to 0.89)	**0.82** (0.80 to 0.85)
4.5	For f_{PB} ≤5, **0.81** (0.78 to 0.84) For f_{PB} >5, **0.75** (0.73 to 0.78)	**0.69** (0.66 to 0.72)
	200°F	***200°F***
2	**0.89** (0.87 to 0.92)	**0.94** (0.93 to 0.96)
3	For f_{PB}≤10, **0.79** (0.76 to 0.82)	**0.79** (0.77 to 0.81)
3.5	For f_{PB}≤5, **0.74** (0.73 to 0.76) For f_{PBx}>5, **0.72.** (0.70 to 0.74)	**0.72** (0.70 to 0.74)
4.5	For f_{PB}≤5, **0.66** (0.64 to 0.68) For f_{PB}>5, **0.62** (0.60 to 0.64)	For f_{PB}≤5, **0.61** (0.60 to 0.63) For f_{PB}>5, **0.59** (0.57 to 0.61)
	400°F	***400°F***
2	**0.77** (0.76 to 0.79)	**0.77** (0.76 to 0.79)
3	**0.66** (0.64 to 0.68)	**0.64** (0.63 to 0.66)
3.5	**0.61** (0.58 to 0.63)	**0.59** (0.57 to 0.61)
4.5	**0.51** (0.49 to 0.54)	**0.49** (0.47 to 0.51)
	600°F	***600°F***
2	**0.67** (0.66 to 0.68)	**0.68** (0.68 to 0.70)
3	**0.56** (0.55 to 0.58)	**0.57** (0.56-0.59)
3.5	**0.52** (0.50 to 0.54)	**0.52** (0.51 to 0.54)
4.5	**0.44** (0.42 to 0.46)	**0.44** (0.42 to 0.46)
	800°F	***800°F***
2	**0.62** (0.61 to 0.64)	**0.64** (0.63 to 0.66)
3	**0.52** (0.51 to 0.54)	**0.51** (0.52 to 0.55)
3.5	**0.48** (0.47 to 0.50)	**0.46** (0.48 to 0.51)
4.5	**0.41** (0.39 to 0.43)	**0.40** (0.39 to 0.42)

(1) Recommended values are in bold face, (2) γ_A=γ_M=γ_{PB}=1

6.3.3.2. Performance Function g_7

This performance function considers the loading of pipes that are not pressurized, (e.g., auxiliary piping systems) and are subjected to seismic forces. The normalized performance function is given by Eq. (6-14), where f_y is the normalized yield strength, f_A the normalized sustained weight, and f_O the normalized stress due to the Operating Basis Earthquake (OBE).

$$g_7 = f_y - f_A - f_O \tag{6-14}$$

Table 6-14 provides the probabilistic characteristics for the variables under consideration and the recommended values used for the computation of partial safety factors. Table C-14 provides the calculated mean partial factors for all the examined cases. Table C-15 gives the adjusted nominal resistance factors for predefined load factors. The recommended nominal resistance factors are given in Table 6-15 by summarizing results in Table C-15. For this performance function the seismic loading is examined having two Coefficient Of Variation (*COV*), namely 0.50 and 0.80. Therefore, the influence of the Coefficient Of Variation (*COV*) of the earthquake loading on the results and the value of the target reliability index, β, is examined.

Figure 6-15 presents how the calculated mean factors (φ'_Y, γ'_A, γ'_O for the yield strength, sustained weight, and stress due to earthquake, respectively) vary with respect to the normalized stress due to the OBE for selected values of β=1.5 and 3.0.

Table 6-14: Parameters for the Computations for g_7

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1.0	0.5, 1, 2, 2.5 0.50, 0.80 0.75	Extreme II (Largest)
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable

Table 6-15: Ranges and Recommended[(1)] Nominal Adjusted Resistance Factors for g_7

β	φ_y for γ_A=1.1 & γ_O=1.5			
	CARBON STEEL		STAINLESS STEEL	
	$COV(f_O)$=0.50	$COV(f_O)$=0.80	$COV(f_O)$=0.50	$COV(f_O)$=0.80
	Room Temperature		***Room Temperature***	
1.5	**0.90**[(2)] (0.86 to 0.96)	**0.84**[(2)] (0.79 to 0.91)	**0.96**[(2)] (0.93 to 1.01)	**0.90**[(2)] (0.86 to 0.98)
2	**0.86**[(3)] (0.80 to 0.95)	**0.74**[(3)] (0.67 to 0.85)	**0.92**[(3)] (0.86 to 1.00)	**0.80**[(3)] (0.73 to 0.91)
3	**0.57** (0.51 to 0.67)	**0.39** (0.34 to 0.48)	**0.60** (0.54 to 0.71)	**0.40** (0.36 to 0.45)
	200°F		***200°F***	
1.5	**0.74**[(2)] (0.71 to 0.79)	**0.70**[(2)] (0.65 to 0.75)	**0.86**[(2)] (0.81 to 0.94)	**0.79**[(2)] (0.75 to 0.85)
2	**0.86** (0.84 to 0.89)	**0.75** (0.71 to 0.80)	**0.96** (0.94 to 1.00)	**0.83** (0.80 to 0.87)
3	**0.47** (0.42 to 0.55)	**0.32** (0.28 to 0.40)	**0.52** (0.47 to 0.62)	**0.35** (0.31 to 0.43)
	400°F		***400°F***	
1.5	**0.97** (0.93 to 0.99)	**0.90** (0.90 to 0.91)	**0.96** (0.90 to 1.00)	**0.90** (0.87 to 0.92)
2	**0.78** (0.77 to 0.80)	**0.68** (0.65 to 0.73)	**0.77** (0.77 to 0.78)	**0.67** (0.65 to 0.71)
3	**0.42** (0.38 to 0.50)	**0.29** (0.25 to 0.36)	**0.42** (0.38 to 0.48)	**0.29** (0.26 to 0.35)

Table 6-15: (Continued)

β	CARBON STEEL		STAINLESS STEEL	
	$COV(f_O)$=0.50	$COV(f_O)$=0.80	$COV(f_O)$=0.50	$COV(f_O)$=0.80
	600°F		***600°F***	
1.5	**0.83** (0.80 to 0.86)	**0.78**	**0.85** (0.80 to 0.89)	**0.80** (0.78 to 0.81)
2	**0.67** (0.66 to 0.69)	**0.59** (0.56 to 0.63)	**0.69**	**0.60** (0.58 to 0.63)
3	**0.37** (0.33 to 0.43)	**0.25** (0.22 to 0.31)	**0.37** (0.34 to 0.43)	**0.26** (0.23 to 0.31)
	800°F		***800°F***	
1.5	**0.78** (0.75 to 0.80)	**0.72** (0.72 to 0.73)	**0.80** (0.75 to 0.83)	**0.75** (0.73 to 0.76)
2	**0.63** (0.62 to 0.65)	**0.55** (0.52 to 0.59)	**0.64** (0.64 to 0.65)	**0.56** (0.54 to 0.59)
3	**0.34** (0.31 to 0.40)	**0.23** (0.20 to 0.29)	**0.35** (0.32 to 0.40)	**0.24** (0.21 to 0.29)

(1) Recommended values are in bold face, (2) γ_A=1 and γ_O=0.9, (3) γ_A=1.1 and γ_O=1.1

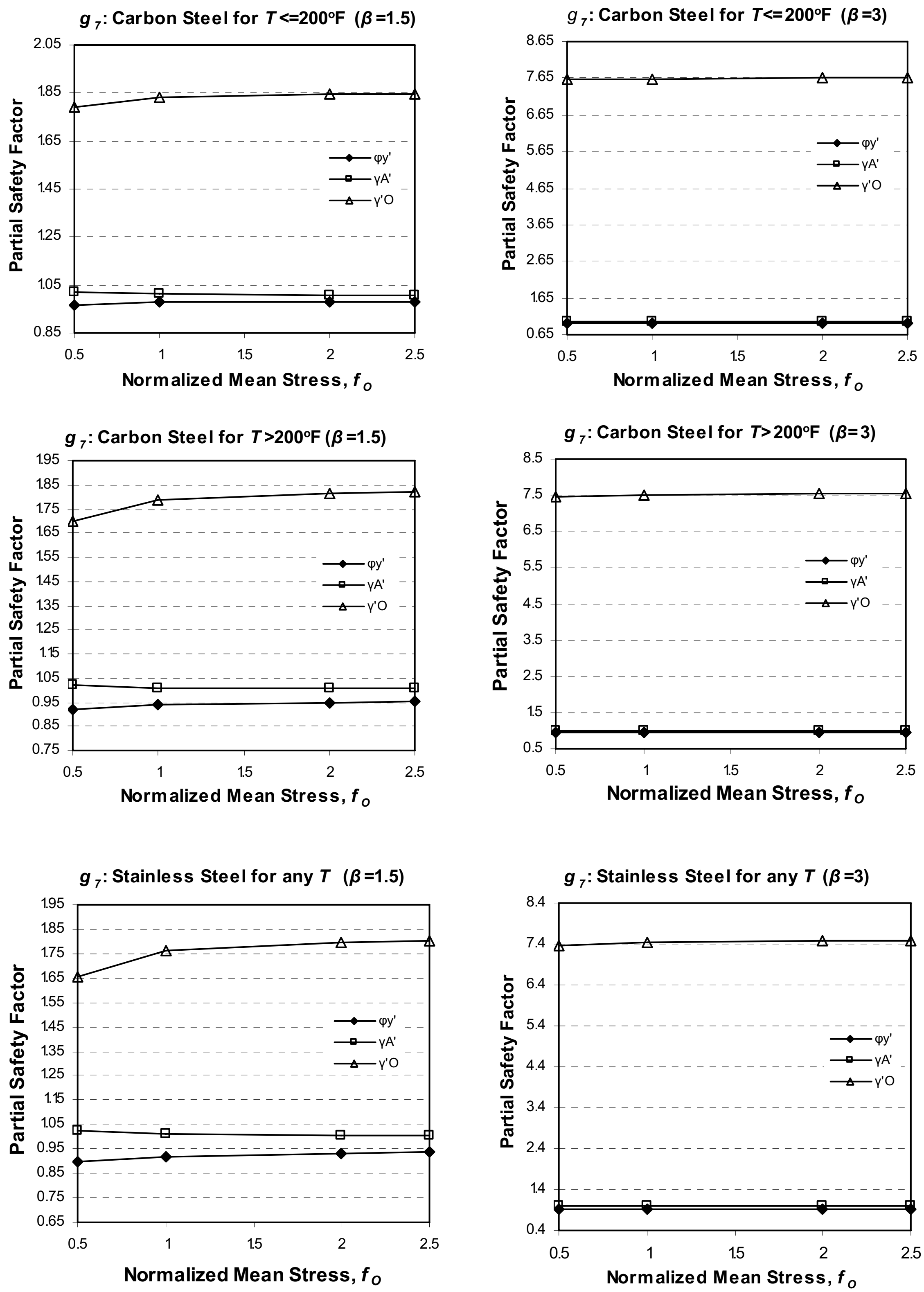


Figure 6-15: Mean Partial Factors with Respect to the Normalized Stress due to OBE for Selected Values of β=1.5 and 3.0 for g_7

Sensitivity Analysis

Figures 6-16 and 6-17 show the variation of the adjusted nominal resistance factor with respect to temperature for values of β=1.5 and 3 for carbon and stainless steel, respectively, and the two values of the *COV* for the earthquake loading. It can be seen that for the higher values of β the difference becomes larger and as expected the higher coefficient of variation yields smaller values for φ (conservative). For β=1.5 the diagrams are not smooth since the nominal resistance factor is evaluated for different sets of load factors. The *COV* of the earthquake loading has significant impact on the resultant value of β, which can be as high as 0.5, when the target reliability index is equal to 3 and for operation at room temperature. Nevertheless, for the rest of performance functions the *COV* for earthquake loading is considered 0.80, as an estimated value considering the big range that the *COV* for earthquake loading attains.

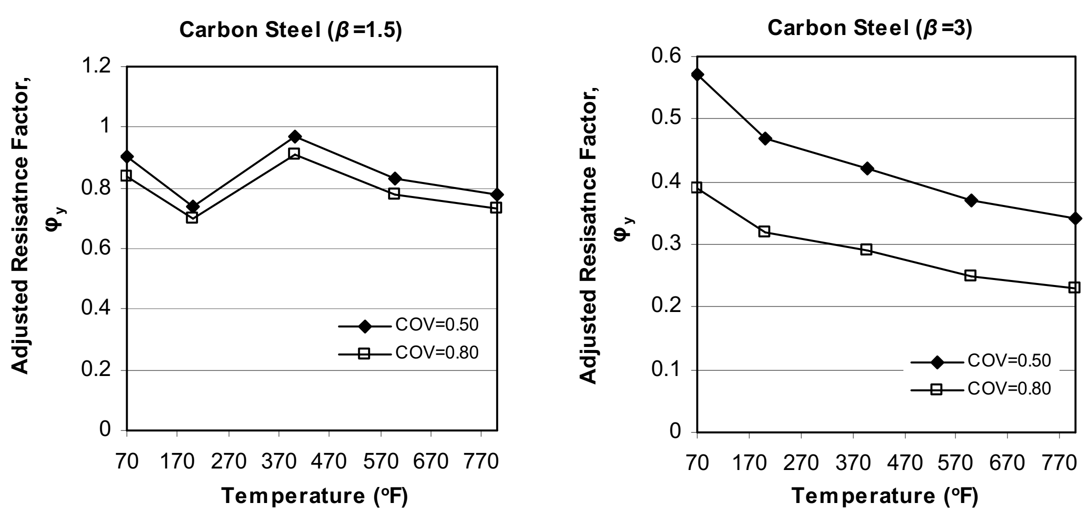


Figure 6-16: Variation with Temperature of the Recommended Nominal Resistance Factor for Carbon Steel and *COV* for Earthquake Loading

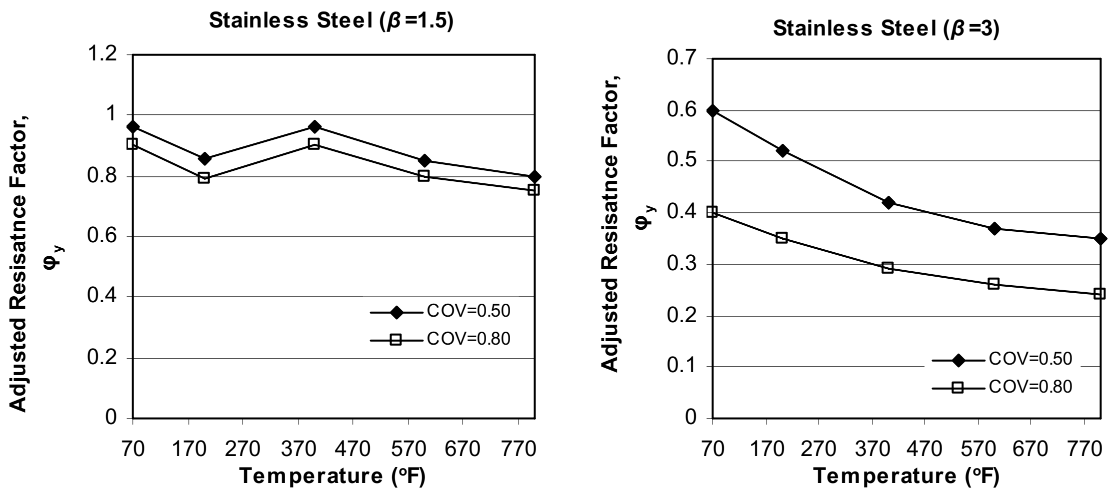


Figure 6-17: Variation with Temperature of the Recommended Nominal Resistance Factor for Stainless Steel and *COV* for Earthquake Loading

6.3.3.3. Performance Function g_8

This performance function checks pressurized pipes subjected to the OBE. Table 6-16 presents the probabilistic characteristics for the parameters in the performance function, given by Eq. (6-15), where f_{PO} is the normalized stress due the pressure coincident with the OBE, f_y the normalized yield strength of steel, and f_O the normalized stress due to OBE.

$$g_8 = f_y - f_A - f_{PO} - f_O \tag{6-15}$$

Table C-16 gives the mean partial load and resistance factors for different operating temperatures, values of β, and types of steel. The calculated adjusted nominal resistance factor is presented for all cases in Table C-17. A summary with the recommended values for the adjusted nominal resistance factors is shown in Table 6-17.

Table 6-16: Parameters for the Calculations for g_8

Parameter	Statistical Properties	Examined Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PO}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1	0.5, 1, 2, 2.5 0.50, 0.80 0.75	Extreme II (Largest)
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Table 6-17: Recommended(1) Values and Ranges for the Nominal Resistance Factor for g_8

β	**φ_y for γ_A=1.1, γ_{PO}=1.2 & γ_O=1.5**	
	CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
1.5	• For $f_{PO}\le1$ and $f_O\ge2$ **0.85**(2) (0.82 to 0.87) • Otherwise **0.95**(2) (0.90 to 1.01)	• For $f_{PO}\le1$ and $f_O\ge2$ **0.91**(2) (0.89 to 0.94) • Otherwise **1.00**(2) (0.97 to 1.04)
2	• For $f_{PO}\le1$ and $f_O\ge2$ **0.63**(2) (0.60 to 0.66) • For $f_{PO}\le1$ and $0.5<f_O<2$ or $f_{PO}=3$ and $f_O\le2$ **0.73**(2) (0.71 to 0.76) • Otherwise **0.87**(2) (0.83 to 0.92)	• For $f_{PO}\le1$ and $f_O\ge2$ **0.68**(2) (0.65 to 0.71) • For $f_{PO}\le1$ and $0.5<f_O<2$ **0.78**(2) (0.76 to 0.82) • Otherwise **0.90**(2) (0.39 to 0.54)
3	• For $f_{PO}\le1$ and $f_O\ge1$ **0.43** (0.36 to 0.50) • For $1<f_{PO}<10$ and $f_O\ge2$ or for $f_{PO}\le1$ and $f_O<1$ **0.55** (0.47 to 0.69) • For f_O=2.5 and f_{PO}=10 **0.69** • Otherwise **0.86** (0.76 to 0.95)	• For $f_{PO}\le1$ and $f_O\ge1$ **0.46** (0.39 to 0.54) • For $1<f_{PO}<10$ and $f_O\ge2$ or $f_{PO}\le1$ and $f_O<1$ **0.58** (0.49 to 0.68) • Otherwise **0.86** (0.74 to 0.92)
	200°F	***200°F***
1.5	• For $f_{PO}\le1$ and $f_O\ge1$ **0.72**(2) (0.67 to 0.77) • Otherwise **0.80**(2) (0.76 to 0.83)	• For $f_{PO}\le1$ and $f_O\ge1$ **0.83**(2) (0.78 to 0.87) • Otherwise **0.88**(2) (0.86 to 0.91)
2	• For $f_{PO}\le1$ and $f_O\ge2$ **0.75** (0.73 to 0.77) • Otherwise **0.88** (0.80 to 0.95)	• For $f_{PO}\le1$ and $f_O\ge2$ **0.86** (0.84 to 0.89) • Otherwise **0.97** (0.91 to 1.04)
3	• For $f_{PO}\le1$ and $f_O\ge1$ **0.35** (0.30 to 0.41) • For $f_{PO}<1$ and f_O=0.5 or f_{PO}=5 and $f_O\ge2$ or f_O=1 and f_{PO}=3 **0.50** (0.45 to 0.54) • Otherwise **0.70** (0.61 to 0.78)	• For $f_{PO}\le3$ and $f_O\ge1$ **0.46** (0.34 to 0.61) • For $f_{PO}<1$ and f_O=0.5 or for f_{PO}=5 and $f_O\ge2$ or f_O=1 and f_{PO}=3 **0.56** (0.51 to 0.61) • Otherwise **0.74** (0.64 to 0.83)
	400°F	***400°F***
1.5	**0.90** (0.84 to 0.96)	**0.90** (0.85 to 0.97)
2	• For $f_{PO}\le1$ and $f_O\ge2$ **0.70** (0.67 to 0.71) • Otherwise **0.80** (0.76 to 0.85)	• For $f_{PO}\le1$ and $f_O\ge2$ **0.70** (0.69 to 0.72) • Otherwise **0.80** (0.75 to 0.85)
3	• For $f_{PO}\le1$ and $f_O\ge1$ or for f_{PO}=3 and $f_O\ge2$ **0.33** (0.27 to 0.38) • For $f_{PO}\le1$ and $f_O>1$ or for $1<f_{PO}<10$ or for $f_O\ge2$ **0.50** (0.43 to 0.57) • Otherwise **0.64** (0.57 to 0.69)	• For $f_{PO}\le1$ and $f_O\ge1$ or for f_{PO}=3 and $f_O\ge2$ **0.35** (0.28 to 0.39) • For $f_{PO}\le1$ and $f_O>1$or $1<f_{PO}<10$ or $f_O\ge2$ **0.50** (0.44 to 0.57) • Otherwise **0.63** (0.58 to 0.68)
	600°F	***600°F***
1.5	**0.78** (0.73 to 0.83)	**0.80** (0.76 to 0.86)
2	• For $f_{PO}\le1$ and $f_O\ge1$ **0.62** (0.58 to 0.66) • Otherwise **0.69** (0.65 to 0.73)	• For $f_{PO}\le1$ and $f_O\ge1$ **0.65** (0.61 to 0.69) • Otherwise **0.73** (0.69 to 0.76)
3	• For $f_{PO}\le1$ and $f_O\ge1$ **0.28** (0.24 to 0.32) • For $f_{PO}\le1$ and $f_O<1$ or for $3\le f_{PO}\le5$ and $f_O\ge2$ or **0.37** (0.33 to 0.41) • For $3\le f_{PO}\le5$ and $0.5<f_O<2$ or f_{PO}=10 and $f_O\ge2$ **0.45** (0.42 to0.49) • Otherwise **0.56** (0.53 to 0.59)	• For $f_{PO}\le1$ and $f_O\ge2$ **0.26** (0.25 to 0.28) • For $f_{PO}\le1$ and $f_O<2$ or for $3\le f_{PO}\le5$ and $f_O\ge1$ **0.40** (0.35 to 0.45) • Otherwise **0.55** (0.47 to 0.60)

Table 6-17: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	800°F	***800°F***
1.5	**0.73** (0.68 to 0.77)	**0.76** (0.71 to 0.81)
2	• For f_{PO}≤1 and f_O≥2 **0.56** (0.54 to 0.57) • Otherwise **0.65** (0.63 to 0.68)	• For f_{PO}≤1 and f_O≥2 **0.58** (0.57 to 0.60) • Otherwise **0.68** (0.64 to 0.71)
3	• For f_{PO}≤1 and f_O≥1 **0.26** (0.22 to 0.30) • For f_{PO}≤1 and f_O<1 or for 3≤f_{PO}≤5 and f_O≥2 **0.34** (0.29 to 0.39) • For 3≤f_{PO}≤5 and 0.5<f_O<2 **0.45** (0.42 to 0.49) • Otherwise **0.54** (0.48 to 0.59)	• For f_{PO}≤1 and f_O≥2 **0.27** (0.23 to 0.32) • For f_{PO}≤1 and f_O<2 or for 3≤f_{PO}≤5 and f_O≥2 **0.34** (0.30 to 0.38) • Otherwise **0.47** (0.41 to 0.55)

(1) Recommended values are in bold face (2) $\gamma_A=\gamma_{PO}=1$ and $\gamma_O=0.9$

6.3.3.4. Performance Function g_9

This performance function checks pressurized pipes subjected to the OBE and mechanical loading. Table 6-18 presents the probabilistic characteristics for the parameters used in the performance function, given by Eq. (6-16), where f_{PO} is the normalized stress due the pressure coincident with the OBE, f_y the normalized yield strength of steel, f_O the normalized stress due to OBE, and f_M the normalized stress due to mechanical loading.

$$g_9 = f_y - f_A - f_{PO} - E(f_O + f_M) \qquad (6\text{-}16)$$

Table C-18 gives the mean partial load and resistance factors for different operating temperatures, values of β, and types of steel. Figure 6-18, moreover, presents the mean factors (φ_y', γ'_A, γ'_{PO}, γ'_M, γ'_O for the yield strength of steel, the sustained weight, the internal pressure, mechanical loading, and earthquake, respectively) for the selected case of β=1.5, f_M=0.5, and f_O=2. The calculated adjusted nominal resistance factors are presented for all examined cases in Table C-19. A summary with the recommended values for the adjusted nominal resistance factors is shown in Table 6-19.

Table 6-18: Parameters for the Calculations for g_9

Parameter	Statistical Properties	Examined Range	Recommended Value	Distribution
β	na	na	1.5, 2.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PB}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1	0.5, 1, 2, 2.5 0.80 0.75	Extreme II (Largest)
f_M	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.15 1.00	Lognormal
E	NA	NA	1.0	NA
f_y	Mean *COV* Bias	NA Table 3-5 Table 3-5	NA Table 3-5 Table 3-5	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

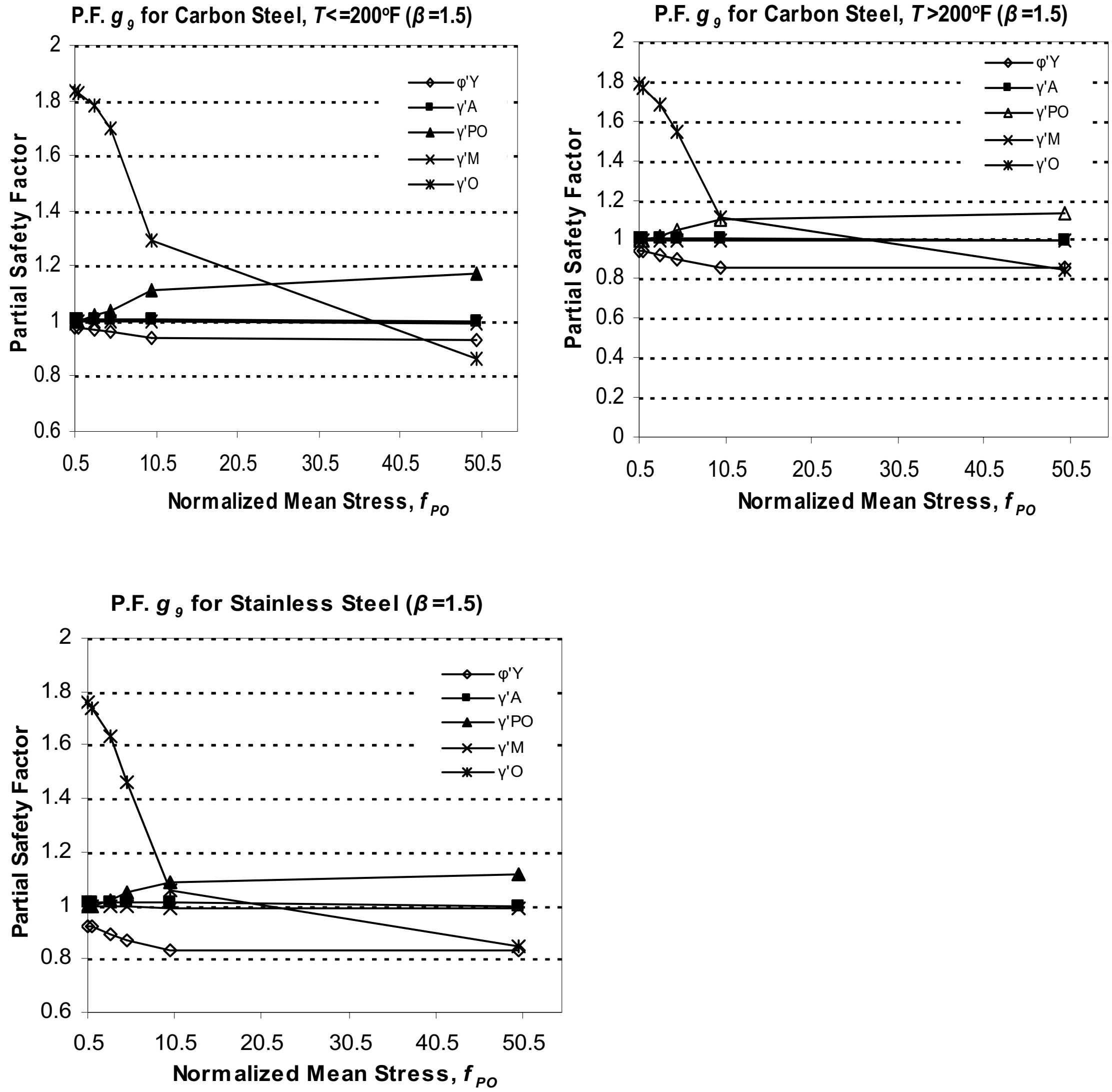


Figure 6-18: Mean Partial Factors with Respect to the Normalized Stress Pressure Coincident with Earthquake for Selected Values of β=1.5, f_M=0.5, and f_O=2 for g_9

Table 6-19: Recommended[1] Values and Ranges for the Adjusted Nominal Resistance Factor for g_9

β	φ_y for γ_A=1.1, γ_{PO}=γ_M=1.2 & γ_{PO}=1.5 CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
1.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.88**[2] (0.84 to 0.93) • Otherwise **0.98**[2] (0.95 to 1.01)	**0.98**[2] (0.93 to 1.04)
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.69**[2] (0.62 to 0.76) • For $1<f_{PO}\leq5$, $f_O\geq2$ or for $f_{PO}\leq1$, $f_M\leq0.5$ and $f_O\leq1$ **0.84**[2] (0.75 to 0.93) • For $f_{PO}\leq1$, f_M=1 and $f_O\leq1$ **0.87**[2] (0.78-0.96) • For $f_{PO}\leq1$, f_M=2 and $f_O\leq1$ **0.94**[2] (0.86-1.01) • Otherwise **1.00**[2] (0.94 to 1.07)	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.74**[2] (0.67 to 0.81) • For $1<f_{PO}\leq5$, $f_O\geq2$ or for $f_{PO}\leq1$, $f_M\leq0.5$ and $f_O\leq1$ **0.87**[2] (0.80 to 0.94) • For $f_{PO}\leq1$, f_M=1 and $f_O\leq1$ **0.95**[2] (0.85-1.02) • For $f_{PO}\leq1$, f_M=2 and $f_O\leq1$ **0.98**[2] (0.91-1.05) • Otherwise **1.00**[2] (0.98 to 1.07)
	200°F	***200°F***
1.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.76**[2] (0.71 to 0.81) • Otherwise **0.80**[1] (0.76 to 0.83)	**0.85**[2] (0.79 to 0.91)
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.56**[2] (0.51 to 0.62) • For $1<f_{PO}\leq5$, $f_O\geq2$ or for $f_{PO}\leq1$, $f_M\leq0.5$ and $f_O\leq1$ **0.69**[2] (0.62 to 0.76) • For $f_{PO}\leq1$, f_M=1 and $f_O\leq1$ **0.72**[2] (0.65 to 0.79) • For $f_{PO}\leq1$, f_M=2 and $f_O\leq1$ **0.77**[2] (0.70 to 0.83) • Otherwise **0.83**[2] (0.76 to 0.89)	• For $f_{PO}\leq$ 1, and $f_O\geq2$ **0.65**[2] (0.59 to 0.71) • For $1<f_{PO}\leq5$, $f_O\geq2$ or for $f_{PO}\leq1$, $f_M\leq0.5$ and $f_O\leq1$ **0.78**[2] (0.70 to 0.86) • For $f_{PO}\leq1$, f_M=1 and $f_O\leq1$ **0.82**[2] (0.74 to 0.89) • Otherwise **0.87**[2] (0.80 to 0.93)
	400°F	***400°F***
1.5	**0.89** (0.84 to 0.96)	**0.90** (0.85 to 0.97)
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ or for f_{PO}=3, f_M=0.5 and f_O=2.5 or f_O=f_M=0.5 and f_{PO}=1.0 **0.52** (0.47 to 0.57) • For $f_{PO}\geq10$ **0.73** (0.70 to 0.76) • Otherwise **0.68** (0.59 to 0.77)	• For $f_{PO}\leq1$ and $f_O\geq2$ or for f_{PO}=3, f_M=0.5 and f_O=2.5 or for f_O=f_M=0.5 and f_{PO}=1.0 **0.53** (0.48 to 0.58) • For $f_{PO}\geq10$ **0.72** (0.70 to 0.75) • Otherwise **0.69** (0.61 to 0.77)
	600°F	***600°F***
1.5	**0.76** (0.73 to 0.83)	**0.82** (0.76 to 0.87)
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ or for f_{PO}=3, f_M=0.5 and f_O=2.5 or f_O=f_M=0.5 and f_{PO}=1.0 **0.45** (0.41 to 0.49) • For $f_{PO}\geq10$ **0.64** (0.61 to 0.66) • Otherwise **0.58** (0.51 to 0.66)	• For $f_{PO}\leq1$ and $f_O\geq2$ or for f_{PO}=3, f_M=0.5 and f_O=2.5 or for f_O=f_M=0.5 and f_{PO}=1.0 **0.45** (0.43 to 0.50) • For $f_{PO}\geq10$ **0.64** (0.60 to 0.67) • Otherwise **0.61** (0.54 to 0.68)

Table 6-19: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	800°F	***800°F***
1.5	**0.71** (0.68 to 0.77)	**0.75** (0.71 to 0.81)
2.5	• For f_{PO}≤1 and f_O≥2 or for f_{PO}=3, f_M=0.5 and f_O=2.5 or f_O=f_M=0.5 and f_{PO}=1.0 **0.42** (0.38 to 0.47) • For f_{PO}≥10 **0.59** (0.57 to 0.61) • Otherwise **0.56** (0.50 to 0.62)	• For f_{PO}≤1 and f_O≥2 or for f_{PO}=3, f_M=0.5 and f_O=2.5 or for f_O=f_M=0.5 and f_{PO}=1.0 **0.44** (0.40 to 0.48) • For f_{PO}≥10 **0.60** (0.58 to 0.63) • Otherwise **0.57** (0.51 to 0.64)

(1) Recommended values are in bold face, (2) γ_A=γ_M=γ_{PO}=1 and γ_O=0.9

6.3.4. Service Level C

In this section the partial safety factors for performance functions g_{11} to g_{14} are calculated. Loads for Service Level C result from emergency conditions during the plant's operation. The OBE earthquake is also considered. The bending stresses are calculated using the plastic section modulus.

6.3.4.1. Performance Function g_{11}

This performance function considers the loading of pipes that are not pressurized (for example auxiliary piping systems) and subjected to seismic forces. The normalized performance function is given by Eq. (6-17), where f_u is the normalized ultimate strength, f_A the normalized sustained weight, and f_O the normalized stress due to the OBE.

$$g_{11} = f_u - f_A - f_O \qquad (6\text{-}17)$$

Table 6-20 provides the probabilistic characteristics for the variables under consideration and recommended values used for the calculation of partial safety factors. Table C-20 provides the calculated mean partial factors for all the examined cases. Table C-21 gives the adjusted nominal resistance factors. The recommended nominal resistance factors are given in Table 6-21 by summarizing results of Table C-21.

Table 6-20: Parameters for the Calculations for g_{11}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1.00	0.5, 1, 2, 2.5 0.80 0.75	Extreme II (Largest)
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable

Table 6-21: Recommended[1] Values and Ranges for the Adjusted Nominal Resistance Factor for g_{11}

	φ_u for γ_A=1.1 & γ_O=1.5	
β	CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
1.5	**0.93**[2] (0.87 to 0.98)	**0.91**[2] (0.86 to 0.96)
2	**0.94** (0.88 to 1.00)	**0.92** (0.86 to 0.98)
3	**0.41** (0.34 to 0.49)	**0.40** (0.34 to 0.48)
	200°F	***200°F***
1.5	**0.85**[2] (0.80 to 0.89)	**0.79**[2] (0.75 to 0.83)
2	**0.85** (0.80 to 0.91)	**0.80** (0.75 to 0.85)
3	**0.38** (0.31 to 0.45)	**0.35** (0.29 to 0.42)
	400°F	***≥400°F***
1.5	**0.85**[2] (0.88 to 0.98)	**0.90** (0.91 to 0.94)
2	**0.95** (0.88 to 1.00)	**0.70** (0.65 to 0.76)
3	**0.42** (0.35 to 0.49)	**0.30** (0.25 to 0.38)
	600°F	
1.5	**0.88**[2] (0.83 to 0.92)	
2	**0.88** (0.83 to 0.94)	
3	**0.39** (0.32 to 0.46)	
	800°F	
1.5	**0.92** (0.92 to 0.93)	
2	**0.70** (0.66 to 0.75)	
3	**0.31** (0.26 to 0.37)	

(1) Recommended values are in bold face, (2) γ_A=1.0 and γ_O=1.0

6.3.4.2. Performance Function g_{12}

This performance considers the loading of pipes that are pressurized and subjected to earthquake load. The normalized performance function is given by Eq. (6-18), where f_u is the normalized ultimate strength, f_A the normalized sustained weight, f_O the normalized stress due to the OBE, and f_{PO} the normalized stress coinciding with earthquake.

$$g_{12} = f_u - f_A - f_{PO} - f_O \tag{6-18}$$

Table 6-22 provides the probabilistic characteristics for the variables under consideration and the recommende values used for the calculation of partial safety factors. Table C-22 provides the calculated mean partial safety factors for all the examined cases. Table C-23 gives the adjusted nominal resistance factors. The recommended nominal resistance factors are given in Table 6-23 by summarizing results in Table C-23.

Table 6-22: Parameters for the Calculations for g_{12}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	2, 2.5, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1.0	0.5, 1, 2, 2.5 0.80 0.75	Extreme II (Largest)
f_{PO}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Table 6-23: Recommended[1] Values and Ranges for the Adjusted Nominal Resistance Factor for g_{12}

β	φ_u **for** γ_A**=1.1,** γ_{PO}**=1.2 &** γ_O**=1.5** CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.64**[2] (0.61 to 0.67) • For $f_{PO}\leq1$ and $0.5<f_O<2$ or for $1<f_{PO}<5$ and $f_O\geq2$ **0.75**[2] (0.73 to 0.78) • For $f_{PO}\leq1$ and $f_O=0.5$ or $f_{PO}=5$ and $f_O\geq2$ **0.84**[2] (0.81 to 0.89) • Otherwise **0.94**[2] (0.91 to 0.97)	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.63**[2] (0.60 to 0.66) • For $f_{PO}\leq1$ and $0.5<f_O<2$ or for $1<f_{PO}<5$ and $f_O\geq2$ **0.74**[2] (0.71 to 0.77) • For $f_{PO}\leq1$ and $f_O=0.5$ or $f_{PO}=5$ and $f_O\geq2$ **0.83**[2] (0.80 to 0.87) • Otherwise **0.92**[2] (0.89 to 0.95)
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$: **0.44**[2] (0.41 to 0.47) • For $1<f_{PO}<5$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $1<f_O<2$ **0.55**[2] (0.52 to 0.58) • For $f_{PO}\leq1$ and $f_O\leq0.5$ or for $3<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}=3$ and $f_O=1$ **0.69**[2] (0.66 to 0.72) • For $f_{PO}=10$ and $f_O\geq2$ or for $f_{PO}=5$ and $f_O=1$ **0.77**[2] (0.74 to 0.80) • Otherwise **0.88**[2] (0.86 to 0.91)	• For $f_{PO}\leq1$ and $f_O\geq2$: **0.43**[2] (0.40 to 0.46) • For $1<f_{PO}<5$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $1<f_O<2$ **0.54**[2] (0.51 to 0.57) • For $f_{PO}\leq1$ and $f_O\leq0.5$ or $3<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}=3$ and $f_O=1$ **0.66**[2] (0.61 to 0.71) • For $f_{PO}=10$ and $f_O\geq2$ or for $f_{PO}=5$ and $f_O=1$ **0.75**[2] (0.73 to 0.79) • Otherwise **0.87**[2] (0.85 to 0.89)
3	• For $f_{PO}\leq1$ and $f_O\geq1$ **0.44** (0.37 to 0.51) • For $1<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $f_O<1$ **0.56** (0.48 to 0.65) • For $1<f_{PO}<10$ and $0.5<f_O<2$ or for $f_{PO}=10$ and $f_O\leq2$ **0.72** (0.67 to 0.78) • For $f_{PO}=3$ and $f_O=0.5$ **0.85** • Otherwise **0.98** (0.96 to 1.01)	• For $f_{PO}\leq1$ and $f_O\geq1$ **0.43** (0.36 to 0.50) • For $1<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $f_O<1$ **0.56** (0.48 to 0.64) • For $1<f_{PO}<10$ and $0.5<f_O<2$ or for $f_{PO}=10$ and $f_O\leq2$ **0.71** (0.66 to 0.77) • For $f_{PO}=3$ and $f_O=0.5$ **0.83** • Otherwise **0.96** (0.93 to 0.99)

Table 6-23: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	200°F	***200°F***
2	• For $f_{PO} \le 1$ and $f_O \ge 2$: **0.58**[2] (0.56 to 0.62) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ **0.73**[2] (0.68 to 0.78) • For $f_{PO} \le 1$ and $f_O \le 0.5$ **0.78**[2] (0.76 to 0.81) • Otherwise **0.85**[2] (0.82 to 0.89)	• For $f_{PO} \le 1$ and $f_O \ge 2$ **0.54**[2] (0.52 to 0.57) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ **0.68**[2] (0.64 to 0.72) • For $f_{PO} \le 1$ and $f_O \le 0.5$ or for $f_{PO}=3$ and $f_O=1$ or for $f_{PO}=10$ and $f_O=2.5$ **0.74**[2] (0.71 to 0.77) • Otherwise **0.81**[2] (0.79 to 0.83)
2.5	• For $f_{PO} \le 1$ and $f_O \ge 2$ **0.58** (0.56 to 0.61) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ **0.74** (0.68 to 0.80) • For $f_{PO} \le 1$ and $f_O \le 0.5$ or for $f_{PO}=10$ and $f_O > 2$ **0.87** (0.83 to 0.89) • Otherwise **0.95** (0.92 to 1.02)	• For $f_{PO} \le 1$ and $f_O \ge 2$ **0.54** (0.52 to 0.57) • For $1 < f_{PO} < 10$ and $f_O \ge 2$: **0.74** (0.64 to 0.74) • For $f_{PO} \le 1$ and $f_O \le 0.5$ or for $f_{PO}=10$ and $f_O > 2$ or for $f_{PO}=5$ and $f_O=1$ **0.75** (0.71 to 0.79) • Otherwise **0.91** (0.87 to 0.95)
3	• For $f_{PO} \le 1$ and $f_O \ge 2$: **0.35** (0.34 to 0.38) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ or for $f_{PO} \le 0.5$ and $f_O < 2$ or for $f_{PO}=f_O=1$ **0.50** (0.44 to 0.55) • For $f_{PO}=3$ and $f_O=0.5$ or for $f_{PO}=5$ and $f_O=1$ or for $f_{PO}=10$ and $f_O=2.0$ **0.74** (0.70 to 0.77) • Otherwise **0.90** (0.87 to 0.92)	• For $f_{PO} \le 1$ and $f_O \ge 2$: **0.33** (0.31 to 0.36) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ or for $f_{PO} \le 0.5$ and $f_O < 2$ or for $f_{PO}=f_O=1$ **0.45** (0.39 to 0.52) • For $f_{PO}=1$ and $f_O=0.5$ or for $f_{PO}=5$ and $f_O=1$ or for $f_{PO}=10$ and $f_O \ge 2$ **0.61** (0.56 to 0.66) • For $f_{PO}=3$ and $f_O=0.5$ • Otherwise **0.83** (0.80 to 0.86)
	400°F	***≥400°F***
2	• For $f_{PO} \le 1$ and $f_O \ge 2$ **0.38**[2] (0.34 to 0.42) • For $1 < f_{PO} < 10$ and $f_O \ge 2$ **0.80**[2] (0.75 to 0.85) • For $f_{PO} \le 1$ and $f_O \le 0.5$ **0.85**[2] (0.83 to 0.88) • Otherwise **0.92**[2] (0.89 to 0.94)	• For $f_{PO} \le 1$ and $f_O \ge 2$ **0.70** (0.67 to 0.74) • For $f_{PO} \le 0.5$ and $f_O \le 1$ or for $0.5 < f_{PO} \le 1$ and $0.5 < f_O < 2$ or for $1 < f_{PO} \le 5$ and $f_O \ge 2$ **0.79** (0.74 to 0.83) • For $f_{PO} > 10$ **0.85** (0.82 to 0.88) • Otherwise **0.88** (0.85 to 0.92)

Table 6-23: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	400°F	***≥400°F***
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.44**(2) (0.41 to 0.47) • For $1<f_{PO}<5$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $1<f_O<2$ **0.55**(2) (0.52 to 0.58) • For $f_{PO}\leq1$ and $f_O\leq0.5$ or $3<f_{PO}<10$ and $f_O\geq2$ **0.68**(2) (0.65 to 0.71) • For $f_{PO}=10$ and $f_O\geq2$ **0.75**(2) (0.74 to 0.79) • For $f_{PO}=5$ and $f_O=1.0$ **1.01**(2) • Otherwise **0.85**(2) (0.83 to 0.87)	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.48** (0.45 to 0.51) • For $f_{PO}\leq0.5$ and $f_O\leq1$ or for $0.5<f_{PO}\leq1$ and $f_O\leq1$ or for $1<f_{PO}\leq5$ and $f_O\geq2$ **0.61** (0.53 to 0.69) • For $f_{PO}>10$ **0.85** (0.82 to 0.88) • For $f_{PO}=3$ and $f_O=0.5$ or for $f_{PO}=10$ and $f_O\leq2$ **0.76** (0.71 to 0.81) • Otherwise **0.88** (0.85 to 0.92)
3	• For $f_{PO}\leq1$ and $f_O\geq1$ **0.44** (0.37 to 0.51) • For $1<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $f_O<1$ **0.56** (0.49 to 0.65) • For $1<f_{PO}<10$ and $0.5<f_O<2$ or for $f_{PO}=10$ and $f_O\leq2$ **0.72** (0.67 to 0.78) • For $f_{PO}=3$ and $f_O=0.5$ **0.85** • Otherwise **0.95** (0.92 to 0.99)	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.30** (0.27 to 0.32) • For $f_{PO}\leq0.5$ and $f_O\leq1$ or for $0.5<f_{PO}\leq1$ and $f_O\leq1$ or for $1<f_{PO}\leq5$ and $f_O\geq2$ **0.42** (0.34 to 0.50) • For $f_{PO}=3$ and $f_O=0.5$ or for $f_{PO}=10$ and $f_O\leq2$ or for $1<f_{PO}<10$ and $0.5<f_O<2$ **0.56**(0.50 to 0.63) • Otherwise **0.73** (0.70 to 0.77)
	600°F	
2	• For $f_{PO}\leq1$ and $f_O\geq2$: **0.61**(2) (0.58 to 0.64) • For $1<f_{PO}<10$ and $f_O\geq2$ **0.75**(2) (0.70 to 0.80) • For $f_{PO}\leq1$ and $f_O\leq0.5$ **0.80**(2) (0.78 to 0.83) • Otherwise **0.86**(2) (0.83 to 0.89)	
2.5	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.42**(2) (0.39 to 0.44) • For $1<f_{PO}<10$ and $f_O\geq2$ **0.56**(2) (0.51 to 0.62) • For $f_{PO}\leq1$ and $f_O\leq0.5$ or for $f_{PO}=10$ and $f_O>2$ **0.70**(2) (0.65 to 0.74) • For $f_{PO}=3$ and $f_O=0.5$ **0.95**(2) • Otherwise **0.80**(2) (0.78 to 0.82)	
3	• For $f_{PO}\leq1$ and $f_O\geq2$: **0.37** (0.35 to 0.39) • For $1<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}\leq0.5$ and $f_O<2$ or for $f_{PO}=f_O=1$ **0.48** (0.44 to 0.53) • For $f_{PO}=3$ and $f_O=0.5$ or for $f_{PO}=5$ and $f_O=1$ or for $f_{PO}=10$ and $f_O\geq2.0$ **0.68** (0.63 to 0.73) • Otherwise **0.89** (0.86 to 0.93)	

Table 6-23: (Continued)

β	CARBON STEEL
	800°F
2	• For f_{PO}≤1 and f_O≥2 or for f_{PO}≤1 and 0.5<f_O≤1 or for f_{PO}=3 and f_O=2.5 **0.73** (0.69 to 0.78) • For 5<f_{PO}≤10 **0.86** (0.84 to 0.89) • Otherwise **0.84** (0.80 to 0.88)
2.5	• For f_{PO}≤1 and f_O≥2 or for f_{PO}≤1 and 0.5<f_O≤1 or for f_{PO}=3 and f_O≥2 **0.52** (0.46 to 0.59) • For f_{PO}≥10 or for 3≤f_{PO}≤5 and f_O≤0.5 **0.76** (0.72 to 0.80) • Otherwise **0.65** (0.62 to 0.68)
3	• For f_{PO}≤1 and f_O≥2 or for f_{PO}≤1 and 0.5<f_O≤1 or for f_{PO}=3 and f_O≥2 **0.33** (0.28 to 0.39) • For f_{PO}≤1 and f_O≤0.5 or for 3<f_{PO}≤5 and f_O≥2 **0.45** (0.42 to 0.49) • For f_{PO}=10 and f_O≥2 **0.55** (0.53 to 0.57) • Otherwise **0.70** (0.64 to 0.74)

(1) Recommended values are shown in bold face (2) γ_A=γ_{PO}=1 and γ_O=0.9

6.3.4.3. Performance Function g_{13}

This performance considers the loading of pipes that are pressurized and subjected to mehanical load (water hammer, etc.). The normalized performance function is given by Eq. (6-19), where f_u is the normalized ultimate strength of steel, f_A the normalized sustained weight, f_{PC} the normalized stress due to pressure under Service Level C operation, and f_M the normalized stress due to the mechanical loading.

$$g_{13} = f_u - f_A - f_{PC} - f_M \qquad (6\text{-}19)$$

Table 6-24 provides the probabilistic characteristics for the variables under consideration and the recommended values used for the calculation of partial safety factors. Table C-24 provides the calculated mean partial factors for all the examined cases. Table C-25 gives the adjusted nominal resistance factors. The recommended nominal resistance factors are given in Table 6-25 by summarizing results in Table C-25.

Table 6-24: Parameters for the Calculations for g_{13}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	3, 4.5, 5.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_M	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.15 1.00	Lognormal
f_{PC}	Mean *COV* Bias	0.5 to 50* NA NA	0.5, 1, 3, 5, 10, 50 0.15 0.85	Extreme I (Largest)
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Table 6-25: Ranges and Recommended[1] Nominal Resistance Factors for g_{13}

β	φ_u for γ_A=1.1, γ_M=1.2 and γ_{PC}=1.2 CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
3	• For f_{PC}≤1 and f_M≤1 **0.99**[2] (0.98 to 1.00) • For 1<f_{PC}<10 or for f_{PC}≤1 and f_M>1 **0.93**[2] (0.90 to 0.96) • For f_{PC}≥10 **0.88**[2] (0.86 to 0.90)	• For f_{PC}≤1 and f_M≤1 **0.98**[2] (0.96 to 0.99) • For f_{PC}≤5 and f_M=2 **0.93**[2] (0.92 to 0.95) • For f_{PC}≥10 **0.86**[2] (0.84 to 0.89) • Otherwise **0.91**[2] (0.89 to 0.93)
4.5	• For f_{PC}≤1 and f_M≤1 **0.87** (0.85 to 0.90) • For f_{PC}≤3 and f_M=2 **0.84** (0.82 to 0.87) • For f_{PC}=3 and f_M=1 **0.78** • For f_{PC}≥10 **0.70** (0.66 to 0.72) • Otherwise **0.74** (0.71 to 0.77)	• For f_{PC}≤1 and f_M≤1 **0.86** (0.84 to 0.89) • For f_{PC}≤5 and f_M=2 **0.82** (0.80 to 0.85) • For f_{PC}≥10 **0.68** (0.65 to 0.71) • Otherwise **0.73** (0.70 to 0.76)
5.5	• For f_{PC}≤0.5 and f_M≤1 **0.80** • For f_{PC}≤1 **0.75** (0.73 to 0.77) • For f_{PC}=3 and f_M=1 **0.69** • For f_{PC}≥10 **0.55** (0.52 to 0.58) • Otherwise **0.61** (0.58 to 0.64)	• For f_{PC}≤1 and f_M≤0.5 **0.79** • For f_{PC}≤1 **0.74** (0.72 to 0.76) • For f_{PC}≥10 **0.54** (0.51 to 0.57) • For f_{PC}=3 and f_M=1 **0.68** • Otherwise **0.60** (0.57 to 0.63)
	200°F	***200°F***
3	• For f_{PC}≤1 and f_M<2 **0.95** (0.94 to 0.96) • For f_{PC}≤5 and f_M=2 **0.93** (0.91 to 0.95) • For f_{PC}≥10 **0.87** (0.85 to 0.89) • Otherwise **0.90** (0.89 to 0.93)	• For f_{PC}≤1 and f_M≤1 **0.89** (0.88 to 0.90) • For f_{PC}≤5 and f_M=2 **0.87** (0.85 to 0.89) • For f_{PC}≥10 **0.85** (0.83 to 0.87) • Otherwise **0.91** (0.89 to 0.93)
4.5	• For f_{PC}≤1 and f_M<2 **0.80** (0.78 to 0.82) • For f_{PC}≤3 and f_M≥2 **0.77** (0.75 to 0.79) • For f_{PC}≥10 **0.63** (0.60 to 0.66) • Otherwise **0.68** (0.65 to 0.71)	• For f_{PC}≤1 and f_M≤1 **0.74** (0.73 to 0.77) • For f_{PC}≤5 and f_M=2 **0.72** (0.70 to 0.74) • For f_{PC}≥10 **0.58** (0.56 to 0.61) • Otherwise **0.63** (0.61 to 0.66)
5.5	• For f_{PC}≤1 and f_M<2 **0.70** (0.67 to 0.73) • For 1<f_{PC}<10 and f_M≤2 or for f_{PC}=3 and f_M=1 **0.60** (0.58 to 0.63) • For f_{PC}≥10 **0.50** (0.48 to 0.53) • Otherwise **0.55** (0.53 to 0.56)	• For f_{PC}≤1 and f_M≤0.5 **0.68** (0.68 to 0.69) • For f_{PC}≤1 **0.64** (0.62 to 0.66) • For f_{PC}≥10 **0.47** (0.44 to 0.50) • For f_{PC}=3 and f_M=1 **0.59** • Otherwise **0.52** (0.49 to 0.55)
	400°F	***400°F***
3	• For f_{PC}≤0.5 and f_M≥1 or for f_{PC}≥10 **0.93** (0.91 to 0.95) • Otherwise **0.96** (0.93 to 0.99)	• For f_{PC}≤1 and f_M≤1 **0.80** (0.79 to 0.81) • For f_{PC}≤5 and f_M=2 **0.78** (0.76 to 0.80) • For f_{PC}≥10 **0.73** (0.71 to 0.75) • Otherwise **0.85** (0.83 to 0.87)

Table 6-25: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	400ºF	***400ºF***
4.5	• For $f_{PC}\leq 1$ **0.80** (0.79 to 0.81) • For $1<f_{PC}<10$ and $f_M=2$ **0.74** (0.73 to 0.76) • For $f_{PC}\geq 10$ **0.63** (0.61 to 0.66) • Otherwise **0.69** (0.67 to 0.71)	• For $f_{PC}\leq 1$ and $f_M\leq 1$ **0.67** (0.65 to 0.69) • For $f_{PC}\leq 3$ and $f_M=2$ **0.64** (0.63 to 0.66) • For $f_{PC}\geq 10$ **0.52** (0.50 to 0.55) • Otherwise **0.57** (0.55 to 0.59)
5.5	• For $f_{PC}\leq 1$ **0.69** (0.67 to 0.71) • For $1<f_{PC}<10$ and $f_M=2$ **0.62** (0.59 to 0.63) • For $f_{PC}\geq 10$ **0.50** (0.48 to 0.53) • Otherwise **0.55** (0.54 to 0.57)	• For $f_{PC}\leq 1$ and $f_M\leq 0.5$ **0.61** (0.61 to 0.62) • For $f_{PC}\leq 1$ **0.57** (0.56 to 0.59) • For $f_{PC}\geq 10$ **0.42** (0.40 to 0.44) • For $f_{PC}=3$ and $f_M=2$ **0.53** • Otherwise **0.47** (0.44 to 0.49)
	600ºF	***600ºF***
3	• For $f_{PC}\leq 5$ **0.91** (0.89 to 0.93) • Otherwise **0.87** (0.85 to 0.89)	• For $f_{PC}\leq 1$ and $f_M\leq 1$ **0.80** (0.79 to 0.81) • For $f_{PC}\leq 5$ and $f_M=2$ **0.78** (0.76 to 0.80) • For $f_{PC}\geq 10$ **0.73** (0.71 to 0.75) • Otherwise **0.85** (0.83 to 0.87)
4.5	• For $f_{PC}\leq 1$ and $f_M<2$ **0.75** (0.74 to 0.76) • For $f_{PC}\leq 3$ and $f_M\geq 2$ **0.72** (0.71 to 0.74) • For $f_{PC}\geq 10$ **0.61** (0.59 to 0.64) • Otherwise **0.68** (0.65 to 0.71)	• For $f_{PC}\leq 1$ and $f_M\leq 1$ **0.67** (0.65 to 0.69) • For $f_{PC}\leq 3$ and $f_M=2$ **0.64** (0.63 to 0.66) • For $f_{PC}\geq 10$ **0.52** (0.50 to 0.55) • Otherwise **0.57** (0.55 to 0.59)
5.5	• For $f_{PC}\leq 1$ and $f_M<2$ **0.65** (0.63 to 0.67) • For $f_{PC}\leq 3$ and $f_M\geq 2$ **0.62** (0.60 to 0.64) • For $f_{PC}\geq 10$ **0.48** (0.46 to 0.51) • Otherwise **0.53** (0.51 to 0.56)	• For $f_{PC}\leq 1$ and $f_M\leq 0.5$ **0.61** (0.61 to 0.62) • For $f_{PC}\leq 1$ **0.57** (0.56 to 0.59) • For $f_{PC}\geq 10$ **0.42** (0.40 to 0.44) • For $f_{PC}=3$ and $f_M=2$ **0.53** • Otherwise **0.47** (0.44 to 0.49)
	800ºF	***800ºF***
3	• For $f_{PC}\leq 5$ **0.73** (0.71 to 0.75) • For $f_{PC}=0.5$ and $f_M=2$ **0.70** • Otherwise **0.69** (0.68 to 0.71)	• For $f_{PC}\leq 1$ and $f_M\leq 1$ **0.77** (0.76 to 0.78) • For $f_{PC}\leq 5$ and $f_M=2$ **0.75** (0.73 to 0.77) • Otherwise **0.71** (0.69 to 0.73)
4.5	• For $f_{PC}\leq 1$ and $f_M<2$ or for $f_{PC}=1$ and $f_M=2$ **0.60** (0.59 to 0.61) • For $f_{PC}\leq 3$ and $f_M\geq 2$ **0.56** (0.55 to 0.57) • For $f_{PC}\geq 10$ **0.49** (0.47 to 0.51) • Otherwise **0.53** (0.51 to 0.55)	• For $f_{PC}\leq 1$ and $f_M\leq 1$ **0.64** (0.63 to 0.66) • For $f_{PC}\leq 3$ and $f_M=2$ **0.62** (0.60 to 0.64) • For $f_{PC}\geq 10$ **0.51** (0.49 to 0.53) • Otherwise **0.57** (0.55 to 0.59)
5.5	• For $f_{PC}\leq 1$ and $f_M<2$ **0.51** (0.50 to 0.53) • For $f_{PC}\leq 3$ and $f_M\geq 2$ **0.50** (0.48 to 0.52) • For $f_{PC}\geq 10$ **0.48** (0.46 to 0.51) • Otherwise **0.39** (0.37 to 0.41)	• For $f_{PC}\leq 1$ and $f_M\leq 0.5$ **0.60** (0.59 to 0.61) • For $f_{PC}\leq 1$ **0.55** (0.54 to 0.57) • For $f_{PC}\geq 10$ **0.41** (0.39 to 0.43) • For $f_{PC}=3$ and $f_M=2$ **0.51** • Otherwise **0.47** (0.44 to 0.49)

(1) Recommended values are in bold face, (2) $\gamma_A=\gamma_M=\gamma_{PC}=1.1$

6.3.4.4. Performance Function g_{14}

This performance function checks pressurized pipes subjected to the OBE and mechanical loading. Table 6-26 presents the probabilistic characteristics for the parameters used in the performance function, given by Eq. (6-20), where f_{PO} is the normalized stress due the pressure coincident with the OBE, f_u the normalized ultimate strength of steel, f_O the normalized stress due to OBE, and f_M the normalized stress due to mechanical loading.

$$g_{14} = f_u - f_A - f_{PO} - E(f_O + f_M) \tag{6-20}$$

Table C-26 gives the mean partial load and resistance factors (φ'_u, γ'_A, γ'_{PO}, γ'_O, γ'_M for the ultimate strength of steel, sustained weight, internal pressure, earthquake, and mechanical loading, respectively) for different operating temperatures, values of β, and types of steel. The calculated adjusted nominal resistance factor is presented for all cases in Table C-27. A summary with the recommended values for the adjusted nominal resistance factors is shown herein in Table 6-27.

Table 6-26: Parameters for the Calculations for g_{14}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	2.5, 3.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PO}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_O	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.65 to 1	0.5, 1, 2, 2.5 0.80 0.75	Extreme II (Largest)
f_M	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.15 1.00	Lognormal
E	NA	NA	1.0	NA
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Table 6-27: Recommended[1] Values and Ranges for the Nominal Resistance Factor for g_{14}

β	φ_u for γ_A=1.1, γ_{PO}=γ_M=1.2 & γ_O=1.5	
	CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2.5	• For f_{PO}≥3 and f_O≤0.5 or f_{PO}≥5 and 0.5≤f_O≤1 or f_{PO}>10 and f_O>1 **0.88**[2] (0.83 to 0.93) • For f_{PO}≤3 and f_O>2 or for f_{PO}≤1 and f_O=2 or for f_{PO}≤0.5 f_M≤1 and f_O=1 **0.55**[2] (0.47 to 0.63) • Otherwise **0.73**[2] (0.62 to 0.83)	• For f_{PO}≥3 and f_O≤0.5 or f_{PO}≥5 and 0.5≤f_O≤1 or f_{PO}>10 and f_O>1 or f_{PO}=10 and f_O=2 or f_M>1, f_{PO}≤1 and f_O≤0.5 **0.86**[2] (0.80 to 0.92) • For f_{PO}≤1 and f_O≥2 or **0.51**[2] (0.46 to 0.56) • Otherwise **0.65**[2] (0.59 to 0.71)
3.5	• For f_{PO}<10 and f_O>1 or f_{PO}≤1 and f_O>0.5 **0.32** (0.22 to 0.42) • For f_{PO}>10 or f_{PO}=10 and f_O≤0.5 **0.93** (0.90 to 0.97) • For f_{PO}=10 and f_O=1 or 1<f_{PO}<10 and f_O≤0.5 **0.70** (0.63 to 0.80) • Otherwise **0.50** (0.41 to 0.60)	• For f_{PO}<10 and f_O>1 or f_{PO}≤1 and f_O>0.5 **0.30** (0.21 to 0.42) • For f_{PO}>10 or f_{PO}=10 and f_O≤0.5 **0.92** (0.89 to 0.96) • For f_{PO}=10 and f_O=1 or 1<f_{PO}<10 and f_O≤0.5 **0.70** (0.62 to 0.79) Otherwise **0.50** (0.40 to 0.59)
	200°F	***200°F***
2.5	• For f_{PO}≥3 and f_O≤0.5 or f_{PO}≥5 and 0.5≤f_O≤1 or f_{PO}≥10 and 1≤f_O≤2 f_{PO}>10 and f_O>2 **0.97** (0.93 to 1.03) • For f_{PO}≤3 and f_O>1 or **0.68** (0.58 to 0.79) Otherwise **0.78** (0.70 to 0.85)	• For f_{PO}≤1 and f_O≥2 **0.59** (0.54 to0.64) • For 1<f_{PO}<10 and f_O≥2 or for f_{PO}≤1 and 0.5<f_O<2 or for f_M<1, f_O≤0.5, and f_{PO}≤0.5 **0.72** (0.65 to 0.79) • Otherwise **0.89** (0.81 to 0.97)
3.5	• For f_{PO}<10 and f_O>1 or f_{PO}≤1 and f_O>0.5 **0.30** (0.20 to 0.39) • For f_{PO}>10 or f_{PO}=10 and f_O≤0.5 **0.85** (0.82 to 0.89) • For f_{PO}=10 and f_O=1 or 1<f_{PO}<10 and f_O≤0.5 **0.65** (0.57 to 0.73) • Otherwise **0.46** (0.37 to 0.55)	• For f_{PO}<10 and f_O>1 or f_{PO}≤1 and f_O>0.5 **0.30** (0.19 to 0.36) • For f_{PO}>10 or f_{PO}=10 and f_O≤0.5 **0.80** (0.77 to 0.83) • For f_{PO}=10 and f_O=1 or 1<f_{PO}<10 and f_O≤0.5 **0.60** (0.53 to 0.68) Otherwise **0.40** (0.35 to 0.51)

Table 6-27: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	400°F	***≥400°F***
2.5	• For $f_{PO}\geq3$ and $f_O\leq0.5$ or $f_{PO}\geq5$ and $0.5\leq f_O\leq1$ or $f_{PO}>10$ and $f_O>1$ or $f_M>1$, $f_O\leq0.5$, and $f_{PO}\leq0.5$ **0.85**(1) (0.82 to 0.90) • For $f_{PO}\leq3$ and $f_O>2$ or for $f_{PO}\leq1$ and $f_O=2$ **0.55**(1) (0.47 to 0.63) Otherwise **0.73**(1) (0.60 to 0.85)	• For $f_{PO}\leq1$ and $f_O\geq2$ **0.53** (0.49 to0.57) • For $1<f_{PO}<10$ and $f_O\geq2$ or for $f_{PO}\leq1$ and $f_O<2$ or **0.68** (0.59 to 0.77) • Otherwise **0.80** (0.73 to 0.86)
3.5	• For $f_{PO}<10$ and $f_O>1$ or $f_{PO}\leq1$ and $f_O>0.5$ **0.32** (0.22 to 0.42) • For $f_{PO}>10$ or $f_{PO}=10$ and $f_O\leq0.5$ **0.93** (0.90 to 0.97) • For $f_{PO}=10$ and $f_O=1$ or $1<f_{PO}<10$ and $f_O\leq0.5$ **0.70** (0.63 to 0.80) • Otherwise **0.50** (0.41 to 0.60)	• For $f_{PO}<10$ and $f_O>1$ or $f_{PO}\leq1$ and $f_O>0.5$ **0.20** (0.16 to 0.31) • For $f_{PO}>10$ or $f_{PO}=10$ and $f_O\leq0.5$ **0.70** (0.67 to 0.74) • For $f_{PO}=10$ and $f_O=1$ or $1<f_{PO}<10$ and $f_O\leq0.5$ **0.55** (0.48 to 0.61) Otherwise **0.40** (0.35 to 0.51)
	600°F	
2.5	• For $f_{PO}\geq3$ and $f_O\leq0.5$ or $f_{PO}\geq5$ and $0.5\leq f_O\leq1$ or $f_{PO}\geq10$ and $1\leq f_O\leq2$ $f_{PO}>10$ and $f_O>2$ **0.97** (0.94 to 1.03) • For $f_{PO}\leq3$ and $f_O>1$ **0.70** (0.60 to 0.81) • Otherwise **0.83** (0.72 to 0.93)	
3.5	• For $f_{PO}<10$ and $f_O>1$ or $f_{PO}\leq1$ and $f_O>0.5$ **0.31** (0.21 to 0.43) • For $f_{PO}>10$ or $f_{PO}=10$ and $f_O\leq0.5$ **0.83** (0.80 to 0.86) • For $f_{PO}=10$ and $f_O=1$ or $1<f_{PO}<10$ and $f_O\leq0.5$ **0.67** (0.59 to 0.75) • For $f_{PO}=5$, $f_O=0.5$, and $f_M=2$ **0.89** • Otherwise **0.47** (0.39 to 0.55)	

Table 6-27: (Continued)

β	CARBON STEEL
	800°F
2.5	• For f_{PO}≤1 and f_O≤2 **0.54** (0.48 to 0.59) • For 1<f_{PO}≤5 and f_O≥2 or for f_M<1, f_O≤0.5and f_{PO}≤0.5 or for 10<f_{PO}<1 and f_O≥2 or for f_{PO}≤1 and 0.5<f_O<2 **0.64** (0.58 to 0.70) • Otherwise **0.76** (0.71 to 0.81)
3.5	• For f_{PO}<10 and f_O>1 or f_{PO}≤1 and f_O>0.5 **0.24** (0.16 to 0.32) • For f_{PO}>10 or f_{PO}=10 and f_O≤0.5 **0.66** (0.64 to 0.68) • For f_{PO}=10 and f_O=1 or 1<f_{PO}<10 and f_O≤0.5 **0.52** (0.47 to 0.57) • For f_{PO}=5, f_O=0.5, and f_M=2 **0.70** • Otherwise **0.38** (0.31 to 0.44)

(1) Recommended values are in bold face (2) $\gamma_A=\gamma_M=\gamma_{PO}=\gamma_O=1.0$

6.3.5. Service Level D

In this section the performance functions g_{16} to g_{19} are examined. Loads for Service Level D are accidental, therefore lower reliability indices are expected as for Service Level C. For the calculation of bending stresses the plastic section modulus is considered.

6.3.5.1. Performance Function g_{16}

This performance considers the loading of pipes that are not pressurized while the Safe Shutdown Earthquake occurs. The magnitude of the SSE is expected to be greater than the OBE examined in the previous service levels. The normalized performance function is given by Eq. (6-21).

$$g_{16} = f_u - f_A - f_S \tag{6-21}$$

Table 6-28 provides the probabilistic characteristics for the variables under consideration and the assumptions used for the calculation of partial safety factors. Table C-28 provides the calculated mean factors for all cases examined. Table C-29 gives the adjusted nominal resistance factors. The recommended nominal resistance factors are given in Table 6-29. Figure 6-19 presents how the mean safety factors (φ'_u, γ'_A, γ'_S for the ultimate strength of steel, sustained weight, and SSE, respectively) vary with respect to the normalized stress due to earthquake for values of β=1.5 and 3 and different properties of steel.

Table 6-28: Parameters for the Calculations for g_{16}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_S	Mean *COV* Bias	2 to 4 0.40 to 0.90 0.60 to 1.0	2, 3, 4 0.80 0.75	Extreme II (Largest)
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable

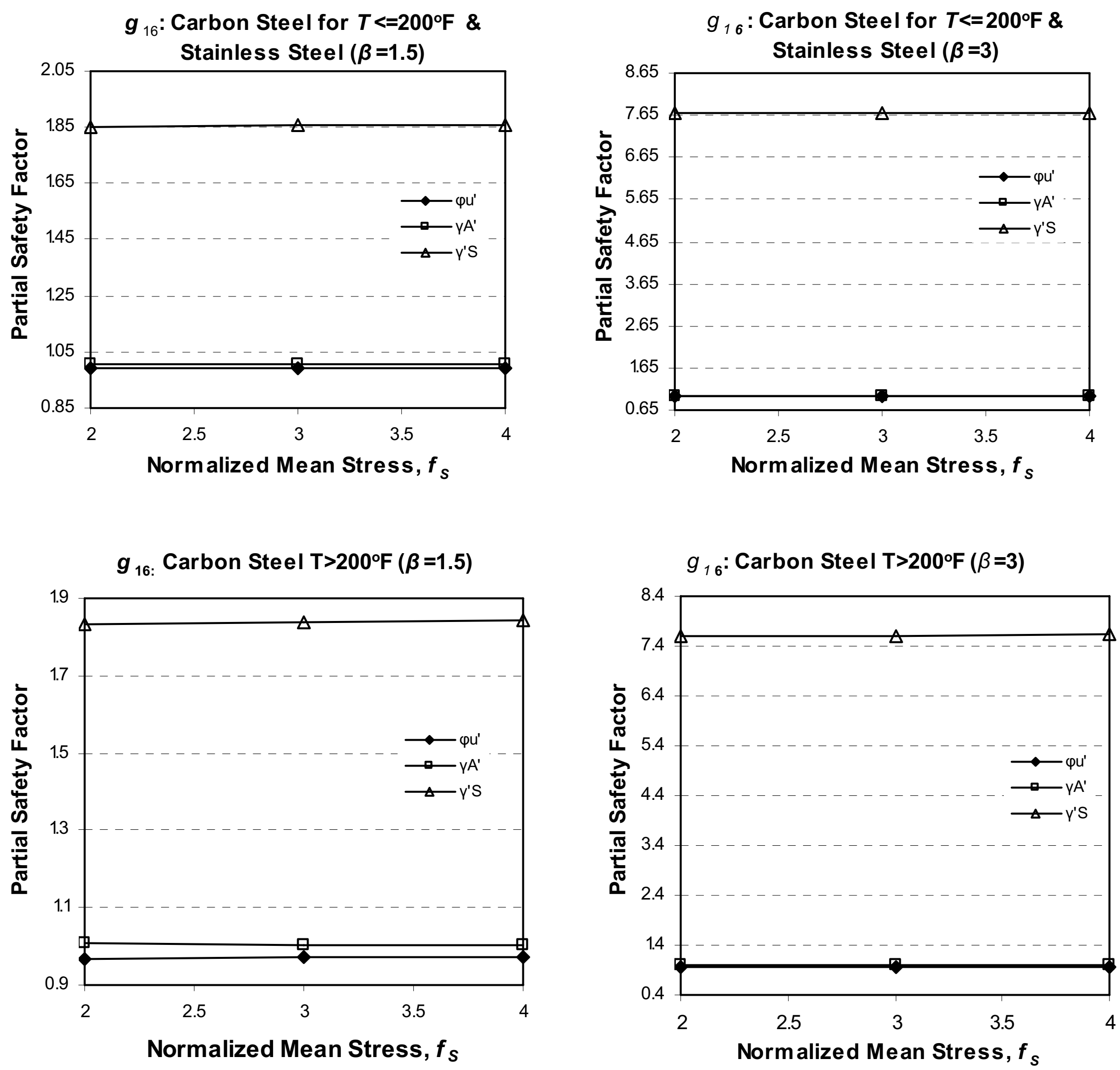


Figure 6-19: Mean Partial Safety Factors for β=1.5 and 3 for g_{16}

Table 6-29: Recommended[(1)] Values and Ranges for the Adjusted Nominal Resistance Factor for g_{16}

β	φ_u for γ_A=1.1 & γ_S=1.5 CARBON STEEL	STAINLESS STEEL
	T≤600°F	***Room Temperature***
1.5	**0.90**[(2)] (0.86 to 0.98)	**0.95**[(2)] (0.92 to 0.96)
2	**0.85** (0.78 to 0.89)	**0.85** (0.84 to 0.87)
3	**0.30** (0.25 to 0.36)	**0.35** (0.32 to 0.35)
	800°F	***200°F***
1.5	**0.90** (0.93)	**0.80**[(2)] (0.80 to 0.83)
2	**0.65** (0.65 to 0.67)	**0.75** (0.73 to 0.76)
3	**0.25** (0.25 to 0.27)	**0.30** (0.28 to 0.30)
		≥400°F
1.5		**0.94** (0.91 to 0.94)
2		**0.65** (0.64 to 0.68)
3		**0.25** (0.24 to 0.26)

(1) Recommended values are in bold face, (2) γ_A=1.1 and γ_S=1.1

6.3.5.2. Performance Function g_{17}

This performance function checks pressurized pipes subjected to the Safe Shut-Down Earthquake (SSE). Table 6-30 presents the probabilistic characteristics for the parameters in the performance function, given by Eq. (6-22).

$$g_{17} = f_u - f_A - f_{PS} - f_S \quad (6\text{-}22)$$

Table C-30 gives the mean partial load and resistance factors for different operating temperature, values of β, and types of steel. The calculated adjusted nominal resistance factor is presented for all cases in Table C-31. A summary with the recommended values for the adjusted nominal resistance factor is shown herein in Table 6-31.

Table 6-30: Parameters for the Calculations for g_{17}

Parameter	Statistical Properties	Examined Range	Recommended Value	Distribution
β	na	na	1.5, 2, 3	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PS}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_S	Mean *COV* Bias	0.5 to 2.5 0.40 to 0.90 0.60 to 1.00	2, 3, 4, 4.5 0.80 0.75	Extreme II (Largest)
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Table 6-31: Recommended Values[1] and Ranges for the Adjusted Nominal Resistance Factor for g_{17}

β	**φ_u for γ_A=1.1, γ_{PS}=1.2 & γ_S=1.5** CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2	• For $f_{PS}\leq3$ or for $3\leq f_{PS}<10$ and $f_S\geq3$ **0.68**[2] (0.57to 0.79) • Otherwise **0.92**[2] (0.85 to 0.95)	• For $f_{PS}\leq3$ or for $3<f_{PS}\leq5$ and $f_S\geq3$ **0.66**[2] (0.56 to 0.77) • For f_{PS}=5 and f_S=2 or for $5<f_{PS}\leq10$ **0.87**[2] (0.82 to 0.92) • Otherwise **0.92**[2] (0.92 to 0.93)
2.5	• For $f_{PS}\leq3$ or for $3<f_{PS}\leq5$ and $f_S\geq3$ **0.68** (0.58to 0.79) • For f_{PS}=5 and f_S=2 or for $5<f_{PS}\leq10$ **0.93** (0.86 to 1.00) • Otherwise **1.06** (1.06 to 1.10)	• For $f_{PS}\leq3$ or for $3<f_{PS}\leq5$ and $f_S\geq3$ **0.68** (0.57 to 0.78) • For f_{PS}=5 and f_S=2 or for $5<f_{PS}\leq10$ **0.92** (0.84 to 0.99) Otherwise **1.06**[2] (1.04 to 1.08)
3	• For $f_{PS}\leq3$ or for $3<f_{PS}\leq5$ and $f_S\geq3$ **0.44** (0.34 to 0.53) • For f_{PS}=5 and f_S=2 or for $5<f_{PS}\leq10$ **0.68** (0.59 to 0.76) • Otherwise **1.00** (0.99 to 1.02)	• For $f_{PS}\leq3$ or for $3<f_{PS}\leq5$ and $f_S\geq3$ **0.46** (0.34 to 0.57) • For f_{PS}=5 and f_S=2 or for $5<f_{PS}\leq10$ **0.66** (0.58 to 0.75) • Otherwise **0.98**[2] (0.97 to 1.00)

Table 6-31: (Continued)

β	φ_u for γ_A=1.1, γ_{PS}=1.2 & γ_S=1.5 CARBON STEEL	 STAINLESS STEEL
	200°F	***200°F***
2	• For f_{PS}≤3 or for 3≤f_{PS}<10 and f_S≥3 **0.62**(2) (0.52 to 0.72) • Otherwise **0.83**(2) (0.78 to 0.87)	• For f_{PS}≥10 and f_S≤3 or for f_{PS} =50 and f_S=50 **0.80**(2) (0.80 to 0.81) • Otherwise **0.62**(2) (0.51 to 0.72)
2.5	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.63** (0.53to 0.72) • For f_{PS}=5 and f_S=2 or for 5≤f_{PS}≤10 and f_S≥3 **0.86** (0.80 to 0.92) • Otherwise **1.00** (0.97 to 1.05)	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.58** (0.49 to 0.67) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 and f_S≥3 **0.75** (0.73 to 0.78) • Otherwise **0.91** (0.86 to 0.93)
3	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.40** (0.31 to 0.48) • For f_{PS}=5 and f_S=2 or for 5≤f_{PS}≤10 and f_S≥3 **0.62** (0.54 to 0.70) • Otherwise **0.92** (0.91 to 0.93)	• For f_{PS}≤5 and f_S≥3 or for 3<f_{PS}≤5 and f_S≥3 or for f_{PS}≤0.5 and f_S<3 **0.37** (0.29 to 0.45) • For f_{PS}>10 **0.85** (0.85 to 0.87) • Otherwise **0.57** (0.50 to 0.65)
	400°F	***≥400°F***
2	• For f_{PS}≤3 or for 3≤f_{PS}<10 and f_S≥3 **0.68**(2) (0.58 to 0.78) • Otherwise **0.89**(2) (0.84 to 0.92)	• For f_{PS}≤1 **0.70** (0.65 to 0.74) • For 1<f_{PS}≤5 **0.79** (0.72 to 0.86) • Otherwise **0.87** (0.85 to 0.91)
2.5	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.68** (0.58to 0.79) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.93** (0.86 to 1.00) • Otherwise **1.03** (1.02 to 1.05)	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.55** (0.43 to 0.67) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.70** (0.64 to 0.77) • Otherwise **0.81** (0.79 to 0.84)
3	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.44** (0.36 to 0.53) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.68** (0.59 to 0.76) • Otherwise **0.95** (0.94 to 0.97)	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.32** (0.25 to 0.40) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.51** (0.44 to 0.58) • Otherwise **0.75** (0.73 to 0.76)
	600°F	
2	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.64**(2) (0.54 to 0.74) • Otherwise **0.84**(2) (0.79 to 0.87)	
2.5	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.65** (0.54to 0.75) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.88** (0.81 to 0.94) • Otherwise **0.96** (0.94 to 0.98)	

Table 6-31: (Continued)

β	CARBON STEEL
	600°F
3	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.40** (0.32 to 0.49) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.68** (0.59 to 0.76) • Otherwise **0.90** (0.89 to 0.91)
	800°F
2	• For f_{PS}≤3 or for 3≤f_{PS}<10 and f_S≥3 **0.74**(2) (0.67 to 0.80) • Otherwise **0.86**(2) (0.84 to 0.89)
2.5	• For f_{PS}≤3 or for 3<f_{PS}≤10 and f_S≥3 **0.68** (0.58to 0.79) • Otherwise **0.76** (0.73 to 0.79)
3	• For f_{PS}≤3 or for 3<f_{PS}≤5 and f_S≥3 **0.33** (0.26 to 0.40) • For f_{PS}=5 and f_S=2 or for 5<f_{PS}≤10 **0.50** (0.45 to 0.57) • Otherwise **0.72** (0.71 to 0.73)

(1) Recommended values are in bold face (2) $\gamma_A = \gamma_{PS}$=1.0 & γ_S=0.9

6.3.5.3. Performance Function g_{18}

This performance considers the loading of pipes that are pressurized and subjected to mehanical load due to LOCA. The normalized performance function is given by Eq. (6-23), where f_u is the normalized ultimate strength of steel, f_A the normalized sustained weight, f_{PD} the normalized stress due to pressure under Service Level D operation, and f_L the normalized stress of a mechanical load due to LOCA.

$$g_{18} = f_u - f_A - f_{PD} - f_L \qquad (6\text{-}23)$$

Table 6-32 provides the probabilistic characteristics for the variables under consideration and the recommended values used for the calculation of mean partial safety factors. Table C-32 provides the calculated mean partial factors for all the examined cases. Table C-33 gives the adjusted nominal resistance factors. The recommended nominal resistance factors are given in Table 6-33 by summarizing results in Table C-33.

Table 6-32: Parameters for the Calculations for g_{18}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	3, 4, 5.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_L	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.20 0.85	Extreme I (Largest)
f_{PD}	Mean *COV* Bias	0.5 to 50* NA NA	0.5, 1, 3, 5, 10, 50 0.20 0.80	Extreme I (Largest)
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, * The value of 50 is shown, whereas the same results are obtained also for values greater than 50.

Figure 6-20 presents the variation of the mean partial safety factors (φ'_u, γ'_A, γ'_{PD}, γ'_L for the ultimate strength of steel, the sustained weight, the internal pressure and mechanical loading due to LOCA, respectively) with respect to normalized pressure for f_L=1 and β=3 and 5.5. On the other hand, Figure 6-21 gives the variation of the mean partial safety factors with respect to mechanical loading due to LOCA for f_{PD}=0.5 and β=3 and 5.5.

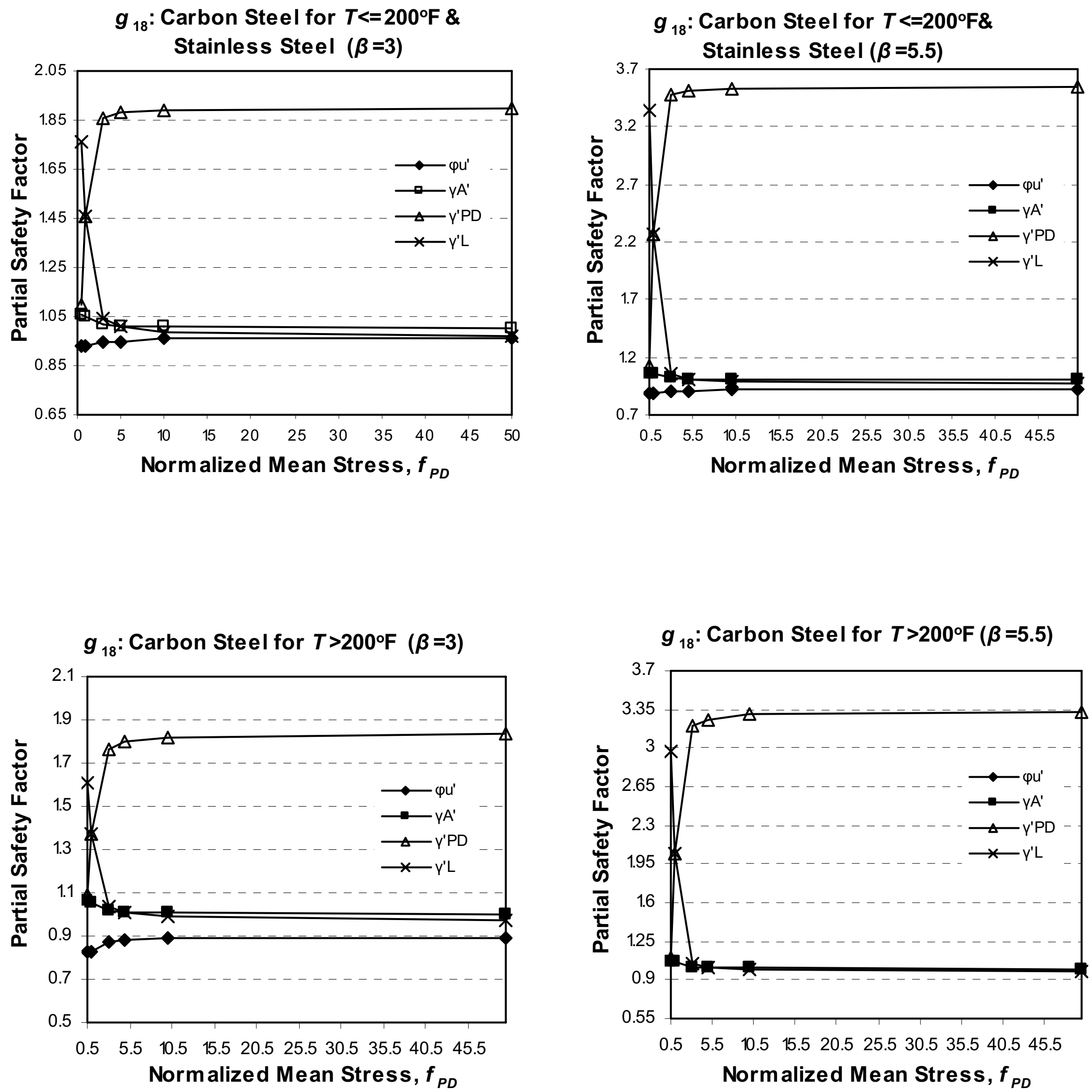


Figure 6-20: Variation of Mean Partial Safety Factors with Respect to the Normalized Pressure for f_L=1 and β=3 and 5.5

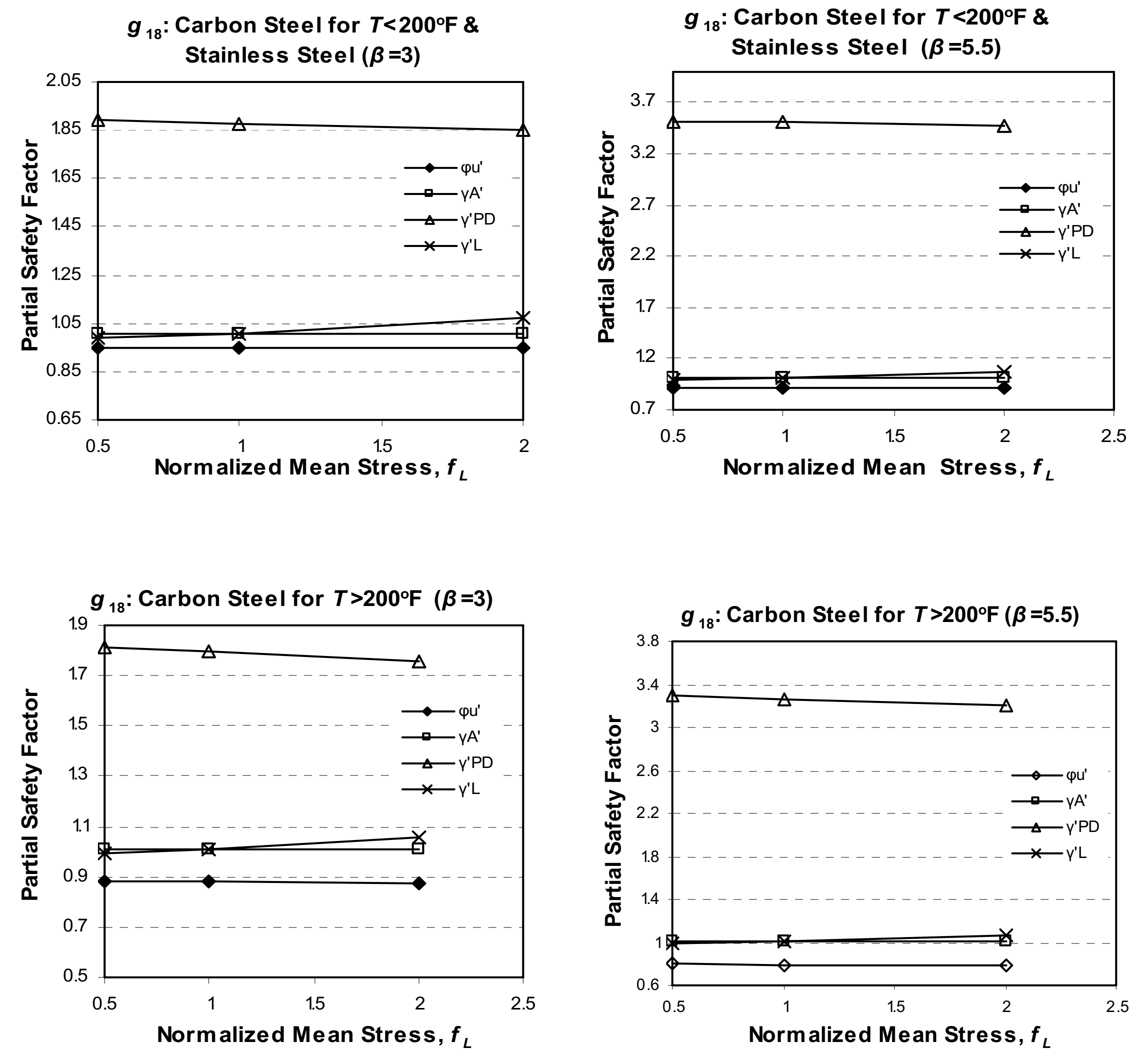


Figure 6-21: Variation of Mean Partial Safety Factors with Respect to the Normalized Stress due to LOCA for f_{PB}=5 and β=3 and 5.5

Table 6-33: Ranges and Recommended[1] Adjusted Nominal Resistance Factors for g_{18}

β	φ_u for γ_A=1.1, γ_L=1.3 and γ_{PD}=1.2 CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
3	• For 0.5<f_{PD}≤3 and f_L≥2 or for f_{PD}≤1 and f_L<2 **0.99**[2] (0.95 to 1.03) • For f_{PD}≥5 and f_L≤0.5 or f_{PD}≥10 **0.84**[2] (0.81 to 0.87) • Otherwise **0.90** (0.89 to 0.93)	• For f_{PD}≤1 and f_L≤1 or for 1≤f_{PD}≤3 and f_L>1 or **0.97**[2] (0.94 to 1.01) • For f_{PD}≥10 and f_L≤1 **0.81**[2] (0.79 to 0.83) • Otherwise **0.88**[2] (0.85 to 0.91)
4	• For f_{PD}≤1 and f_L≤1 **0.94** (0.91 to 0.97) • For f_{PD}≥10 and f_L<2 or for f_{PD}=50 and f_L=2 **0.70** (0.67 to 0.72) • For f_{PD}≤5 and f_L≥2 or for f_{PD}=3 and f_L=2 **0.85** (0.82 to 0.87) • Otherwise **0.72** (0.74 to 0.78)	• For f_{PD}≤1 and f_L≤1 or **0.92** (0.89 to 0.96) • For f_{PD}=10 and f_L≤0.5 or for f_{PD}>10 **0.64** (0.61 to 0.67) • For f_{PD}≤5 and f_L>1 or for f_{PD}=3 and f_L=1 **0.84** (0.81 to 0.88) • Otherwise **0.74** (0.71 to 0.77)
5.5	• For f_{PD}≤0.5 and f_L≤0.5 **0.79** • For f_{PD}≤1 and f_L≤1 **0.72** (0.70 to 0.75) • For f_{PD}≤5 and f_L≥2 **0.63** (0.60 to 0.66) • For f_{PD}≥10 or for f_{PD}=5 and f_L=0.5 **0.50** (0.46 to 0.53) • Otherwise **0.57** (0.54 to 0.60)	• For f_{PD}≥10 **0.48** (0.45 to 0.52) • For f_{PD}≤5 and f_L>1 **0.62** (0.59 to 0.65) • For f_{PD}≤0.5 and f_L≤0.5 **0.78** • For 0.5<f_{PD}≤1 and f_L≤0.5 or for f_{PD}≤1 and 0.5<f_L≤1 **0.71** (0.69 to 0.74) • Otherwise **0.55** (0.51 to 0.59)
	200°F	***200°F***
3	• For f_{PD}≥5 and f_L≤0.5 or f_{PD}≥10 **0.76**[2] (0.73 to 0.80) • for f_{PD}≤0.5 and f_L<2 or for f_{PD}=1.0 and f_L=1.0 **0.92**[2] (0.90 to 0.94) • Otherwise **0.84**[2] (0.81 to 0.87)	• For f_{PD}≤1 and f_L≤1 or for 1≤f_{PD}≤3 and f_L>1 or **0.84**[2] (0.81 to 0.87) • For f_{PD}≥10 **0.71**[2] (0.69 to 0.74) • Otherwise **0.76**[2] (0.74 to 0.79)
4	• For f_{PD}≥5 and f_L≤0.5 or f_{PD}≥10 **0.65** (0.61 to 0.69) • For f_{PD}≤1 an1 f_L≤1 or f_{PD}=3 an1 f_L=2 **0.85** (0.82 to 0.89) • Otherwise **0.73** (0.71 to 0.76)	• For f_{PD}≥10 **0.60** (0.57 to 0.64) • For f_{PD}≤5 and f_L>1 or for f_{PD}=3 and f_L=1 **0.73** (0.70 to 0.76) • For f_{PD}≤1 and f_L≤1 **0.80** (0.77 to 0.83) • Otherwise **0.63** (0.60 to 0.66)
5.5	• For f_{PD}>10 **0.42** (0.42 to 0.43) • For f_{PD}=10 or for f_{PD}≥5 and f_L≤0.5 **0.46** (0.44 to 0.48) • For f_{PD}≤0.5 and and f_L≤0.5 **0.72** • For f_{PD}≤1 and and f_L≤1 **0.66** (0.64 to 0.68) • For f_{PD}≤5 and and f_L>1 **0.57** (0.54 to 0.60) • Otherwise **0.52** (0.50 to 0.55)	• For f_{PD}≥10 **0.42** (0.39 to 0.45) • For f_{PD}≤5 and f_L>1 **0.54** (0.51 to 0.57) • For f_{PD}≤0.5 and f_L≤0.5 **0.68** • For 0.5<f_{PD}≤1 and f_L≤0.5 or for f_{PD}≤1 and 0.5<f_L≤1 or for f_{PD}=3 and f_L=1 **0.56** (0.54 to 0.59) • Otherwise **0.44** (0.41 to 0.47)

Table 6-33: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	400°F	***≥400°F***
3	• For $f_{PD} \geq 10$ **0.82**[2] (0.79 to 0.85) • For For $f_{PD} \leq 0.5$ and $f_L \leq 0.5$ **0.97**[2] • For $f_{PD} \leq 1$ and and $f_L \leq 1$ or for $1 \leq f_{PD} \leq 5$ and and $f_L > 1$ **0.93**[2] (0.90 to 0.96) Otherwise **0.87**[2] (0.84 to 0.90)	• For $f_{PD} \leq 1$ and $f_L \leq 1$ **0.74**[2] (0.71 to 0.78) • For $f_{PD} \geq 10$ **0.62**[2] (0.60 to 0.65) • For $1 \leq f_{PD} \leq 5$ and $f_L > 1$ **0.71**[2] (0.69 to 0.74) • Otherwise **0.67**[2] (0.64 to 0.71)
4	• For $f_{PD} \geq 10$ **0.65** (0.62 to 0.69) • For For $f_{PD} \leq 0.5$ and $f_L \leq 0.5$ **0.90** • For $f_{PD} \leq 1$ and and $f_L \leq 1$ or for $1 \leq f_{PD} \leq 3$ and and $f_L > 1$ **0.86** (0.84 to 0.89) • For $3 < f_{PD} \leq 5$ and and $f_L > 1$ or for $f_{PD} \leq 0.5$ and and $f_L > 1$ **0.79** • Otherwise **0.72** (0.70to 0.75)	• For $f_{PD} \leq 0.5$ and $f_L \leq 0.5$ **0.72** (0.72 to 0.74) • For $f_{PD} \leq 1$ and $0.5 < f_L \leq 1$ or For $f_L \leq 0.5$ and $0.5 < f_{PD} \leq 1$ **0.70** (0.67 to 0.73) • For $f_{PD} \leq 10$ or for $f_{PD} = 5$ and $f_L = 0.5$ **0.54** (0.50 to 0.58) • Otherwise **0.64** (0.60 to 0.68)
5.5	• For $f_{PD} \geq 10$ **0.46** (0.43 to 0.50) • For For $f_{PD} \leq 0.5$ and $f_L \leq 0.5$ **0.72** • For $f_{PD} \leq 1$ and and $f_L \leq 1$ or for $1 \leq f_{PD} \leq 3$ and and $f_L > 1$ **0.63** (0.61 to 0.65) • For $3 < f_{PD} \leq 5$ and and $f_L > 1$ or for $f_{PD} \leq 0.5$ and and $f_L > 1$ **0.56** (0.56 to 0.57) • Otherwise **0.52** (0.49 to 0.56)	• For $f_{PD} \leq 10$ or for $f_{PD} = 5$ and $f_L = 0.5$ **0.37** (0.34 to 0.40) • For $f_{PD} \leq 0.5$ and $f_L \leq 0.5$ **0.60** (0.59 to 0.61) • For $f_{PD} \leq 1$ and $0.5 < f_L \leq 1$ or For $f_L \leq 0.5$ and $0.5 < f_{PD} \leq 1$ **0.55** (0.52 to 0.57) • For $f_{PD} \leq 3$ and $f_L > 1$ **0.48** (0.45 to 0.51) • Otherwise **0.43** (0.40 to 0.46)
	600°F	
3	• For $f_{PD} \leq 1$ and and $f_L \leq 1$ or for $1 \leq f_{PD} \leq 5$ and and $f_L > 1$ **0.88**[2] (0.85 to 0.91) • For $f_{PD} \geq 10$ **0.77** (0.74 to 0.80) • Otherwise **0.82** (0.79 to 0.85)	
4	• For $f_{PD} \leq 1$ and and $f_L \leq 1$ or for $1 \leq f_{PD} \leq 3$ and and $f_L > 1$ **0.82**[2] (0.79 to 0.85) • For $f_{PD} \geq 10$ **0.6** (0.61 to 0.68) • For $3 \leq f_{PD} \leq 5$ and and $f_L \leq 1$ **0.68**[2] (0.67 to 0.70) • Otherwise **0.72**[2] (0.70 to 0.75)	
5.5	• For $f_{PD} \leq 1$ and and $f_L \leq 1$ **0.64** (0.61 to 0.67) • For $f_{PD} \leq 5$ and and $f_L > 2$ or for **0.55** (0.53 to 0.58) • For $f_{PD} \geq 10$ **0.44** (0.41 to 0.47) • Otherwise **0.52** (0.49 to 0.56)	

Table 6-33: (Continued)

β	CARBON STEEL
	800°F
3	• For f_{PD}≤1 and and f_L≤1 or for f_{PD}=3 and f_L=2 **0.72**(2) (0.71 to 0.73) • For f_{PD}≥10 **0.61**(2) (0.59 to 0.64) • Otherwise **0.66**(2) (0.63 to 0.69)
4	• For f_{PD}≤1 and and f_L≤1 **0.66** (0.65 to 0.68) • For f_{PD}≤5 and and f_L>2 or for **0.62** (0.60 to 0.64) • For f_{PD}≥10 **0.52** (0.49 to 0.55) • Otherwise **0.56** (0.54 to 0.59)
5.5	• For f_{PD}≤1 and and f_L≤1 **0.51** (0.48 to 0.54) • For f_{PD}≤5 and and f_L>2 or for **0.44** (0.42 to 0.47) • For f_{PD}≥10 **0.35** (0.33 to 0.38) • Otherwise **0.39** (0.37 to 0.42)

(1) Recommended values are in bold face (2) γ_A=1.1, γ_L=1.1 and γ_{PD}=1.1

6.3.5.4. Performance Function g_{19}

This performance function checks pressurized pipes subjected to the SSE and loading resulted from LOCA. Table 6-34 presents the probabilistic characteristics for the parameters used in the performance function, given by Eq. (6-24) where f_{PS} is the normalized stress due the pressure coincident with the SSE, f_u the normalized ultimate strength of steel, f_S the normalized stress due to SSE, and f_L the normalized bending stress due to LOCA. Moreover, E is a factor applied to the combination of the dynamic loads that in this study is not examined and considered equal to 1 as explained in Chapter 5.

$$g_{19} = f_u - f_A - f_{PS} - E(f_S + f_L) \qquad (6\text{-}24)$$

Table 6-34 gives the parameters used in the computations. Table C-34 gives the mean partial load and resistance factors for different operating temperature, values of β, and types of steel. The calculated adjusted nominal resistance factors are presented for all cases in Table C-35. A summary and the recommended values for the adjusted nominal resistance factor are shown herein in Table 6-35.

Table 6-34: Parameters for the Calculations for g_{19}

Parameter	Statistical Properties	Range	Recommended Value	Distribution
β	na	na	1.5, 2.5	na
f_A	Mean *COV* Bias	NA 0.05 to 0.10 1 to 1.05	1 0.10 1	Normal
f_{PS}	Mean *COV* Bias	0.5 to 50* 0.10 to 0.14 NA	0.5, 1, 3, 5, 10, 50 0.13 0.95	Lognormal
f_S	Mean *COV* Bias	2 to 4 0.40 to 0.90 0.65 to 1	2, 3, 4 0.80 0.75	Extreme II (Largest)
f_L	Mean *COV* Bias	0.5 to 2 NA 0.80 to 1.05	0.5, 1, 2 0.20 0.85	Lognormal
E	NA	NA	1.0	NA
f_u	Mean *COV* Bias	NA Table 3-10 Table 3-10	NA Table 3-10 Table 3-10	Lognormal

NA=Not Available, na=not applicable, *The value of 50 is shown, whereas the same results are obtained also for values greater than 50

Table 6-35: Recommended[1] Values and Ranges for the Adjusted Nominal Resistance Factor for g_{19}

β	φ_u **for** γ_A**=1.1,** γ_{PS}**=1.2,** γ_L**=1.3 &** γ_S**=1.5**	
	CARBON STEEL	STAINLESS STEEL
	Room Temperature	***Room Temperature***
2.5[2]	• For $f_{PS}\leq1$, $f_S>2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq1$, $f_S=2$, and $f_L=0.5$ **0.67** (0.63 to 0.71) • For $f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.98** (0.94 to 1.04) • For $f_{PS}>10$ **0.90** (0.88 to 0.94) • Otherwise **0.83** (0.72 to 0.94)	• For $f_{PS}\leq1$, $f_S>2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq1$, $f_S=2$, and $f_L=0.5$ **0.65** (0.61 to 0.69) • For $f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.98** (0.94 to 1.02) • For $f_{PS}>10$ **0.90** (0.87 to 0.92) • Otherwise **0.83** (0.71 to 0.95)
3.0	• For $f_{PS}>10$ **0.99** (0.98 to 1.02) • For $f_{PS}\leq1$, and $f_S\geq2$ or for $f_{PS}\leq0.5$, $f_S\leq1$, and $f_L\leq1$ or for $1<f_{PS}\leq5$ and $f_S>2$ or for $f_L\leq1$ and $f_S=2$ **0.50** (0.39 to 0.60) • For $5<f_{PS}\leq10$ and $f_S\leq1$ or for $f_{PS}=3$, $f_S=1$, and $f_L=2$ **0.92** (0.83 to 1.02) • Otherwise **0.73** (0.63 to 0.83)	• For $f_{PS}>10$ **0.98** (0.96 to 1.01) • For $f_{PS}\leq1$, and $f_S\geq2$ or for $f_{PS}\leq0.5$, $f_S\leq1$, and $f_L\leq1$ or for $1<f_{PS}\leq5$ and $f_S>2$ or for $f_L\leq1$ and $f_S=2$ **0.48** (0.38 to 0.59) • For $5<f_{PS}\leq10$ and $f_S\leq1$ or for $f_{PS}=3$, $f_S=1$, and $f_L=2$ or **0.90** (0.81 to 1.00) • Otherwise **0.72** (0.62 to 0.82)
	200°F	***200°F***
2.5[2]	• For $f_{PS}\leq1$, $f_S>2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq1$, $f_S=2$, and $f_L=0.5$ **0.59** (0.51 to 0.67) • For $f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.91** (0.86 to 0.95) • Otherwise **0.77** (0.70 to 0.88)	• For $f_{PS}\leq1$, $f_S>2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq1$, $f_S=2$, and $f_L=0.5$ **0.65** (0.53 to 0.60) • For $f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.57** (0.70 to 0.89) • For $f_{PS}>10$ **0.77** (0.75 to 0.80) • Otherwise **0.72** (0.61 to 0.82)
3.0	• For $f_{PS}\leq1$, $f_S\geq2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq0.5$ and $f_S\leq1$ **0.41** (0.35 to 0.48) • For $3\leq f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.85** (0.76 to 0.93) • For $f_{PS}>10$ **0.91** (0.89 to 0.94) • Otherwise **0.63** (0.50 to 0.77)	• For $f_{PS}\leq1$, $f_S>2$, and $f_L\leq1$ or for $f_{PS}=3$, $f_S>2$, and $f_L=0.5$ or for $f_{PS}\leq1$, $f_S=2$, and $f_L=0.5$ **0.37** (0.33 to 0.41) • For $3\leq f_{PS}\leq10$, $f_L>1$and $f_S\leq1$ or for $5\leq f_{PS}\leq10$, $f_L\leq1$, and $f_S\leq1$ **0.78** (0.69 to 0.87) • For $f_{PS}>10$ **0.85** (0.83 to 0.87) • Otherwise **0.58** (0.45 to 0.71)

Table 6-35: (Continued)

β	CARBON STEEL	STAINLESS STEEL
	400°F	***≥400°F***
2.5(2)	• For f_{PS}≤1, f_S>2, and f_L≤1 or for f_{PS}=3, f_S>2, and f_L=0.5 or for f_{PS}≤1, f_S=2, and f_L=0.5 **0.67** (0.63 to 0.71) • For f_{PS}≤10, f_L>1and f_S≤1 or for 5≤f_{PS}≤10, f_L≤1, and f_S≤1 **0.98** (0.94 to 1.02) • For f_{PS}>10 **0.85** (0.73 to 0.96) • Otherwise **0.83** (0.72 to 0.94)	• For f_{PS}≤3 and f_S≥2 or for f_{PS}≤0.5, f_S<2 and f_L≤1 or for 3<f_{PS}≤5, f_S≥2 and f_L≤1 or for 3<f_{PS}≤5, f_S>2 and f_L>1 **0.56** (0.46 to 0.66) • Otherwise **0.70** (0.62 to 0.80)
3.0	• For f_{PS}>10 **0.82** (0.80 to 0.85) • For f_{PS}≤1, and f_S≥2 or for f_{PS}≤0.5, f_S≤1, and f_L≤1 or for 1<f_{PS}≤5 and f_S>2 or for f_L≤1 and f_S=2 **0.48** (0.39 to 0.56) • For 5<f_{PS}≤10 and f_S≤1 or for f_{PS}=3, f_S=1, and f_L=2 **0.93** (0.83 to 1.04) • Otherwise **0.68** (0.57 to 0.80)	• For f_{PS}≤3 and f_S≥2 or for 3<f_{PS}≤5, f_S>2 or for f_{PS}≤1, f_S<2, and f_L≤1 **0.37** (0.29 to 0.46) • For f_{PS}≥10 and f_S≥1 or or for f_{PS}>10 **0.75** (0.72 to 0.78) • Otherwise **0.58** (0.47 to 0.69)
	600°F	
2.5(2)	• For f_{PS}≤1, and f_S≥2 or for f_{PS}≤0.5, f_S≤1, and f_L≤1 or for 1<f_{PS}≤5 and f_S>2 or for f_L≤1 and f_S=2 **0.66** (0.59 to 0.73) • For f_{PS}≤10, f_L>1and f_S≤1 or for 5≤f_{PS}≤10, f_L≤1, and f_S≤1 **0.92** (0.89 to 0.96) • Otherwise **0.77** (0.69 to 0.90)	
3.0	• For f_{PS}≤1, f_S≥2, and f_L≤1 or for 1<f_{PS}≤3, f_S≥2, and f_L≤1 or for f_S≤1 and f_{PS}=f_L≤0.5 or for f_{PS}≤3, f_L=2, and f_S>2, **0.46** (0.36 to 0.56) • For 3≤f_{PS}≤10, f_L>1and f_S≤1 or for 5≤f_{PS}≤10, f_L≤1, and f_S≤1 **0.87** (0.76 to 0.98) • For f_{PS}>10 **0.90** (0.88 to 0.92) • Otherwise **0.69** (0.60 to 0.78)	

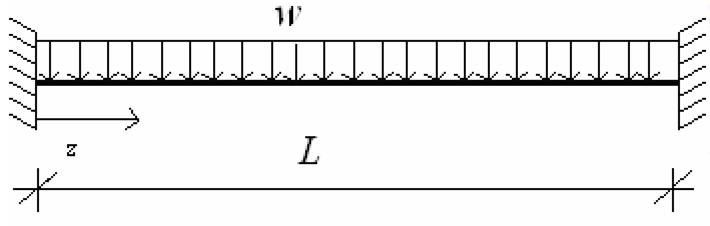
Table 6-35: (Continued)

β	CARBON STEEL
	800°F
2.5[(2)]	• For f_{PS}≤5, and f_S≥2 or for f_{PS}≤0.5, f_S≤1, and f_L≤1 or **0.56** (0.47 to 0.65) • For f_{PS}>10, **0.66** (0.64 to 0.68) • Otherwise **0.70** (0.63 to 0.77)
3.0	• For f_{PS}≤1, f_S≥2, and f_L≤1 or for 1<f_{PS}≤3, f_S≥2, and f_L≤1 or for f_S≤1 and f_{PS}=f_L≤0.5 or for f_{PS}≤3, f_L=2, and f_S>2, **0.38** (0.29 to 0.46) • For 3≤f_{PS}≤10, f_L>1and f_S≤1 or for 5≤f_{PS}≤10, f_L≤1, and f_S≤1 **0.70** (0.61 to 0.78) • For f_{PS}>10 **0.71** (0.70 to 0.73) • Otherwise **0.58** (0.47 to 0.68)

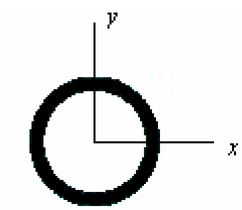
(1) Recommended values are in bold face, (2) γ_A=1.1, γ_{PS}=1.0, γ_L=1.3 & γ_S=1.5

6.4. Computational Example

Figure 6-22 shows a Class 2 straight piping segment anchored at both ends (e.g., pipe between two tanks) that should be designed to withstand the loads for Service Levels A, B, and D given in Table 6-36. Loading is given readily in the form of moments.



(a)



(b)

Figure 6-22: (a) A Piping Segment with Anchored Ends and (b) Cross-Section Used for Sample Computations

Table 6-36: Data for Example Computations

Material	SA312, Type 304
Yield Strength, S_y^*=	30 ksi
Ultimate Strength, S_u^*=	75 ksi
D_o=	12.75 in
t=	0.375 in
L=	236 in
Z=	43.82 in^3
Z_P=	57.46 in^3
Design Temperature=	200 ^{o}F
P_{Des}=	820 psi
P_{max}=	845 psi
P_O=	1,080 psi
P_B=	1,080 psi
P_S=	1,350 psi
M_x^A=	46,420 lb-in
**M_x^M=	36,000 lb-in
M_x^O=	75,000 lb-in
M_y^O=	80,000 lb-in
M_x^S=	140,000 lb-in
M_y^S=	150,000 lb-in

*Values obtained from ASME B&PV Code, Part II
**Loading under Service Level B conditions

Loading Nomenclature:

M_x^A=Moment due to sustained weight
M_x^O, M_y^O =Moments due to OBE
M_x^S, M_y^S=Moments due to SSE
M_x^M=Moment due to an instantaneous valve closure
P_{Des}=Design Pressure
P_{max}=Maximum Operating Pressure
P_B=Pressure under Service Limit B loading
P_O=Pressure coincident with OBE
P_S=Pressure coincident with SSE

Initially, in Table 6-37 the normalized nominal stresses are evaluated and using the appropriate bias factor, they are converted into mean normalized stresses. This procedure is necessary in order to choose the appropriate factors for the LRFD. Computation results according to the derived LRFD equations are given in Table 6-38. Values of the reliability index β are arbitrary chosen. The symbols used are similar to the ones in the previous sections.

Table 6-37: Nominal and Mean Normalized Stresses

Symbol	Nominal Normalized Stress [1]	Bias [2]	Mean Normalized Stress [1]x[2]
f_A	1	1	1
f_{PDes}	6.58	1	6.6
f_{Pmax}	6.76	0.95	6.4
$f_{PO}=f_{PB}$	11.36	0.95	10.8
f_{PS}	14.20	0.95	13.5
f_M	0.77	1	0.8
f_O	2.36	0.75	1.8
f_S	4.42	0.75	3.3

Table 6-38: Computations with the Developed LRFD Equations

Service Level	P.F.*	β	LRFD Equation
Design	g_2	6	$0.45S_y \ge 1.2\frac{M_A}{Z}$ or $13{,}500\text{psi} \ge \frac{(1.2)46{,}420}{43.82} = 1{,}271.20\text{psi}$
	g_3	3.5	$0.70S_y \ge 1.1\frac{M_A}{Z} + 1.2\frac{P_{PDes}D_o}{4t}$ or $21{,}000 \ge \frac{1.1(46{,}420)}{43.82} + \frac{1.2(820)(12.75)}{4(0.375)}$ or $21{,}000\text{psi} \ge 9{,}529.3$ psi
A	g_4	3.5	$f_{Pmax}=6.4>5$ $0.66S_y \ge 1.1\frac{M_A}{Z} + 1.2\frac{P_{\max}D_o}{4t}$ or $19{,}800\text{psi} \ge \frac{1.1(46{,}420)}{43.82} + \frac{1.2(845)(12.75)}{4(0.375)} = 9{,}784.3$ psi
B	g_6	3.5	$0.72S_y \ge 1.1\frac{M_A}{Z_P} + 1.2\frac{P_{PB}D_o}{4t} + 1.2\frac{M_M}{Z_P}$ or $21{,}600\ psi \ge \frac{1.1(46{,}420)}{57.46} + \frac{1.2(845)(12.75)}{4(0.375)} + \frac{1.2(36{,}000)}{57.46} = 10{,}259$ psi
	g_7	3	$M_O = \sqrt{(M_x{}^o)^2 + (M_y{}^o)^2} = 109{,}660$ lb in $0.35S_y \ge 1.1\frac{M_A}{Z_P} + 1.5\frac{M_O}{Z_P}$ or $10{,}500 \ge \frac{1.1(46{,}420)}{57.46} + \frac{1.5(109{,}660)}{57.46} = 3{,}751$ psi
	g_8	3	$f_{PO}=10.8$ and $f_O=1.8$ $0.74\,S_y \ge 1.1\frac{M_A}{Z_P} + 1.2\frac{P_O D_o}{4t} + 1.5\frac{M_O}{Z_P}$ $22{,}200\,psi \ge 1.1\frac{(46{,}420)}{57.46} + 1.2\frac{(1{,}080)(12.75)}{4(0.375)} + 1.5\frac{(109{,}660)}{57.46} = 14{,}767$ psi
	g_9	2.5	$f_{PO}=10.8$, $f_O=1.8$, and $f_M=0.8$ $0.87\,S_y \ge 1.0\frac{M_A}{Z_P} + 1.0\frac{P_O D_o}{4t} + 1.0\frac{M_M}{Z_P} + 0.9\frac{M_O}{Z_P}$ $26{,}100 \ge \frac{46{,}420}{57.46} + \frac{(1{,}080)(12.75)}{4(0.375)} + \frac{36{,}000}{57.46} + 0.9\frac{109{,}660}{57.46} = 12{,}333$ psi

*P.F.=Performance Function

Table 6-38: (Continued)

Service Level	P.F.*	β	LRFD Equation
D	g_{16}	3	$M_S = \sqrt{(M_x^o)^2 + (M_y^o)^2} = 205{,}180$ lb in $0.30 S_u \geq 1.1 \frac{M_A}{Z_P} + 1.5 \frac{M_S}{Z_P}$ or $22{,}500 \geq \frac{1.1(46{,}420)}{57.46} + \frac{1.5(205{,}180)}{57.46} = 6{,}245$ psi
	g_{17}	3.0	f_{PS}=13.5>10 $0.85 S_u \geq 1.1 \frac{M_A}{Z_P} + 1.2 \frac{P_s D_o}{4t} + 1.5 \frac{M_S}{Z_P}$ $63{,}750 \geq \frac{(1.1)\,46{,}420}{57.46} + \frac{1.2(1{,}350)(12.75)}{4(0.375)} + \frac{1.5(205{,}180)}{57.46} = 20{,}015$ psi

*P.F.=Performance Function

6.5. Conclusions

From the computation of partial safety factors in the previous sections the following can be deduced:

1. For the design only for internal pressure, the partial safety factors were computed for different types of steel and design temperatures. Linear interpolation can be used to obtain only approximate values of factors for other design temperatures or values of the target reliability index, β. The adjusted nominal resistance factors were modified only in order to obtain rounded numbers, since the ranges of the mean values of the used variables yielded the same values for the mean partial safety factors.
2. For the performance functions with combined loading, the magnitude of loads significantly influences the adjusted nominal resistance factor. In order to achieve consistent reliability levels (β in the space [β-0.25, β+0.25]) and for all the examined performance functions, several categories were derived for different magnitude of loading. Usually, the pressure alone or in combination with other

loads (e.g., earthquake) controls the separation in different categories. More categories usually result for higher values of the target reliability index.

3. For ratios of stresses of pressure to sustained weight greater or equal than 10, the resultant adjusted nominal resistance factor, in most of the cases examined, attains the highest values, meaning that for the same target reliability index, these loading cases are less critical.
4. Tables were provided with the ranges for the resultant nominal resistance factor for a predefined set of load factors, as well as recommended values. In order to obtain recommended mean partial factors, the nominal load and resistance partial factors listed in the tables should be devided by the considered recommended bias for each performance function. The relation of factors applied to the mean value of variables (mean factors) and those applied to nominal values (nominal factors) was explained in Chapter 4.

   Such calculations are not shown herein due to their simplicity. The need of having the recommended mean values may arise, should different bias factors than the ones used in this study, need to be applied. In the tables, the normalized load ratios also correspond to ratios of mean values. Dividing by the used bias, the nominal ratio may be obtained. In a computational example nominal normalized ratios were converted into equivalent mean ratios.
5. Figures showing the variation of mean factors are available for selected cases and performance functions, since there is a repeatability of results and any further the cases examined would be excessive. Nonetheless, computation results for the mean partial safety factors are listed comprehensively in tables of Appendix C.

From the figures showing the variation of mean factors, it can be seen that the difference between the partial mean factors is significant, e.g., in case of earthquake, or different levels of piping pressurization, whereas the transition in a predefined set of nominal load factors diminish differences and provides uniformer results.

6. The obtained nominal partial resistance and load factors correspond to the recommended probabilistic characteristics of this study. The impact of them (e.g., different coefficient of variation for the earthquake load, etc.) should be considered with respect to the selected value of the target reliability index. Differences become significantly less important for lower values of the target reliability index.
7. It can be noticed in the calculation results that for some cases the adjusted resistance factors are very close for carbon and stainless steel or for operation in different temperatures (e.g., design temperature at 400^{o}F or at room temperature for Service Levels C and D, etc.). Therefore, for the target reliability index, derived according to the procedures described in Chapter 5, simplifications can be achieved that may diminish the volume of the adjusted nominal resistance factors. Such simplifications must take into consideration the impact on the target reliability index, β, and consequently the probability of piping failure.
8. For the performance functions for combined loading, it is important to perform the calculations for a specific predefined reliability index, since the derived categories for the adjusted resistance factor can vary with different reliability indeces or different design temperatures. Therefore, the use of approximate

methods such as the linear interpolation for immediate values of the target reliability index, β, seems not efficient.

CHAPTER 7: FATIGUE DESIGN OF PIPING

The fatigue design of piping belongs to Service Levels A and B. Although the design equations for all piping classes are similar with only different the allowable stress, design for fatigue is different for Class 1 piping compared to those of Class 2 and 3 piping. The chapter starts with a general discussion describing the fatigue design of all pipes according to the ASME B&PV Code, followed by a proposed probability-based framework for the design of Class 2 and 3 piping for bending cycling loading (e.g., thermal expansion). The proposed methodology is built on the design equations of the ASME B&PV Code (2001), Sections NC-3653.2 and ND-3653.2.

7.1. General Discussion

Nuclear pipes are subjected to cycling loading. Significant cycles of stress in piping are produced by a) moment loading, b) pressure and c) thermal forces. Table 7-1 shows for example the design cycles of Class 1 piping. The produced stress cycles from these loadings are less than 10^5 and more often just few thousand during the service life of piping. This type of fatigue is called low-cycle fatigue in opposition to high-cycle fatigue that also occurs to piping components and is due for example to flow-induced vibrations, vibrating machines, etc.

Low-cycle fatigue, the primary type of piping fatigue, significantly influences the high pressure injection makeup lines, the residual heat removal piping, surge lines, feedwater lines, and the reactor coolant piping. It involves plastic strain and high stress levels in opposition to high-cycle fatigue, where the structure remains in the elastic region and the number of load cycles to cause failure is high. For low-cycle fatigue strain is the controlled variable, and not the stress, in fatigue tests that are conducted in order to determine the inherent decreasing strength of steel due to cycling loading.

Table 7-1: Design Transients and Cycles for the Reactor Coolant System (IAEA, 2003)

Transient	Number	Description
More Significant Contributor to CUF*		
Heat-up	250	From T_{ave} = <200^{o}F to >550^{o}F at <100^{o}F/h
Cooldown	250	From T_{ave} = >550^{o}F to <200^{o}F at <100^{o}F/h
Pressurizer cooldown	250	From $T_{pressurizer}$>650^{o}F to <200^{o}F at 200^{o}F/h
Loss of Load, without reactor trip	100	>15 to 0% of rated thermal power
Loss of off-site ac	50	Loss of ac off-site electrical
Reactor trip	500	100 to 0% of rated thermal power
Reactor trip from full power	400	
Primary hydrotest at 3125psi, 400^{o}F	10	
Less Significant Contributor to CUF*		
Large step load decrease	200	100 to 0% of rated thermal power
Inadvertent auxiliary spray actuation	10	Spray water temperature differential >320^{o}F
Loss of flow in one loop	100	Loss of only one reactor coolant pump
Pipe break	1	Break in reactor coolant system pipe>6in
Operating Basis Earthquake	400	20 earthquakes with 20 cycles/earthquake
Unloading between 0 and 15% power	500	
Loading between 0 and 15% power	500	
Plant unloading 5% full power/minute	13,200	
Reduced temperature return to power	2,000	
Step load increase at 10% full power	2,000	
Step load decrease at 10% full power	2,000	
Feedwater cycling	2,000	
Primary side leak test	200	

*CUF: Cumulative Usage Factor

The fatigue design of Class 1 piping and those of Class 2 and 3 is different in the Code. More specifically, the fatigue design of Class 1 piping is based on fatigue curves (*S*-*N*) for the initiation of a crack on small size, polished specimens operating at room temperature, while those of Class 2 and 3 is based on equations derived from fatigue curves calculated for the through the wall crack of full-scale pipes at room temperature.

For Class 1 piping fatigue curves are plotted in the ASME Code's Figures I-9.1 for carbon and low alloy steel and I-9.2 for austenitic stainless steel. For fatigue tests for Class 1 piping the strain for the initiation of the crack was measured and an equivalent stress was evaluated by multiplying the strain with the modulus of elasticity and dividing by two in order to obtain the stress amplitude. Moreover, the fatigue curves were lowered by a factor of 2 either on strain or of by 20 on the cycles, whichever resulted in a more conservative estimate for each curve point (for low cycle fatigue the factor of 20 usually dominates, whereas the factor of 2 on strain is dominant for high cycle fatigue points). These factors are not safety factors but rather aim to adjust the experimental results to real conditions of pipe functioning (temperature, not polished real size pipes). Moreover, using the modified Goodman diagram the mean stress effects were also considered for the construction of the Code fatigue curves. The cumulative fatigue damage based on Miner's rule is also evaluated for these pipes. Figure 7-1 provides the nomenclature for a sinusoidal cycling load.

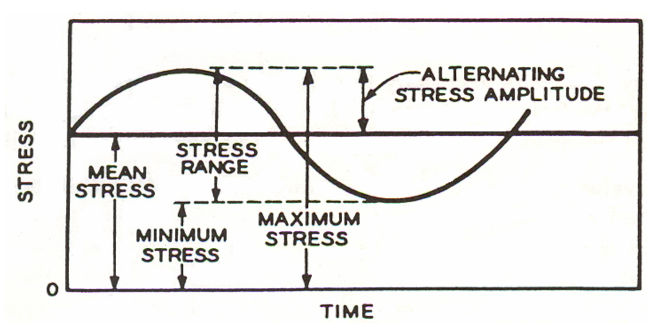


Figure7-1: Nomenclature for Cycling Loading with Mean Stress (ASME Criteria, 1969)

For Class 1 piping research has been done in order to modify the curves for pipes operating in real LWR coolant environment conditions (e.g., effect of oxidized water, etc.) by Chopra, et al. (1999). Moreover, some studies exist in literature for the probabilistic design of piping. For example, Zhao, et al. (2000), propose an analysis based on the local-strain-approach life prediction and a performance function with respect to strains. Sudret, et al. (2005) quantifies the uncertainties of fatigue design by considering the cumulative damage as a criterion of failure due to crack initiation.

7.2. ASME Practice for Class 2 and 3 Piping

Class 2 and 3 piping subjected to cyclic loading such as thermal expansion - contraction or anchor / support movements, are designed according to the ASME Boiler and Pressure Vessel Code, Section III, (2001) subsections NC-3653.2 and ND-3653.2, respectively. For the thermal loading, moment ranges from a flexibility analysis are considered and stresses are calculated in locations, where the pipe is restraint to move freely due to the displacements caused by thermal loading. Class 2 and 3 piping, unlike Class 1 piping, is not designed for peak stresses (e.g., radial gradient temperature, etc.) or cycles of alternating pressure (e.g., start-up, shut down, etc.).

More specifically, the Code provides two equations, here Eqs. (7-1) and (7-2), for thermal expansion in subsections NC and ND-3653.2, which are identical for Classes 2 and 3 piping. Equation (7-1) allows considering only secondary stresses (stresses due to thermal expansion, and other support movements inducing moment loading), whereas Eq. (7-2) combines primary (sustained weight and internal pressure) with secondary stresses (thermal expansion stresses).

$$S_E = \frac{iM_C}{Z} \le S_A \tag{7-1}$$

where

M_C=range of resultant moments due to thermal expansion that also includes anchor movements of not reversing dynamic loading

Z=elastic section modulus

i=stress intensification factor

S_E=stress range

$$S_{TE} = \frac{P D_o}{4 t_n} + 0.75 i \left(\frac{M_A}{Z} \right) + i \left(\frac{M_C}{Z} \right) \le S_h + S_A \tag{7-2}$$

where

P=internal design pressure

D_o=outside diameter of pipe

t_n=nominal wall thickness

Z=elastic section modulus

M_A=resultant moment due to weight and other sustained load

M_C=range of resultant moments due to thermal expansion

i=stress intensification factor, while the factor (0.75i) shall not be less than 1.

S_{TE}=stress range

The stress intensification factor, i, is the ratio of the moment producing fatigue failure in a given number of cycles in a girth butt-welded pipe, shown in Figure 7-2, of nominal dimensions to that producing failure in the same number of cycles for the component under consideration. In Eqs. (7-1) and (7-2), the allowable stress range for cyclic stresses, S_A, is given as a combination of the allowable stress at maximum temperature, S_h, and the minimum (cold) temperature allowable stress, S_c, of the cycle, as Eq. (7-3) shows, and also described in Table 2-1. In addition, a reduction factor for the stress, f, is used in order to account for the cycling nature of the load, which is dependent on thermal full cycles as Table 7-2 shows.

$$S_A = f(1.25S_c + 0.25S_h) \tag{7-3}$$

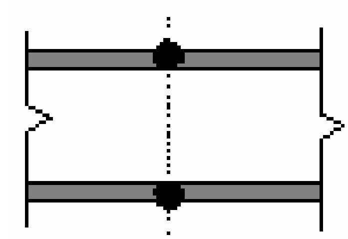


Figure7-2: Girth Butt-Welded Straight Pipe

Table 7-2: Values for the Reduction Factor, *f*

Number of equivalent full temperature cycles, *N*	*f*
≤ 7,000	1.0
7,000 to 14,000	0.9
14,000 to 22,000	0.8
22,000 to 45,000	0.7
45,000 to 100,000	0.6
100,000	0.5

The thermal full cycles, *N*, are obtained using Eq. (7-4).

$$N = N_E + r_1^5 N_1 + r_2^5 N_2 + ... + r_n^5 N_n \tag{7-4}$$

where N_E=number of cycles at full temperature ΔT_E for which expansion stress was calculated, N_1, N_2, …, N_n=number of cycles at lesser temperatures, ΔT_1, ΔT_2,..., ΔT_n, and r_1, r_2,…,r_n = ratios of any lesser temperature cycles for which the expansion stress has been calculated, e.g., r_1=$\Delta T_1/\Delta T_E$, etc.

The philosophy of the present design is to permit designers to avoid accounting reduction of fatigue cycles, when the latter are less than 7,000, which is a usual case. As shown later, significant conservatism is introduced in the calculations.

Fatigue design of Class 2 and 3 piping in the Code is based on the work done by Markl, et al. (1952), while Rodabaugh, et al. (1983) gives a commentary and presents a comparative study for the fatigue design of all piping Classes. Markl, et al. (1952) tested various cantilevered piping products (butt-welded pipes, straight pipes, elbows, tees, etc.) made of carbon steel A-106 Grade B, in actual dimensions, at room temperature, filled with water. Load was related to deflection by a calibration curve and nominal stresses, S_n, were estimated, using Eq. (7-5).

$$S_n = \frac{P\,L}{Z} \tag{7-5}$$

S_n=nominal stress
P=load
L=distance between failure point and load application point
Z=elastic section modulus

The approach of considering the nominal stress, which is the maximum stress due to applied loading at the crack location, for fatigue design is the simplest among others like the hot spot approach, or approaches where the material's constitutive relations are taken into consideration.

Markl, et al. (1952), moreover, derived a general best fit equation representing the results of the tested piping components, Eq. (7-6), which is applicable to all components by using different values of *i*, and thus the equation is in accordance with the whole philosophy of the Code design, where indices are used in order to obtain design equations for different piping components other than straight pipes. The equation here is expressed in terms of the stress range, whereas Markl, et al. (1952) presented them with the stress amplitude, instead.

$$i\,S = a\,N^{-b} \tag{7-6a}$$

where,
S=applied stress range
N=cycles to failure
i=stress intensification factor as described above, for butt welded pipes equal to 1
α=490,000 for butt girth welds
b=0.2

By substituting in Eq. (7-6a) the above values for α and b, Eq. (7-6b) is obtained:

$$i\,S = 490{,}000\,N^{-0.2} \tag{7-6b}$$

Assuming a safety factor of 2 to be applied to the derived stress (Rodabaugh, 1983), reducing this way α to 245,000, Eq. (7-6c) is obtained.

$$i\,S = 245{,}000\,N^{-0.2} \tag{7-6c}$$

Figure 7-3 shows fatigue curves (log-log scale) developed by Markl, et al. (1952) -the test data includes experiments performed also by other researchers- while in Figure 7-4 Eqs. (7-3), (7-6b), and (7-6c) are plotted for butt-welded pipe (i=1). Equation (7-3) is plotted for carbon steel A106B and austenitic steel Type 304 for a temperature range between 70^{o}F and 200^{o}F. From this figure, it can be inferred that the safety factor varies considerably in the allowable stress design method, since in all cases it is greater than 2 and especially for values of N less than 7,000. The difference between carbon and stainless steel is not significant as shown in Figure 7-4. From additional fatigue tests on stainless steel reported by Rodabaugh (1983), it is derived that carbon steel specimens present greater resistance to fatigue as piping made of stainless steel.

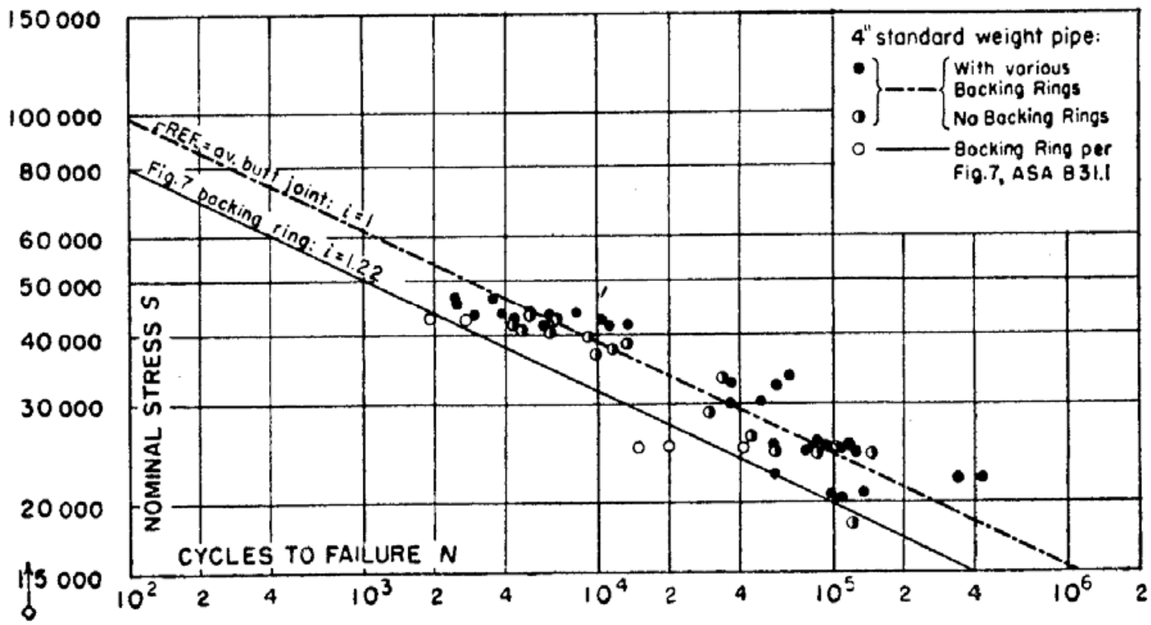


Figure7-3: Fatigue Curves for Girth Butt-Welded Joints in Straight Pipes (Markl, et al., 1952), where the Nominal Stress Refers to the Stress Amplitude

The stress intensification factor proposed by Markl, et al. (1952) for curved pipes is also used in the Code and more specifically is given by the following equation:

$$i = \frac{0.90}{h^{2/3}}$$

where *h* is a flexibility characteristic given by the formula:

$$h = \frac{t\,R}{r^2}$$

where *t*=pipe wall thickness, *R*=bend radius, and *r*=mean pipe radius.

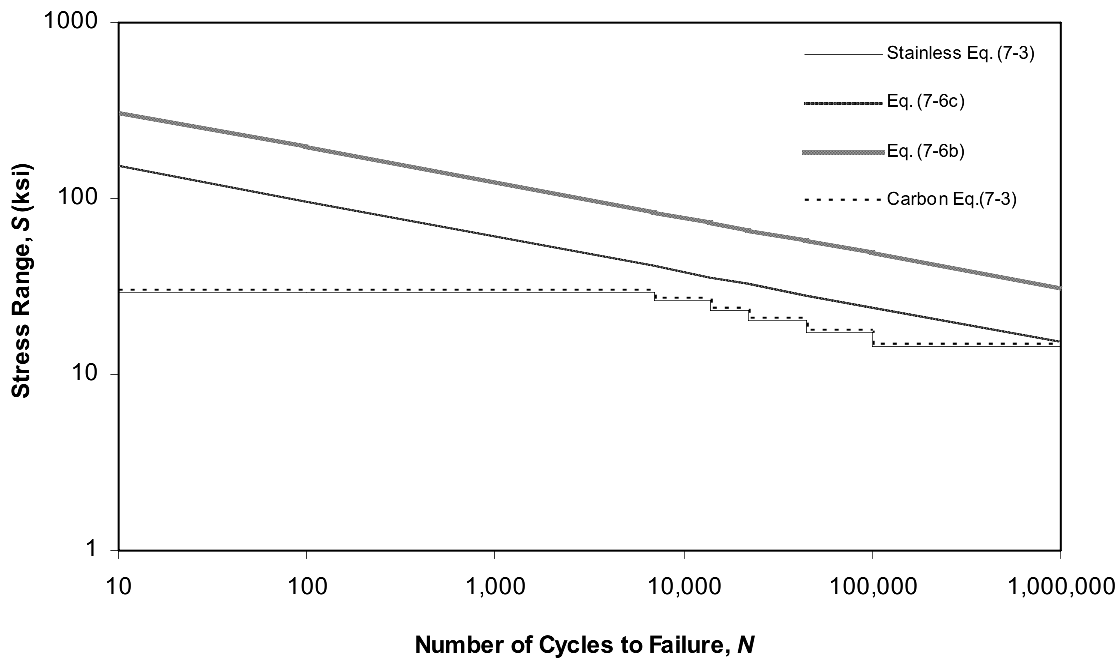


Figure7-4: Allowable Fatigue Stress, S_A, for Class 2 and 3 Piping, and Fatigue Test Stress versus Cycles to Failure for Girth Butt-Welded Pipe

7.3. Reliability-Based Fatigue Design

Several structures are designed today for fatigue, based on reliability methods, e.g., bridges, ships, aircrafts, etc. In what follows, a probabilistic design method is suggested for Class 2 and 3 piping based on the fatigue curves proposed by Markl, where only cycling moment loading is considered. Therefore, for the consideration of loading other than cycling moments (e.g., thermal peak stresses, etc.) the proposed methodology is not recommended and pipes that need to be designed for such loads should be designed according to the provisions for Class 1 piping.

For the reliability–based fatigue analysis of structures there are generally two approaches, a) the direct reliability method, and b) the Load and Resistance Factor Design method. In both approaches a limit state equation is first formulated. Then, for the first method the design is checked by comparing the calculated reliability index for the specific design with a target reliability index. The second method is similar to the one used in the previous chapter, where load and resistance factors are calculated according to a target reliability index. The first approach is used herein, since it is the one usually adopted for the reliability fatigue design of structures and, moreover, it is not always possible to achieve uniform partial safety factors for all fatigue designs. Analysis is similar to that developed by Ayyub, et al. (2002) for fatigue of ship details.

7.3.1. Performance Function and Equivalent Stress Range

Usually, performance functions for fatigue are either based on cycles, Eq. (7-7), or cumulative damage ratios, Eq. (7-8).

$$g_1 = N_f - N \tag{7-7}$$

$$g_2 = D_f - D \tag{7-8}$$

where

N_f=cycles that lead to failure
N=expected cycles to act during service life of component
D_f=cumulative damage ratio that leads to failure
D=expected accumulated damage ratio for the service life of component

In this study the performance function g_2 is used. The expected accumulated damage, D, the pipe will be subjected to, is calculated using the Miners' rule, which is based on a linear damage hypothesis and more specifically in the following two assumptions (Meiner, 1945; Kesioglu, 1991):

1. Each component (in this case pipe) can absorb a maximum amount of energy before failure, W, which is the sum of the amount of energy absorbed W_i at each

stress range (level) S_i, i=1 to n_b that the component is subjected to during its service life.

$$W = W_1 + W_2 + ... + W_k \tag{7-9}$$

2. For a specific stress level the component absorbs energy that is proportional to the total energy, W, by an amount called usage factor, U, defined as the ratio of the expected cycles, n_i, at a specific service to the total life (or cycles), N_{fi}, to failure for that stress level, as if it was the only one that was acting on the component.

$$U = \frac{n_i}{N_{f\,i}} \tag{7-10}$$

and therefore Eq. (7-9) yields:

$$W = W\frac{n_1}{N_{f\,1}} + W\frac{n_2}{N_{f\,2}} + ... + W\frac{n_k}{N_{f_k}}$$

or

$$1 = \frac{n_1}{N_{f\,1}} + \frac{n_2}{N_{f_2}} + ... + \frac{n_k}{N_{f\,k}}$$

or

$$\sum_{i=1}^{n_b} U_i = \sum_{i=1}^{n_b} \frac{n_i}{N_{f_i}} = 1 \tag{7-11}$$

Based on the above discussion the performance function of Eq. (7-8) can be rewritten as:

$$g = g_2 = D_f - \sum_{i=1}^{n_b} \frac{n_i}{N_{f\,i}} \tag{7-12}$$

where,
n_i=expected number of cycles at the ith stress range level
N_{fi}=number of cycles to failure at the ith stress-range level
n_b=number of stress-range levels in a stress range histogram

Generally, the Miner model is a good assumption if cycles of small and large stresses are evenly distributed throughout the service life of piping. If smaller ranges are applied first the cumulative damage ratio, D_f, can reach values as high as 4 or 5 or be less than 1 in the opposite case, as then failure can be much accelerated, (ASME Criteria, 1969). Therefore, D_f is actually a random variable with a high coefficient of variation, and a mean value considered to be 1, as explained later.

The stress range, S, is also a random variable such as it can be described by a probability density functions $f_S(s_i)$, as Figure 7-5 shows. The probability density function can be composed by considering the anticipated structural behavior of piping to expected, in this case, moment loading. The random stress probability density distribution can be divided into a large number, n_b, of narrow stress blocks of width ΔS. In each block, the number of cycles, n_i, is given by Eq. (7-13), where N denotes the total anticipated number of cycles during the service life of a pipe.

$$n_i = Nf_S(s_i)\Delta S \tag{7-13}$$

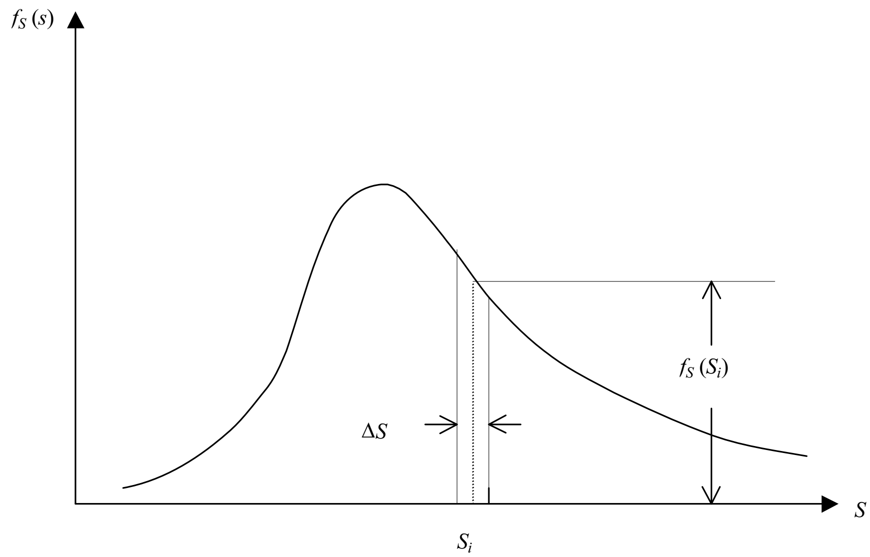


Figure7-5: Probability Density Function (PDF) for the Bending Stresses (Ayyub, et. al., 2002)

By rewriting Markl's general Eq. (7-6a) as in Eq (7-14) and solving for N, Eq. (7-15) is obtained.

$$S = \frac{a}{i} N^{-b} = A N^{-b} \tag{7-14}$$

$$N = \left(\frac{A}{S}\right)^m \tag{7-15}$$

where m=1/b and A=α/i

Equation (7-15) based on Markl's fatigue tests correspond to constant range applied stress. Nevertheless, in real loading conditions cycles come with variant stress ranges. Considering Eqs. (7-13) and (7-15) and the failure cycles for the stress range S_i, D in Eq. (7-12) becomes:

$$D = \sum_{i=1}^{n_b} \frac{n_i}{N_{f\,i}} = \sum_{i=1}^{n_b} \frac{N\, f_S(s_i)\Delta S}{\left(\dfrac{A}{S_i}\right)^m} \tag{7-16}$$

As ΔS goes to zero and by considering N, A, and m as constants, the sum in Eq. (7-16) becomes:

$$D = \frac{N}{A^m} \int_0^\infty S^m f_S(s)\, ds \tag{7-17a}$$

The integral expression of Eq. (7-17a) is the mean or the expected value, $E(S^m)$, of the random variable S^m. Accordingly, the damage ratio D equals:

$$D = \frac{N}{A^m} E(S^m) \tag{7-17b}$$

By equating Eq. (7-15), having the constant amplitude stress applied during the tests, with Eq. (7-17b) an expression of an equivalent for constant stress range loading, S_e, is obtained as:

$$S_e = \sqrt[m]{\frac{E(S^m)}{D}} \tag{7-18a}$$

Considering Eq. (7-18a) at failure and thus D_f=D=1, Eq. (7-18a) is simplified:

$$S_e = \sqrt[m]{E(S^m)} = \sqrt[m]{\sum_{i=1}^{n_b} S_i{}^m f_i} \tag{7-18b}$$

where f_i=n_i/N and N is the expected number of applied cycles.

Equation (7-18b) can be used to evaluate the equivalent mean stress, $\overline{S}_e$.

7.3.2. Strength and Loading Uncertainties

For the probabilistic design of structures the probabilistic characteristics should be estimated. The applied stress range as well as the cumulative damage, D_f, calculated

Table 7-3: Variables for the Piping Fatigue Design

Variable	Description	Mean	*COV*	Distribution
k_s	Variable that considers uncertainty in fatigue stress range calculation	1	0.10	Normal
A	Variable that reflects the uncertainty in *S*-*N* relationship	Depending on Component A=(490,000/i)	0.20 to 0.40	Lognormal
D_f	Uncertainty introduced by the use of Miner's rule	1	0.20 to 0.50	Lognormal
S_e	Uncertainty arising from variables used in S_e calculation	Eq. (7-18b)	0.10	Lognormal
m	Constant	5	na	na

na=not applicable

7.3.3. Values for the Target Reliability Index, *β*

Usually, for fatigue the value of target reliability index, β, is based on the method of inspection and even the ability or not to inspect the component under consideration. Table 7-4 presents values of β for different structures and for the entire service life of structure.

Table 7-4: Values of Target Reliability Index for Fatigue Design and Different Structures

Target Reliability Index, β	Structure	Reference
1.5 to 3.8	Buildings/Bridges	ENV 1991-1 (1994)
2 to 3.5	Ships	Mansour (1996)

7.3.4. Discussion and Evaluation

The following limitations and disadvantages exist for the use of the developed performance function for Class 2 and 3 pipng:

- It considers only cycling stresses produced by bending such as thermal expansion, anchors' movements, etc. It can therefore substitute Eq. (7-1) of the Code that covers the same type of loading.

- The effect of mean stress is neglected. Mean stress, when tensile, can reduce the strength capacity, since it helps the development of cracks.
- Calculation of stresses refers to a linear elastic behavior of steel, therefore the elastic section modulus should be considered for the calculation of the stresses, whereas the plastic behavior of the material is ignored leading to conservative results.
- The nominal stress approach for fatigue analysis is dependent on the model used. Markl (1952) selected the cantilever model as a more conservative case for the fatigue loading of straight pipes. Svacuzzo (2006) by testing pipes in a four-point fatigue bent test concluded that Markl's equation and results in failure cycles are conservative.
- As in the Code it is assumed that performance in fatigue tests do not change for temperature up to 600^{o}F.
- Thermal stress analysis is needed for all temperature ranges in order to access the value of S_i, while in the Code the thermal analysis is performed for only one thermal range and as explained equivalent thermal loads are evaluated for different temperature difference.

The use of this probabilistic method, however, offers the following advantages:

- The proposed method can substitute the one used in the Code, since here bending cyclic loading from various loads can be considered (thermal expansion, earthquake, induced support movements, etc.) too. The reliability index helps understand the safety margins of the design.

- Calibration with the ASME equations may provide the means for ameliorating the procedure and reducing conservatisms in a rational way.

7.3.5. Computation Procedure

The steps for the reliability-based method presented herein are:

1. The cycles N_i and the stress range $S_i=M_i/Z$ are evaluated for different stress blocks of number n_b. It should be clarified that the cycles are not full cycles as defined in the Code but the estimated cycles for the calculated stress range.
2. The performance function to use is either this of Eq. (7-20a) or (7-20b).
3. Determine $A=\alpha/i$, where α=490,000 and i as defined in Table NC-3673.2(b)-1 of the Code. The probabilistic characteristics of variables A, k_s, D_f, and S_i or S_e are selected and using AFOSM a converged value of β_c is produced.
4. Compare the computed β_c with the target reliability index β. If $\beta_c>\beta$ the pipe's geometrical properties are acceptable. In the opposite case, the elastic section modulus of pipe should be increased, and the above procedure should be repeated.

An alternative procedure can be used to estimate an allowable S'_e given the probabilistic characteristics of variables and a target reliability index. Then, if $S_e<S'_e$ the geometrical properties of the pipe are acceptable and in the opposite case they should be revised. A flowchart of this procedure is given in Figure 7-6.

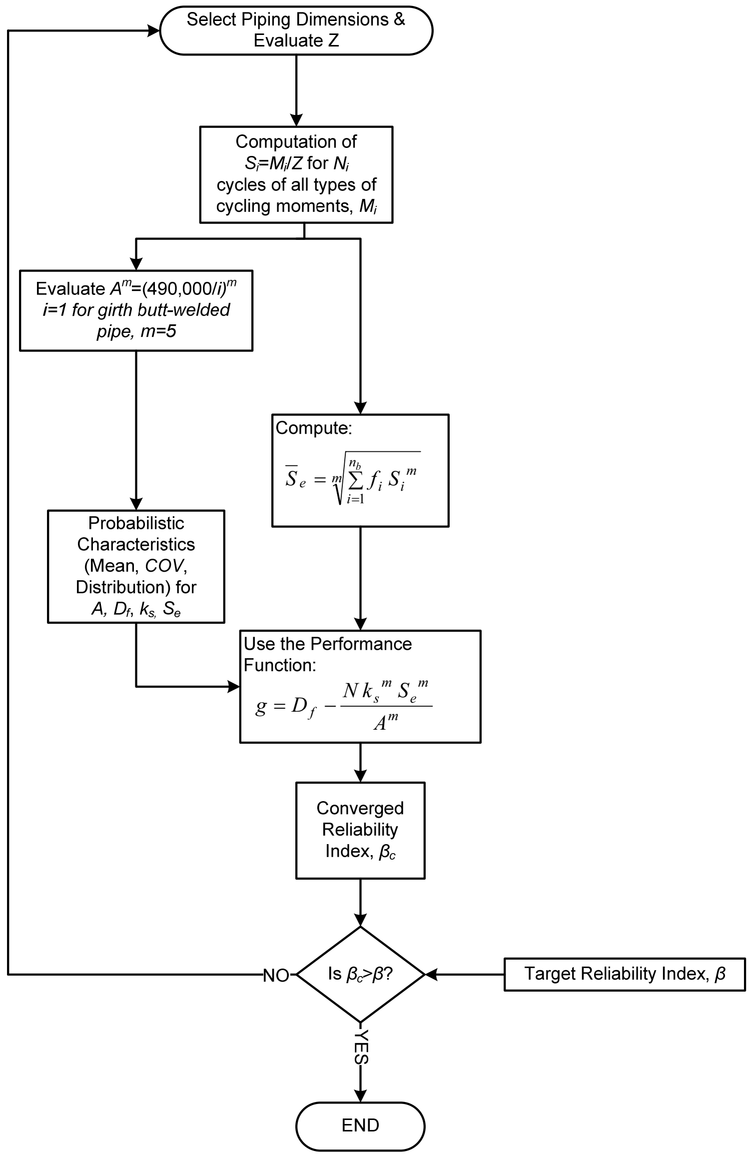


Figure7-6: Flowchart for the Direct Reliability Design for Cyclic Bending Moments

7.3.6. Combination of Secondary and Primary Stresses

In this section, a performance function for the load combination of Eq. (7-2) is proposed for straight components (girth butt-welded pipes, etc.). Nonetheless, it should be mentioned that this equation is not meaningful. It combines cycling thermal loading with the sustained weight and the longitudinal stress due to internal pressure. The latter loads are treated as a mean load. The proposed performance function is given by Eq. (7-21).

$$Z = 1 - \frac{k_s S_{eT}}{S'_e} - \frac{S_A}{S_u} - \frac{S_P}{S_u} \tag{7-21}$$

where,

S_{eT}=stress range due to thermal cycles
S'_e=stress range capacity for anticipated life cycles, calculated for a target reliability index, β.
S_A=elastic stress due to sustained weight=M_A/Z
S_P=longitudinal stress due to internal pressure=$PD_o/4t$
S_u=ultimate strength of steel
k_S=variable representing uncertainty in the fatigue evaluation of the equivalent stress range

For this performance function two procedures are considered, the first is to calculate partial load and resistance factors by altering the performance function as in Eq. (7-21). Moreover, since S'_e is evaluated for a specific acceptable reliability index in the performance function of Eq. (7-21), it may be treated as a constant. The ratio of S_{eT}/S'_e becomes a variable σ_e with a distribution and coefficient of variation equal to those of variable S_{eT}. The performance function of Eq. (7-21) is rewritten by dividing by the mean value of S_u the variables S_A, S_P and S_u and hence Eq. (7-22) yields:

$$Z' = 1 - k_s\,\sigma_e - \frac{\sigma_A}{\sigma_u} - \frac{\sigma_P}{\sigma_u} \tag{7-22}$$

where,
$\sigma_e = \dfrac{S_{eT}}{S'_e}$, $\sigma_A = \dfrac{S_A}{\overline{S}_u}$, $\sigma_u = \dfrac{S_u}{\overline{S}_u}$, and $\sigma_P = \dfrac{S_P}{\overline{S}_u}$
$\overline{S}_u$=Mean value of the ultimate strength of steel

Since for a range of parameters for the variables in performance function of Eq. (7-22) no uniform partial load and resistance factors for all cases can be obtained, the direct reliability method should also be used for the performance function of Eq. (7-21). For this procedure the mean values and other probabilistic characteristics of variables should be available. A converged reliability index, β_c, is evaluated and compared with the predefined target reliability index, β. The procedure is presented in Example 2 of the following section. The flowchart of the computations for the performance function of Eq. (7-21) is given in Figure 7-7. It can be noticed that the flowcharts of Figures 7-6 and 7-7 can be combined should both equations is judged to be used in the design.

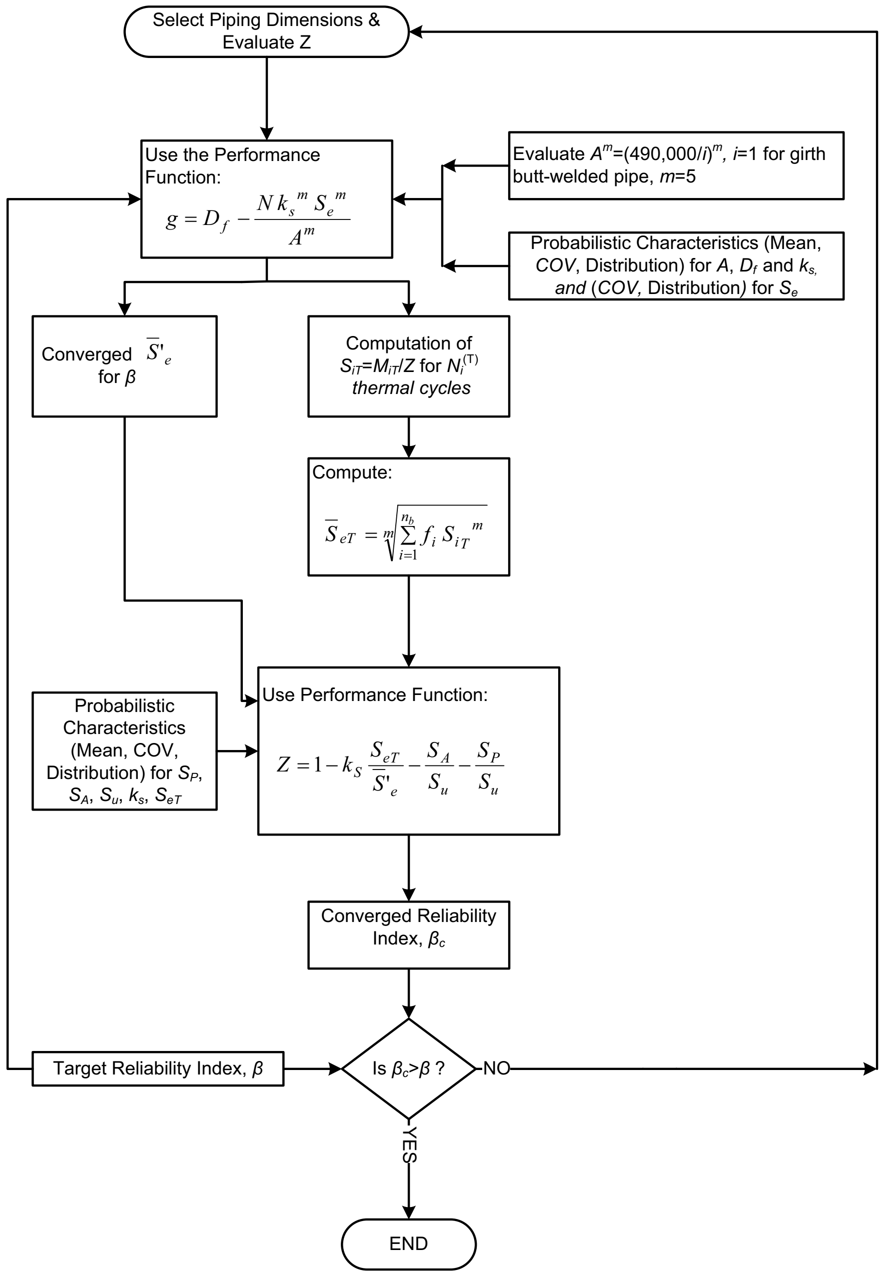


Figure7-7: Flowchart Using Direct Reliability-Based Design for the Combination of Thermal Expansion Stresses with Primary Stresses

7.3.6.1. Example 1

This example shows calculations for the fatigue design of a pipe imposed on load cycles and corresponding stress ranges given in Table 7-5. The probabilistic characteristics of variables presented in Table 7-3 are used, and moreover a girth butt-welded straight pipe is considered. Therefore, i=1 and the *COV* for both A and D_f is considered to be 0.30. From Table 7-5, it is n_b=6 and N=7,806. The target reliability index is considered 3.0.

Table 7-5: Cycles and Stress Ranges for Example 1 Computations

Stress Block	Stress Range, S_i(psi)	Number of Cycles, N_i for 40 Years Service	f_i	$S_i^m f_i$
1	45,000	200	0.01937	4.72785E+21
2	90,000	10	0.001291	7.56457E+21
3	8,000	500	0.064566	2.0989E+18
4	4,000	7,000	0.903926	9.18268E+17
5	12,000	90	0.010331	2.86893+18
6	30,000	6	0.000517	1.86779+19

Using Eq. (7-18b), the equivalent mean stress for the different stress ranges is calculated as:

$$\overline{S}_e = \sqrt[5]{\sum_{i=1}^{6} S_i^{\,5} f_i} = 26{,}188\text{psi}$$

Convergence was achieved for β_c=7.94>β=3 and therefore the design is acceptable. By using the alternative procedure a converged mean value of equivalent stress for β=3 is calculated as $\overline{S}'_e$=52,538psi>26,188psi, showing again the adequacy of the design.

7.3.6.2. Example 2

For this example the performance function of Eq. (7-21) is used. Table 7-6 presents the total of cycles the pipe is subjected to, while from them, the thermal ones have the symbol $^{(T)}$. Table 7-7 shows only the thermal cycles. The assumed probabilistic characteristics of variables are given in Table 7-8. The properties of ultimate strength of steel are considered for the design temperature of the pipe. The target reliability index is β=3. The pipe is straight and girth butt-welded.

Table 7-6: Cycles and Stress Ranges for Example 2 Computations

Stress Block	Stress Range, S_i(psi)	Number of Cycles, N_i for 40 Years Service	f_i	$S_i^m f_i$
1	32,000$^{(T)}$	1,000	0.2257	7.57436E+21
2	80,000$^{(T)}$	80	0.0181	5.91747E+22
3	7,000$^{(T)}$	300	0.0677	1.13817E+18
4	14,000$^{(T)}$	3,000	0.6772	3.64215E+20
5	12,000	50	0.0113	2.80849E+18

Table 7-7: Thermal Cycles and Stress Ranges

Stress Block	Stress Range, S_i(psi)	Number of Cycles, N_i for 40 Years Service	f_i	$S_i^m f_i$
1	32,000$^{(T)}$	1,000	0.2283	7.66083+21
2	80,000$^{(T)}$	80	0.0183	5.98502+22
3	7,000$^{(T)}$	300	0.0685	1.15116E+18
4	14,000$^{(T)}$	3,000	0.6849	3.68373E+20

From the data in Table 7-7, showing only thermal cycles, the equivalent mean stress due to thermal loads, $\overline{S}_{eT}$, is evaluated as:

$$\overline{S}_{eT} = \sqrt[5]{\sum_{i=1}^{4} S_i^{5} f_i} = 36{,}843 \text{ psi} \tag{7-23}$$

Following the procedure described in the previous example and for the data of Table 7-6 and β=3, it produces $\overline{S}'_e$=58,840psi. The performance function of Eq. (7-20b) is also satisfied since $\overline{S}_e$=36,759psi<58,840psi.

Table 7-8: Considered Probabilistic Characteristics of Variables in Eq. (7-21)

Variable	Mean	*COV*	Distribution
k_s	1	0.10	Normal
S_{eT}	36,843psi	0.10	Lognormal
S_A	800psi	0.10	Normal
S_P	6,800psi	0.10	Lognormal
S_u	74,000psi	0.06	Lognormal
S'_e	58,840psi	na	na

na=not applicable

The direct reliability method and AFOSM was used, given the data in Table 7-8, in order to evaluate the converged reliability index for the performance function of Eq. (7-21). It was found that β_c=2.68<3, thus the elastic section modulus of the pipe should be increased.

7.3.7. Conclusions and Recommendations

In this chapter reliability-based design equations were presented for the fatigue design of Class 2 and 3 piping. The derived equations are built up in the equations of the ASME B&PV Code, Part III, NC and ND-3653.2 Eqs. (10) and (11) or Eqs. (A-17) and (A-18) of Appendix A. It should be, moreover, clarified that the performance functions for the fatigue design necessitate that the designer provides the mean values of the variables used (not the nominal). In this study some probabilistic characteristics were proposed, while with future research new data may be used, too.

Fatigue of Class 1 piping uses different fatigue curves that as briefly explained are based on measurements of plastic strains on small specimens and not on real pipes (Langer's model). Class 2 and 3 piping may be also judged to be analyzed as Class 1 piping, permitting this way additional loads to be considered in the design (e.g., thermal peak stresses, etc.). A smaller target reliability index may be then considered for these pipes.

CHAPTER 8: CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

This chapter presents a summary and conclusions of the dissertation. Moreover, it provides suggestions for further research on the reliability-based design of piping.

8.1. Summary

The dissertation provides background information on the reliability–based design of nuclear piping. Allowable stress design equations used in the ASME B&PV Code are also explained. A comparison of the ASD and LRFD methods is shown and the advantages of the LRFD are demonstrated. The total bias of the resistance and the model uncertainty of strength models related to busrt or yielding of pipes due to internal pressure or the ultimate bending capacity is evaluated based on cited experimental results. Probabilistic characteristics of the design variables are summarized.

Load combinations are provided for weight, internal pressure, dynamic loads (OBE, sudden valve closure, etc.), and accidental loads (SSE, pressure and mechanical loading due to Loss of Coolant Accident), and performance functions or else state limit equations are formulated.

The mean partial load and resistance safety factors are evaluated and an adjusted nominal resistance factor is derived for a predefined set of partial load factors for each performance function. Computations are performed for at least two values of the target reliability index for all the performance functions and cases examined. Neither calibration nor the other procedures described in Chapter 5 are used in order to access a unique value of the target reliability index for each performance function. Instead, partial safety factors are computed and recommended for ranges of target reliability indices.

8.2. Conclusions

From the performed research, the following can be deduced:

1. The LRFD is possible for mechanical components such as piping in nuclear plants. This method of design can achieve, among others, more consistent (and known) reliability levels than the Allowable Stress Design that is used in the ASME Codes. The current design practice is expected to yield inconsistent levels of reliability for different design temperatures or loading conditions for piping.
2. A database with the probabilistic characteristics of design variables is created based on literature review and engineering judgement. There is inadequate information for some cases and especially concerning the uncertainties, i.e., bias, of the strength prediction models.
3. The degree of piping pressurization, as compared to sustained weight is critical for the selection of the adjusted nominal resistance factor. The adjusted nominal resistance factor can vary significantly under different loading conditions given a predefined set of load factors.
4. The partial safety factors for LRFD can become fewer compared to the database of allowable stresses in the Code. This reduction is possible since the reliability-based design effectively unifies materials with similar probabilistic characteristics. For the LRFD, the nominal values of steel resistance are

considered for all design temperatures as the minimum specified strength of steel at room temperature. These nominal values are therefore necessary for the design.

5. The proposed fatigue design for Class 2 and 3 piping can yield an estimate of the reliability of piping, which is not possible with the current design practices.

8.3. Suggestions for Future Research

Some suggestions for future research on the reliability-based design of piping are provided below:

1. It is recommended to evaluate the target reliability index for each performance function. As explained in Chapter 5, a combination of methods should be utilized (e.g., code calibration, collection of historical data for failures of piping, etc.). This is a necessary task in order to provide uniform criteria for design, and to overcome conservatisms of the current design.
2. In order to access the uncertainties, i.e., bias, for the loads and strenght, analytical work is needed. It is, moreover, important to estimate the bias for other piping components (curved pipes, reducers, etc.), which can possibly differentiate the partial safety factors developed in this study. Moreover, with analytical work, the impact of combination of dynamic loads, which in this study was expressed by a factor E considered to be one, can also be examined.
3. The database of probabilistic characteristics of the steel strength and loads can be further expanded with the acquisition of new data (e.g., probabilistic properties of mechanical loads). Expert-opinion elicitation can provide useful and credible information. Also experimental studies can provide information and answers in

cases that information is inadequate (e.g., piping loading at elevated temperatures).

4. A reliability-based fatigue framework for Class 1 piping can be developed. Additionally, there are other equations mostly for Class 1 piping design that were not considered herein, e.g., thermal axial forces or thermal ratcheting, for which a probabilistic framework can be developed. Other loadings like the external pressure on piping due for example to vacuum, and other failure modes like buckling may be examined.
5. The LRFD equations developed in this study were built on the ASME B&PV Code. As explained, reliability theory provides the necessary means of systematically evaluating uncertainties of models; therefore amelioration of models is also possible.
6. The set of data space, the first step of the reliability based design, is important. In this study, a wide range of pipes categories and loads was examined. In order to lower the divergence from the target reliability index, the elimination of some cases or categorization of piping systems should be examined.

APPENDIX A: ASME B&PV CODE EQUATIONS

Table A-1: Design Equations for Pipes According to ASME B&PV Code (2001)

Design Equations			
	Equation	**Class**	**ASME BPV Code (2001) Eq. Number**
Design for internal pressure -wall thickness calculation-	$t_m = \frac{PD_o}{2(S_m + Py)} + A$ (A-1)	1	NB-3641.1(1)
	or $t_m = \frac{Pd + 2S_m A + 2yPA}{2(S_m + Py - P)}$		NB-3641.1(2)
	$t_m = \frac{PD_o}{2(S + Py)} + A$ (A-2)	2	NC-3641.1(3)
	or $t_m = \frac{Pd + 2SA + 2yPA}{2(S + Py - P)}$		NC-3641.1(4)
	$t_m = \frac{PD_o}{2(SE + Py)} + A$ (A-3)	3	ND-3641.1(3)
	or $t_m = \frac{Pd + 2SEA + 2yPA}{2(SE + Py - P)}$		ND-3641.1(4)
Design of Primary Stress Intensity Limit	$B_1 \frac{PD_o}{2t_n} + B_2 \frac{D_o M_i}{2I} \le 1.5S_m$ (A-4)	1	NB-3652(9)
	$S_{SL} = B_1 \frac{PD_o}{2t_n} + B_2 \frac{M_A}{Z} \le 1.5S_h$ (A-5)	2 & 3	NC-3652(8) ND-3652(8)
Service Limits A&B			
Primary plus secondary stress intensity range. Elastic cycling Eq.(6), simplified elastic-plastic analysis. Eqs. (7) & (8)	$S_n = C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + C_3 E_{ab} \lvert a_a T_a - a_b T_b \rvert \le 3S_m$ (A-6)	1	NB-3653(10)
	or $S_e = C_2 \frac{D_o}{2I} M_i^* \le 3S_m$ (A-7)		NB-3653.6(12)
	and $C_1 \frac{P_o D_o}{2t} + C_2 \frac{D_o M_i}{2I} + C'_3 E_{\alpha b} \lvert a_a T_a - a_b T_b \rvert \le 3S_m$ (A-8)		NB-3653.6(13)

Table A-1: (Continued)

Service Limits A&B (Continued)			
	Equation	**Class**	**ASME BPV Code (2001) Eq. Number**
Fatigue	$S_p = K_1 C_1 \frac{P_o D_o}{2t} + K_2 C_2 \frac{D_o}{2I} M_i + \frac{1}{2(1-\nu)} K_3 E a \lvert \Delta T_1 \rvert + K_3 C_3 E_{ab} \lvert a_a T_a - a_b T_b \rvert + \frac{1}{1-\nu} E a \lvert \Delta T_2 \rvert$ (A-9) and $S_{alt} = S_p/2$ if (A-6) is satisfied (A-10) or $S_{alt} = K_e S_p/2$ if (A-7)&(A-8) are satisfied (A-11) $S_\alpha = S_{alt}$, from Figs. I-9.0 calculate N $U_i = n_i/N_i$ (A-12) $U = \sum_{i=1}^{n} U_i \le 1.0$ (A-13)	1	NB-3653.2(a)(11) NB-3653.3 NB-3653.6(14) NB-3653.4 NB-3222.4(e)(5)
Thermal Stress Ratcheting	$\Delta T_1 \ range \le \frac{y' S_y}{0.7 E a} C_4$ (A-14)		NB-3653.7
Service Limit B	$B_1 \frac{PD_o}{2t_n} + B_2 \frac{D_o M_i}{2I} \le \min(1.8S_m, 1.5S_y)$, $P \le 1.1P_\alpha$ (A-15)		NB-3654.2(a) (NB-3654.1)
Occasional Loads	$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \frac{(M_A + M_B)}{Z} \le \min(1.8S_h, 1.5S_y)$ (A-16)	2&3	NC-3653.1(9) ND-3653.1(9)
Thermal Expansion (related to equivalent thermal cycles, fatigue) Eqs. (19), (20) refer to seismic dynamic anchor movement	$S_E = \frac{i M_C}{Z} \le S_A = f(1.25S_c + 0.25S_h)$ (A-17) or $S_{TE} = \frac{PD_o}{4t_n} + 0.75i \frac{M_A}{Z} + i \frac{M_c}{Z} \le (S_h + S_A)$ (A-18) $0.75i \ge 1$ and $S_R = \frac{iM_R}{Z} \le 2S_A$ for Class 2 (A-19) and $S_R = \frac{iM_R}{Z} \le 3S_A$ for Class 3 (A-20)		NC-3653.2(a)(10) ND-3653.2(a)(10) NC-3653.2(c)(11) ND-3653.2(c)(11) NC-3652.2(d)(11a) ND-3652.2(d)(11a)
Single Anchor Movement	$\frac{iM_D}{Z} \le 3S_c$ (A-21)		NC-3653.2(b)(10a) ND-3653.2(b)(11)

Table A-1: (Continued)

Service Limit C			
Equation		Class	ASME BPV Code (2001) Eq. Number
Eq. (22) combines reversing and not reversing dynamic loads, while Eqs(23) to (26) are used only when reversing dynamic loadings need to be taken into account	$B_1 \frac{PD_o}{2t_n} + B_2 \frac{D_o M_i}{2I} \le \min(2.25S_m, 1.8S_y)$, $P \le 1.5P_\alpha$ (A-22) or $B_2 \frac{D_o}{2I} M_W \le 0.5S_m$ (A-23) and $B_1 \frac{P_D D_o}{2t_n} + B_2' \frac{D_o}{2I} M_E \le 3(0.70)S_m = 2.10\,S_m$ (A-24) and $C_2 \frac{M_{AM} D_o}{2I} < 0.70S_1 = 0.70(6)\ S_m = 4.2\ S_m$ (A-25) and $\frac{F_{AM}}{A_M} < 0.70\,S_2 = 0.7S_m$ (A-26)	1	NB-3655.2(a) NB-3655.2(b)
Eq. (27) considers only not reversing dynamic loads, while Eqs(28) to (31) are used only when reversing dynamic loadings need to be taken into account	$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \frac{(M_A + M_B)}{Z} \le \min(2.25S_h, 1.8S_y)$, $P \le 1.5P_\alpha$ (A-27) or $B_2 \frac{D_o}{2I} M_W \le 0.5S_m$ (A-28) and $B_1 \frac{P_D D_o}{2t_n} + B_2' \frac{D_o}{2I} M_E \le 3(0.70)S_m = 2.10\,S_m$ (A-29) and $C_2 \frac{M_{AM} D_o}{2I} < 0.70S_1 = 0.70(6)\ S_m = 4.2\ S_m$ (A-30) and $\frac{F_{AM}}{A_M} < 0.70\,S_2 = 0.7S_m$ (A-31)	2&3	NC-3654.2(a) ND-3654.2(a) NC-3654.2(b) ND-3654.2(b)

Table A-1: (Continued)

Service Limit D			
	Equation	**Class**	**ASME BPV Code (2001) Eq. Number**
Eqs. (33) to (37) can be used alternatively for piping fabricated from materials P.No1 through P. No. 9, Do/tn≤50, Table 2A, Section II, Part D	$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \frac{(M_A + M_B)}{Z} \le \min(3.0S_m, 2S_y)$ $P \le 2P_\alpha$ (A-32) or $P_D \le P_{DESIGN}$ (A-33) and $B_2 \frac{D_o}{2I} M_W \le 0.5S_m$ (A-34) and $B_1 \frac{P_D D_o}{2t_n} + B_2' \frac{D_o}{2I} M_E \le 3S_m$ (A-35) and $C_2 \frac{M_{AM} D_o}{2I} < 6S_m$ (A-36) and $\frac{F_{AM}}{A_M} < S_2 = S_m$ (A-37)	1	NB-3656(a) NB-3656(b)
Eqs. (39) to (43) can be used alternatively for piping fabricated from materials P.No1 through P. No. 9, Do/tn≤50, Table 2A, Section II, Part D	$S_{OL} = B_1 \frac{P_{max} D_o}{2t_n} + B_2 \frac{(M_A + M_B)}{Z} \le \min(3.0S_h, 2S_y)$ $P \le 2P_\alpha$ (A-38) or $P_D \le P_{DESIGN}$ (A-39) and $B_2 \frac{D_o}{2I} M_W \le 0.5S_m$ (A-40) and $B_1 \frac{P_D D_o}{2t_n} + B_2' \frac{D_o}{2I} M_E \le 3S_m$ (A-41) and $C_2 \frac{M_{AM} D_o}{2I} < 6S_m$ (A-42) and $\frac{F_{AM}}{A_M} < S_2 = S_m$ (A-43)	2&3	NC-3656(a) ND-3656(a) NC-3656(b) ND-3656(b)

Appendix Nomenclature

A	Additional thickness to provide for material removed in threading, corrosion or erosion allowance, and material required for structural strength of pipe during erection, as appropriate.
P_D	Pressure occurring coincident with the reversing dynamic load, psi
$P_{\max}$	Peak operating pressure, psi
B_1, B_2	Primary stress indices
D_o	Outside diameter of pipe
d	Inside diameter of pipe
I	Moment of inertia
M_i	Resultant moment due to mechanical loads including earthquake loads and non-reversing dynamic loads
P	Internal design pressure
C_1, C_2, C_3	Secondary stress indices that according to Table NB-3681(a)
S	Maximum allowable stress for the material at the design temperature
t_n	Nominal wall thickness of product
S_h	Material allowable stress at temperature consistent with loading
α_a, (α_b)	Coefficient of thermal expansion on side $\alpha(b)$ of a gross structural discontinuity or material discontinuity, at room temperature
S_m	Maximum allowable stress intensity for the material at the design
S_{OL}	Stress due to operating conditions
S_{SL}	Stresses due to pressure, weight, and other sustained loads
S_u	Ultimate stress of material
S_{UL}	Stress due to upset loading conditions
S_y	Material yield strength at temperature consistent with loading
t	Nominal wall thickness of product
t_m	Minimum thickness of pipe
t_n	Nominal wall thickness
M_i*	Same as M_i with only difference that includes only moments due to thermal expansion and thermal anchor movements
C'_3	Values in Table NB-3681(a)-1
E	Joint efficiency for the type of longitudinal joint used or casting quality factor
y	Coefficient having a value of 0.4, except that for pipe with D_o / t_m ratio less than 6, $y = d/(d + D_o)$
Z	Elastic section modulus
Z_p	Plastic section modulus
α	Coefficient of thermal expansion at room temperature

K_1, K_2, K_3	Local stress indices for the specific component under investigation
$\|\Delta T_1\|$	Absolute value of the *range* of the temperature difference between T_o and T_i, assuming moment generating equivalent linear temperature
$\|\Delta T_2\|$	Absolute value of the *range* for the portion of the nonlinear thermal gradient, not included in ΔT_1
T_o	Outside surface temperature
T_i	Inside surface temperature
$E_{\alpha b}$	Average modulus of elasticity of the two sides of a gross structural discontinuity
C_4	1.1 for ferritic material 1.3 for austentic material
y'	Maximum allowable range of thermal stress computed on an elastic basis divided by the yield stress of the material.
M_{AM}	The range of the resultant moment resulting from the anchors motion due to earthquake and other reversing dynamic loading
F_{AM}	The amplitude of the longitudinal force resulting from the anchors motion due to earthquake and other reversing dynamic loading
K_e	Correction factor that eliminates local plasticization effects when the fatigue analysis remains linear-elastic
m, n	Material parameters given in Table NB-3228.5(b)-1
S_{alt}	Alternating stress intensity
S_n	Primary plus secondary stress intensity value
S_p	Peak stress intensity value
U	Cumulative usage factor
M_c	Range of resultant moments due to thermal expansion
i	Stress intensification factor equal to $C_2 K_2/2$
f	Stress range reduction factor for cyclic conditions for total number N of full temperature cycles during the service life of the pipe, (Table NC-3611.2(e)-1).
M_D	Resultant moment due to any single no repeated anchor movement
M_A	Resultant moment due to weight and other sustained loads
M_E	Resultant moment due to sustained weight and earthquake and other dynamic loads
M_w	Moment due to sustained weight

APPENDIX B: STEEL USED IN B&PV CODE, PART III

The following table presents the Specified Minimum Yield Strength (SMYS) and the Specified Minimum Tensile Strength (SMTS) of steels, used in the ASME Code, Part III, for the design of piping. These values are considered as the nominal resistance of steel for the LRFD method. The table, moreover, provides information like the nominal composition, the class, type or grade of these steels, etc.

Table B-1: Steel Used for Nuclear Piping

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes*	Common Name
SA-53	Ty S-Gr A	C Stl	K02504	48	30	welded or seamless black & hot-dipped zinc coated	
	Ty S-Gr B	C-Mn Stl	K03005	60	35		
	Ty E-Gr A	C Stl	K02504	48	30		
	Ty E-Gr B	C-Mn Stl	K03005	60	35		
SA-106	Gr A	C-Si Stl	K02501	48	30	carbon seamless steel pipe for high-temperature service	
	Gr B	C-Si Stl	K03006	60	35		
	Gr C	C-Si Stl	K03501	70	40		
SA-312	Gr TP304	18 Cr-8 Ni	S30400	75	30	austentic stainless steel seamless or welded	
	Gr TP304H	18 Cr-8 Ni	S30409	75	30		
	Gr TP304L	18 Cr-8 Ni	S30403	70	25		
	Gr TP304N	18 Cr-8 Ni-N	S30451	80	35		
	Gr TP304LN	18 Cr-8 Ni-N	S30453	75	30		
	Gr TP309S	23 Cr-12 Ni	S30908	75	30		
	Gr TP309Cb	23 Cr-12 Ni-Cb	S30940	75	30		
	Gr TP310S	25 Cr-20 Ni	S31008	75	30		
	Gr TP310Cb	25 Cr-20 Ni-Cb	S31040	75	30		
	Gr TP316	16Cr-12Ni-2Mo	S31600	75	30		
	Gr TP316H	16Cr-12Ni-2Mo	S31609	75	30		
	Gr TP316L	16Cr-12Ni-2Mo	S31603	70	25		
	Gr TP316N	16Cr-12Ni-2Mo-N	S31651	80	35		

Table B-1: (Continued)

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes	Common Name
SA-312	Gr TP316LN	16Cr-12Ni-2Mo-N	S31653	75	30	austenitic stainless steel	
	Gr TP317	18Cr-13Ni-3Mo	S31700	75	30	seamless or welded	
	Gr TP321	18 Cr-10 Ni-Ti	S32100	75	30	Sm<3/8in	
	Gr TP321H	18 Cr-10 Ni-Ti	S32109	75	30	Sm<3/8in	
	Gr TP347	18 Cr-10 Ni-Cb	S34700	75	30		
	Gr TP347 H	18 Cr-10 Ni-Cb	S34709	75	30		
	Gr TP348	18 Cr-10 Ni-Cb	S34800	75	30		
	Gr TP348 H	18 Cr-10 Ni-Cb	S34809	75	30		
	Gr TP XM19	22Cr-13Ni-Mn	S20910	100	55		nitronic 50 or 22-13-5
SA-333	Gr 1	C- Mn Stl	K03008	55	30	seamless or welded pipe for low-temperature service	
	Gr 6	C- Mn-Ci Stl	K03006	60	35		
	Gr 8	9Ni	K81340	100	75		
	Gr9	2Ni-1Cu	K22035	63	46		
SA-335	Gr P1	C- 1/2Mo	K11522	55	30	ferritic alloy, seamless steel pipe for high-temperature service	
	Gr P2	1/2Cr- 1/2Mo	K11547	55	30		
	Gr P5	5Cr- 1/2Mo	K41545	60	30		
	Gr P9	9Cr- 1Mo	K81590	60	30		
	Gr P11	11/4Cr-1/2Mo-Si	K11597	60	30		
	Gr P12	1Cr- 1/2Mo	K11562	60	30		
	Gr P21	3Cr- 1/2Mo	K31545	60	30		
	Gr P22	21/4Cr- 1Mo	K21590	60	30		
SA-358	Gr 304	18Cr- 8Ni	S30400	75	30	electric-fusion welded austentic chromium-nickel alloy steel pipe low-temperature service	
	Gr 304L	18Cr- 8Ni	S30403	70	25		
	Gr 304N	18Cr- 8Ni-N	S30451	80	35		
	Gr 304LN	18Cr- 8Ni-N	S30453	75	30		
	Gr 304H	18Cr- 8Ni	S30409	75	30		
	Gr 309	23Cr- 12Ni	S30900	75	30		
	Gr 310	25Cr- 20Ni	S31000	75	30		
	Gr 316	16Cr- 12Ni-2Mo	S31600	75	30		
	Gr 316L	16Cr- 12Ni-2Mo	S31603	70	25		
	Gr 316H	16Cr- 12Ni-2Mo	S31609	75	30		
	Gr 316N	16Cr- 12Ni-2Mo-N	S31651	80	35		
	Gr 316N	16Cr- 12Ni-2Mo-N	S31653	75	30		
	Gr 321	18Cr-10Ni-Ti	S32100	75	30		
	Gr 347	18Cr-10Ni-Cb	S34700	75	30		
	Gr 348	18Cr-10Ni-Cb	S34800	75	30		
	Gr XM-19	22Cr-13Ni-5Mn	S22100	100	55		
SA-369	Gr FP1	C-1/2Mo	K11522	55	30	carbon and ferretic alloy steel for high-temperature service	
	Gr FP2	1/2Cr-1/2Mo	K11547	55	30		
	Gr FP5	5Cr-1/2Mo	K41545	60	30		
	Gr FP9	9Cr-1Mo	K90941	60	30		
	Gr FP11	11/4Cr-1/2Mo-Si	K11597	60	30		
	Gr FP12	1Cr-1/2Mo	K11562	60	30		
	Gr FP21	3Cr-1Mo	K31545	60	30		
	Gr FP22	21/4Cr-1Mo	K21590	60	30		

Table B-1: (Continued)

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes	Common Name
SA-376	Gr TP304	18Cr- 8Ni	S30400	75	30	austentic seamless steel pipe for high temperature (central station service)	
	Gr TP304H	18Cr-8Ni	S30409	75	30		
	Gr TP304N	18Cr-8Ni-N	S30451	80	35		
	Gr TP304LN	18Cr-8Ni-N	S30453	75	30		
	Gr TP316	16Cr- 12Ni-2Mo	S31600	75	30		
	Gr TP316H	16Cr- 12Ni-2Mo	S31609	75	30		
	Gr TP316N	16Cr- 12Ni-2Mo-N	S31651	80	35		
	Gr TP316LN	16Cr- 12Ni-2Mo-N	S31653	75	30		
	Gr TP321	18Cr-10Ni-Ti	S32100	75	30	<3/8in	
	Gr TP321	18Cr-10Ni-Ti	S32100	70	25	>3/8in	
	Gr TP321H	18Cr-10Ni-Ti	S32109	75	30	<3/8in	
	Gr TP321H	18Cr-10Ni-Ti	S32109	70	25	>3/8in	
	Gr TP347	18Cr-10Ni-Cb	S34700	75	30		
	Gr TP347H	18Cr-10Ni-Cb	S34709	75	30		
	Gr TP 348	18Cr-10Ni-Cb	S34800	75	30		
SA-409	Gr TP304	18Cr- 8Ni	S30400	75	30	welded pipe of large diameter austentic steel for corrosive or high-temperature service	
	Gr TP304L	18Cr-8Ni	S30403	70	25		
	Gr TP316	16Cr-12Ni-2Mo	S31600	75	30		
	Gr TP316L	16Cr-12Ni-2Mo	S31603	70	25		
	Gr TP321	18Cr-10Ni-Ti	S32100	75	30		
	Gr TP347	18Cr-10Ni-Cb	S34700	75	30		
	Gr TP348	18Cr-10Ni-Ti	S34800	75	30		
SA-426	Gr CP1	C-1/2Mo	J12521	65	35	centrifugally cast ferritic alloy steel for high-temperature service	
	Gr CP2	1/2Cr-1/2Mo	J11547	60	30		
	Gr CP5	5Cr-1/2Mo	J42045	90	60		
	Gr CP9	9Cr-1Mo	J82090	90	60		
	Gr CP11	11/4Cr-1/2Mo	J12072	70	40		
	Gr CP12	1Cr-1/2Mo	J11562	60	30		
	Gr CP21	3Cr-1Mo	J31545	60	30		
	Gr CP22	21/4Cr-1Mo	J21890	70	40		
	Gr CPCA15	13Cr	J91150	90	65		
SA-430	Gr FP304	18Cr-8Ni	S30400	70	30	austentic steel for high-temperature service	
	Gr FP304H	18Cr-8Ni	S30409	70	30		
	Gr FP304N	18Cr-8Ni-N	S03451	75	35		
	Gr FP316	16Cr-12Ni-2Mo	S31600	70	30		
	Gr FP316H	16Cr-12Ni-2Mo	S31609	70	30		
	Gr FP316N	16Cr-12Ni-2Mo-N	S31651	75	35		
	Gr FP321	18Cr-10Ni-Ti	S32100	70	30		
	Gr FP321H	18Cr-10Ni-Ti	S32109	70	30		
	Gr FP347	18Cr-10Ni-Cb	S34700	70	30		
	Gr FP347H	18Cr-10Ni-Cb	S34709	70	30		
SA-452	Gr TP304H	18Cr-8Ni	S30409	75	30	centrifugally cast austentic steel for high temperature	
	Gr TP347H	18Cr-10Ni-Cb	S34709	75	30		
	Gr TP316H	16Cr- 12Ni-2Mo	S31609	75	30		
SA-660	Gr WCA	C-Si Stl	J02504	60	30	centrifugally cast carbon steel for high temperature	
	Gr WCB	C-Si Stl	J03003	70	36		
	Gr WCC	C-Mn-Si Stl	J02505	70	40		

Table B-1: (Continued)

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes	Common Name
SA-451	Gr CPF3	18Cr-8Ni	J92500	70	30	centrifugally cast austentic steel for high-temperature service	
	Gr CPF3A	18Cr-8Ni	J92500	77	25		
	Gr CPF3M	16Cr-12Ni-2Mo	J92800	70	30		
	Gr CPF8	18Cr-8Ni	J92600	70	30		
	Gr CPF8A	18Cr-8Ni	J92600	77	35		
	Gr CPF8M	16Cr-12Ni-2Mo	J92900	70	30		
	Gr CPF8C	18Cr-10Ni-Cb	J92700	70	30		
	Gr CPH8	25Cr-12Ni	J93400	65	28		
	Gr CPK20	25Cr-20Ni	J94202	65	28		
	Gr CPH20	25Cr-12Ni	J93402	70	30		
SA-671	Gr CA55	C Stl	K02801	55	30	electric-fusion welded pipe	SA-515 Gr60
	Gr CB60	C-Si Stl	K02401	60	32		SA-515 Gr65
	Gr CB65	C-Si Stl	K02800	65	35		SA-515 Gr70
	Gr CB70	C-Si Stl	KO3101	70	38		SA-516 Gr60
	Gr CC60	C-Mn-Si Stl	K02100	60	32		
	Gr CC65	C-Mn-Si Stl	K02403	65	35		SA-516 Gr65
	Gr CC70	C-Mn-Si Stl	K02700	70	38		SA-516 Gr70
	Gr CD70	C-Mn-Si Stl	K02400	70	50		SA-537 Cl 1
	Gr CD80	C-Mn-Si Stl	K02400	80	60		SA-537 Cl 2
	Gr CE55	C-Mn-Si Stl	KO2202	55	30		SA-442 Cr 55
	Gr CE60	C-Mn-Si Stl	K02402	60	32		SA-442 Cr 60
	Gr CK75	C-Mn-Si Stl	K02803	75	40		SA-299
SA-672	Gr A45	C Stl	K01700	45	24	electric-fusion welded pipe for high-pressure service at moderate temperature	SA-285 Gr A
	Gr A50	C Stl	K02200	50	27		SA-285 Gr B
	Gr A55	C Stl	K02801	55	30		SA-285 Gr C
	Gr B55	C-Si Stl	K02001	55	30		SA-515 Gr55
	Gr B60	C-Si Stl	K02401	60	32		SA-515 Gr60
	Gr B65	C-Si Stl	K02800	65	35		SA-515 Gr65
	Gr B70	C-Si Stl	K03101	70	38		SA-515 Gr70
	Gr C55	C-Si Stl	K01800	55	30		SA-515 Gr55
	Gr C60	C-Mn-Si Stl	K02100	60	32		SA-516 Gr60
	Gr C65	C-Mn-Si Stl	K02403	65	35		SA-516 Gr65
	Gr C70	C-Mn-Si Stl	K02700	70	38		SA-516 Gr70
	Gr D70	C-Mn-Si Stl	K02400	70	50		SA-537 Cl 1
	Gr D80	C-Mn-Si Stl	K02400	80	60		SA-537 Cl 2

Table B-1: (Continued)

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes	Common Name
SA-672	Gr E55	C-Mn-Si Stl	K02202	55	30	electric-fusion welded pipe for high-pressure service at moderate temperature	SA-442 Gr55
	Gr E60	C-Mn-Si Stl	K02402	60	32		SA-442 Gr 60
	Gr H75	Mn-1/2Mo	K12021	75	45		SA-302 Gr A
	Gr J80	Mn-1/2Mo-1/2Ni	K12539	80	50		SA-533 Gr B, Cl1
	Gr J90	Mn-1/2Mo-1/2Ni	K12539	90	70		SA-533 Gr B, Cl2
	Gr J100	Mn-1/2Mo-1/2Ni	K12539	100	83		SA-533 Gr B, Cl3
	Gr L65	C-1/2Mo	K11820	65	37		SA-204 Gr A
	Gr L70	C-1/2Mo	K12020	70	40		SA-204 Gr B
	Gr L75	C-1/2Mo	K12320	75	43		SA-204 Gr C
	Gr N75	C-Mn-Si Stl	K02803	75	40		SA-299
SA-691	Gr CM65	C-1/2Mo	K11820	65	37		A204 Gr A
	Gr CM70	C-1/2Mo	K12020	70	40		A204 Gr B
	Gr CM75	C-1/2Mo	K12320	75	43		A204 Gr C
	Gr CMSH-70	C-Mn-Si Stl	K02400	70	50		A537 Cl1
	Gr CMS-75	C-Mn-Si Stl	K02803	75	40		
SA-731	Gr TPXM-33	27Cr-1Mo-Ti	S44626	65	40	martensitic stainless steel seamless and welded pipe	
	Gr TPXM-33	27Cr-1Mo	S44627	65	40		
SA-813	Gr TP304	18Cr-8Ni	S30400	75	30	single or double welded austentic stainless steel	
	Gr TP304H	18Cr-8Ni	S30409	75	30		
	Gr TP304L	18Cr-8Ni	S30403	70	25		
	Gr TP304N	18Cr-8Ni-N	S30451	80	32		
	Gr TP304LN	18Cr-8Ni-N	S30453	75	30		
	Gr TP309S	23Cr-12Ni	S30908	75	30		
	Gr TP316	16Cr-12Ni-2Mo	S31600	75	30		
	Gr TP316H	16Cr-12Ni-2Mo	S31609	75	30		
	Gr TP316L	16Cr-12Ni-2Mo	S31603	70	25		
	Gr TP316N	16Cr-12Ni-2Mo-N	S31651	80	32		
	Gr TP321	18Cr-10Ni-Ti	S32100	75	30		
	Gr TP321H	18Cr-10Ni-Ti	S32109	75	30		
	Gr TP347	18Cr-10Ni-Cb	S34700	75	30		
	Gr TP347H	18Cr-10Ni-Cb	S34709	75	30		
	Gr TP348	18Cr-10Ni-Cb	S34800	75	30		
	Gr TP348H	18Cr-10Ni-Cb	S34809	75	30		

Table B-1: (Continued)

Spec.	Gr., Cl., Type	Nominal Composition	UNS #	SMYS	SMTS	Notes	Common Name
SA-814	Gr TP304	18Cr-8Ni	S30400	75	30	cold-worked welded austentic stainless steel	
	Gr TP304H	18Cr-8Ni	S30409	75	30		
	Gr TP304L	18Cr-8Ni	S30403	70	25		
	Gr TP304N	18Cr-8Ni-N	S30451	80	35		
	Gr TP304LN	18Cr-8Ni-N	S30453	75	30		
	Gr TP316	16Cr-12Ni-2Mo	S31600	75	30		
	Gr TP316H	16Cr-12Ni-2Mo	S31609	75	30		
	Gr TP316L	16Cr-12Ni-2Mo	S31603	70	25		
	Gr TP316N	16Cr-12Ni-2Mo-N	S31651	80	35		
	Gr TP321	18Cr-10Ni-Ti	S32100	75	30		
	Gr TP321H	18Cr-10Ni-Ti	S32109	75	30		
	Gr TP347H	18Cr-10Ni-Cb	S34709	75	30		
	Gr TP348	18Cr-10Ni-Cb	S34800	75	30		
	Gr TP348H	18Cr-10Ni-Cb	S34809	75	30		

Spec.=Specification, Gr.=Grade, Cl.=Class, Sm=Seamless, SMYS=Specified Minimum Yield Strength, SMTS=Specified Minimum Tensile Strength

APPENDIX C: PARTIAL MEAN RESISTANCE FACTORS AND ADJUSTED NOMINAL RESISTANCE FACTORS

This appendix provides in tabulated format the calculated mean partial safety factors and the nominal adjusted resistance factors for the performance functions of Table 5-2 under separate headings. Some plots of the mean partial safety factors as well as the summary of the recommended adjusted nominal resistance factors were presented for each performance function in Chapter 6.

C.1. Performance Functions g_1, g_5, g_{10}, and g_{15}

Tables C-1 to C-4 provide the calculated mean values of partial safety factors and Table C-5 the adjusted resistance factor for a given total nominal load factor 1.2.

Table C-1: Mean Partial Load and Resistance Factors for g_1

β	Partial Factor	Design Temperature (^oF) R.T.*	200	400	600	800
Stainless steel						
1.5	φ'_y	0.824	0.824	0.824	0.824	0.824
	γ'_P	1.076	1.076	1.076	1.076	1.076
	γ'_M	1.020	1.020	1.020	1.020	1.020
2.0	φ'_y	0.774	0.774	0.774	0.774	0.774
	γ'_P	1.100	1.100	1.100	1.100	1.100
	γ'_M	1.027	1.027	1.027	1.027	1.027
2.5	φ'_y	0.726	0.726	0.726	0.726	0.726
	γ'_P	1.123	1.123	1.123	1.123	1.123
	γ'_M	1.034	1.034	1.034	1.034	1.034
3.0	φ'_y	0.682	0.682	0.682	0.682	0.682
	γ'_P	1.146	1.146	1.146	1.146	1.146
	γ'_M	1.040	1.040	1.040	1.040	1.040
3.5	φ'_y	0.639	0.639	0.639	0.639	0.639
	γ'_P	1.168	1.168	1.168	1.168	1.168
	γ'_M	1.047	1.047	1.047	1.047	1.047
4.5	φ'_y	0.562	0.562	0.562	0.562	0.562
	γ'_P	1.210	1.210	1.210	1.210	1.210
	γ'_M	1.060	1.060	1.060	1.060	1.060
Carbon Steel						
1.5	φ'_y	0.926	0.926	0.853	0.853	0.853
	γ'_P	1.104	1.104	1.083	1.083	1.083
	γ'_M	1.028	1.028	1.022	1.022	1.022
2.0	φ'_y	0.902	0.902	0.809	0.809	0.809
	γ'_P	1.137	1.137	1.109	1.109	1.109
	γ'_M	1.038	1.038	1.029	1.029	1.029
2.5	φ'_y	0.879	0.879	0.768	0.768	0.768
	γ'_P	1.169	1.169	1.134	1.134	1.134
	γ'_M	1.047	1.047	1.037	1.037	1.037
3.0	φ'_y	0.855	0.855	0.728	0.728	0.728
	γ'_P	1.200	1.200	1.159	1.159	1.159
	γ'_M	1.057	1.057	1.044	1.044	1.044
3.5	φ'_y	0.832	0.832	0.690	0.690	0.690
	γ'_P	1.231	1.231	1.183	1.183	1.183
	γ'_M	1.067	1.067	1.051	1.051	1.051
4.5	φ'_y	0.785	0.785	0.619	0.619	0.619
	γ'_P	1.290	1.290	1.229	1.229	1.229
	γ'_M	1.086	1.086	1.066	1.066	1.066

* R.T.=Room Temperature

Table C-2: Mean Partial Load and Resistance Factors for g_5

β	Partial Factor	Design Temperature (^oF) R.T.*	200	400	600	800
Stainless steel						
1.5	φ'_y	0.834	0.834	0.834	0.834	0.834
	γ'_P	1.116	1.116	1.116	1.116	1.116
	γ'_M	1.019	1.019	1.019	1.019	1.019
2.0	φ'_y	0.786	0.786	0.786	0.786	0.786
	γ'_P	1.152	1.152	1.152	1.152	1.152
	γ'_M	1.025	1.025	1.025	1.025	1.025
2.5	φ'_y	0.739	0.739	0.739	0.739	0.739
	γ'_P	1.186	1.186	1.186	1.186	1.186
	γ'_M	1.032	1.032	1.032	1.032	1.032
3.0	φ'_y	0.695	0.695	0.695	0.695	0.695
	γ'_P	1.219	1.219	1.219	1.219	1.219
	γ'_M	1.038	1.038	1.038	1.038	1.038
3.5	φ'_y	0.653	0.653	0.653	0.653	0.653
	γ'_P	1.251	1.251	1.251	1.251	1.251
	γ'_M	1.045	1.045	1.045	1.045	1.045
4.5	φ'_y	0.576	0.576	0.576	0.576	0.576
	γ'_P	1.313	1.313	1.313	1.313	1.313
	γ'_M	1.057	1.057	1.057	1.057	1.057
Carbon Steel						
1.5	φ'_y	0.934	0.934	0.863	0.863	0.863
	γ'_P	1.150	1.150	1.125	1.125	1.125
	γ'_M	1.025	1.025	1.020	1.020	1.020
2.0	φ'_y	0.912	0.912	0.821	0.821	0.821
	γ'_P	1.197	1.197	1.163	1.163	1.163
	γ'_M	1.034	1.034	1.027	1.027	1.027
2.5	φ'_y	0.890	0.890	0.781	0.781	0.781
	γ'_P	1.243	1.243	1.200	1.200	1.200
	γ'_M	1.043	1.043	1.034	1.034	1.034
3.0	φ'_y	0.867	0.867	0.742	0.742	0.742
	γ'_P	1.287	1.287	1.236	1.236	1.236
	γ'_M	1.052	1.052	1.041	1.041	1.041
3.5	φ'_y	0.845	0.845	0.705	0.705	0.705
	γ'_P	1.330	1.330	1.271	1.271	1.271
	γ'_M	1.061	1.061	1.049	1.049	1.049
4.5	φ'_y	0.800	0.800	0.634	0.634	0.634
	γ'_P	1.413	1.413	1.337	1.337	1.337
	γ'_M	1.080	1.080	1.063	1.063	1.063

* R.T.=Room Temperature

Table C-3: Mean Partial Load and Resistance Factors for g_{10}

β	Partial Factor	Design Temperature (^oF) R.T.*	200	400	600	800
Stainless steel						
1.5	φ'_y	0.972	0.972	0.972	0.972	0.972
	γ'_P	1.218	1.218	1.218	1.218	1.218
	γ'_M	1.018	1.018	1.018	1.018	1.018
2.0	φ'_y	0.965	0.965	0.965	0.965	0.965
	γ'_P	1.337	1.337	1.337	1.337	1.337
	γ'_M	1.023	1.023	1.023	1.023	1.023
2.5	φ'_y	0.959	0.959	0.959	0.959	0.959
	γ'_P	1.478	1.478	1.478	1.478	1.478
	γ'_M	1.027	1.027	1.027	1.027	1.027
3.0	φ'_y	0.954	0.954	0.954	0.954	0.954
	γ'_P	1.643	1.643	1.643	1.643	1.643
	γ'_M	1.031	1.031	1.031	1.031	1.031
3.5	φ'_y	0.947	0.947	0.947	0.947	0.947
	γ'_P	1.832	1.832	1.832	1.832	1.832
	γ'_M	1.035	1.035	1.035	1.035	1.035
4.5	φ'_y	0.934	0.934	0.934	0.934	0.934
	γ'_P	2.281	2.281	2.281	2.281	2.281
	γ'_M	1.044	1.044	1.044	1.044	1.044
Carbon Steel						
1.5	φ'_y	0.972	0.972	0.927	0.927	0.927
	γ'_P	1.218	1.218	1.195	1.195	1.195
	γ'_M	1.018	1.018	1.017	1.017	1.017
2.0	φ'_y	0.965	0.965	0.911	0.911	0.911
	γ'_P	1.337	1.337	1.304	1.304	1.304
	γ'_M	1.023	1.023	1.022	1.022	1.022
2.5	φ'_y	0.959	0.959	0.896	0.896	0.896
	γ'_P	1.478	1.478	1.435	1.435	1.435
	γ'_M	1.027	1.027	1.026	1.026	1.026
3.0	φ'_y	0.954	0.954	0.882	0.882	0.882
	γ'_P	1.643	1.643	1.588	1.588	1.588
	γ'_M	1.031	1.031	1.030	1.030	1.030
3.5	φ'_y	0.947	0.947	0.867	0.867	0.867
	γ'_P	1.832	1.832	1.762	1.762	1.762
	γ'_M	1.035	1.035	1.034	1.034	1.034
4.5	φ'_y	0.934	0.934	0.835	0.835	0.835
	γ'_P	2.281	2.281	2.172	2.172	2.172
	γ'_M	1.044	1.044	1.042	1.042	1.042

* R.T.=Room Temperature

Table C-4: Mean Partial Load and Resistance Factors for g_{15}

β	Partial Factor	Design Temperature (^oF) R.T.*	200	400	600	800
Stainless steel						
1.5	φ'_y	0.977	0.977	0.977	0.977	0.977
	γ'_P	1.303	1.303	1.303	1.303	1.303
	γ'_M	1.015	1.015	1.015	1.015	1.015
2.0	φ'_y	0.971	0.971	0.971	0.971	0.971
	γ'_P	1.465	1.465	1.465	1.465	1.465
	γ'_M	1.019	1.019	1.019	1.019	1.019
2.5	φ'_y	0.965	0.965	0.965	0.965	0.965
	γ'_P	1.656	1.656	1.656	1.656	1.656
	γ'_M	1.023	1.023	1.023	1.023	1.023
3.0	φ'_y	0.960	0.960	0.960	0.960	0.960
	γ'_P	1.879	1.879	1.879	1.879	1.879
	γ'_M	1.027	1.027	1.027	1.027	1.027
3.5	φ'_y	0.954	0.954	0.954	0.954	0.954
	γ'_P	2.134	2.134	2.134	2.134	2.134
	γ'_M	1.031	1.031	1.031	1.031	1.031
4.5	φ'_y	0.940	0.940	0.940	0.940	0.940
	γ'_P	2.739	2.739	2.739	2.739	2.739
	γ'_M	1.040	1.040	1.040	1.040	1.040
Carbon Steel						
1.5	φ'_y	0.977	0.977	0.939	0.939	0.939
	γ'_P	1.303	1.303	1.281	1.281	1.281
	γ'_M	1.015	1.015	1.014	1.014	1.014
2.0	φ'_y	0.971	0.971	0.924	0.924	0.924
	γ'_P	1.465	1.465	1.433	1.433	1.433
	γ'_M	1.019	1.019	1.018	1.018	1.018
2.5	φ'_y	0.965	0.965	0.910	0.910	0.910
	γ'_P	1.656	1.656	1.614	1.614	1.614
	γ'_M	1.023	1.023	1.022	1.022	1.022
3.0	φ'_y	0.960	0.960	0.896	0.896	0.896
	γ'_P	1.879	1.879	1.823	1.823	1.823
	γ'_M	1.027	1.027	1.026	1.026	1.026
3.5	φ'_y	0.954	0.954	0.881	0.881	0.881
	γ'_P	2.134	2.134	2.061	2.061	2.061
	γ'_M	1.031	1.031	1.030	1.030	1.030
4.5	φ'_y	0.940	0.940	0.849	0.849	0.849
	γ'_P	2.739	2.739	2.618	2.618	2.618
	γ'_M	1.040	1.040	1.038	1.038	1.038

* R.T.=Room Temperature

Table C-5a: Adjusted Nominal Resistance Factors, φ, for Total Load Factor γ=1.2 and Carbon Steel for g_1, g_5, g_{10}, and g_{15}.

Service Level	Temper. (^{o}F)	***Adjusted Value of φ for β:***					
		1.5	2	2.5	3	3.5	4.5
Design and A	70	0.99	0.93	0.87	0.82	0.77	0.68
	200	0.81	0.76	0.71	0.67	0.63	0.56
	400	0.72	0.66	0.61	0.56	0.52	0.51
	600	0.62	0.57	0.52	0.48	0.45	0.44
	800	0.58	0.53	0.49	0.45	0.42	0.41
B	70	1.01	0.94	0.87	0.82	0.76	0.67
	200	0.83	0.77	0.72	0.67	0.63	0.55
	400	0.74	0.67	0.62	0.57	0.52	0.44
	600	0.64	0.58	0.53	0.49	0.45	0.38
	800	0.59	0.54	0.50	0.45	0.42	0.36
C	70	1.21	1.09	0.98	0.87	0.77	0.61
	200	1.11	1.00	0.89	0.79	0.70	0.55
	400	1.20	1.07	0.96	0.85	0.75	0.58
	600	1.13	1.01	0.90	0.80	0.70	0.55
	800	0.90	0.81	0.72	0.64	0.56	0.44
D	70	1.21	1.07	0.94	0.82	0.71	0.54
	200	1.11	0.98	0.85	0.75	0.65	0.50
	400	1.21	1.06	0.92	0.80	0.69	0.52
	600	1.13	1.00	0.87	0.75	0.65	0.49
	800	0.91	0.80	0.69	0.60	0.52	0.39

Table C-5b: Adjusted Nominal Resistance Factors, φ, for Total Load Factor γ=1.2 and Stainless Steel for g_1, g_5, g_{10}, and g_{15}.

Service Level	Temper. (°F)	***Adjusted Value of φ for β:*** 1.5	2	2.5	3	3.5	4.5
Design and A	70	1.01	0.92	0.84	0.77	0.70	0.59
	200	0.88	0.81	0.74	0.67	0.62	0.52
	400	0.72	0.66	0.60	0.55	0.50	0.42
	600	0.64	0.59	0.54	0.49	0.45	0.38
	800	0.60	0.55	0.50	0.46	0.42	0.35
B	70	1.04	0.95	0.86	0.78	0.71	0.59
	200	0.91	0.83	0.75	0.68	0.62	0.51
	400	0.74	0.67	0.61	0.56	0.51	0.42
	600	0.66	0.60	0.54	0.50	0.45	0.37
	800	0.62	0.58	0.51	0.46	0.42	0.35
C	70	1.19	1.07	0.96	0.86	0.76	0.60
	200	1.03	0.93	0.83	0.74	0.66	0.52
	400	0.93	0.83	0.75	0.67	0.59	0.46
	600	0.93	0.83	0.75	0.67	0.59	0.46
	800	0.90	0.81	0.72	0.64	0.57	0.45
D	70	1.19	1.050	0.92	0.80	0.70	0.53
	200	1.03	0.911	0.80	0.70	0.61	0.46
	400	0.93	0.82	0.72	0.63	0.54	0.41
	600	0.93	0.82	0.72	0.63	0.54	0.41
	800	0.90	0.79	0.69	0.60	0.53	0.40

C.2. Performance Function g_2

Table C-6 presents the calculated mean load and resistance factors for the performance function g_2.

Table C-6: Load and Resistance Factors Applied to Mean Values of Variables for P.F. g_2

Temperature, T (°F)	β	Carbon Steel			Stainless Steel		
		μ_y	ϕ'_y	γ'_A	μ_y	ϕ'_y	γ'_A
≤200	6	2.007	0.697	1.400	2.856	0.448	1.279
>200		2.569	0.508	1.306	2.856	0.448	1.279
≤200	7	2.232	0.652	1.456	3.379	0.390	1.317
>200		2.984	0.452	1.348	3.379	0.390	1.317
≤200	8	2.478	0.609	1.511	3.992	0.339	1.355
>200		3.462	0.401	1.389	3.992	0.339	1.355

Table C-7: Adjusted Nominal Values of Load and Resistance Factors for g_2

Temperature T (°F)	β	Carbon Steel		Stainless Steel	
		ϕ_y	γ_A	ϕ_y	γ_A
Room Temperature	6	0.68	1.2	0.53	1.2
200		0.56	1.2	0.46	1.2
400		0.41	1.2	0.38	1.2
≥600		0.34	1.2	0.33	1.2
Room Temperature	7	0.61	1.2	0.45	1.2
200		0.50	1.2	0.39	1.2
400		0.35	1.2	0.32	1.2
≥600		0.29	1.2	0.27	1.2
Room Temperature	8	0.55	1.2	0.38	1.2
200		0.45	1.2	0.33	1.2
400		0.30	1.2	0.27	1.2
≥600		0.25	1.2	0.23	1.2

C.3. Performance Function g_3

Table C-8 provides the calculated mean load and resistance factors for performance function g_3. In this table, μ_{fy} is the converged mean value of the steel resistance. Table C-9 presents the adjusted nominal resistance factor for γ_A=1.1 and γ_{PDes}=1.2.

Table C-8: Mean Load and Resistance Factors for Different Operating Temperature, T, for g_3

	β	Carbon Steel ($T \leq 200^{o}F$)				Carbon Steel ($T > 200^{o}F$)				Stainless Steel (for any T)			
		μ_{fy}	ϕ'_y	γ'_A	γ'_{PD}	μ_{fy}	ϕ'_y	γ'_A	γ'_{PD}	μ_{fy}	ϕ'_y	γ'_A	γ'_{PD}
$f_{PDes}=0.5$	2.0	1.86	0.883	1.115	1.057	2.03	0.790	1.085	1.040	2.11	0.755	1.076	1.035
	3.0	2.07	0.829	1.169	1.090	2.35	0.703	1.124	1.062	2.49	0.659	1.111	1.055
	3.5	2.18	0.803	1.194	1.107	2.53	0.664	1.143	1.074	2.70	0.615	1.128	1.065
	4.5	2.41	0.752	1.243	1.143	2.93	0.590	1.179	1.097	3.18	0.536	1.162	1.086
	5.5	2.67	0.704	1.290	1.180	3.38	0.524	1.214	1.121	3.74	0.466	1.193	1.107
$f_{PDes}=1$	2.0	2.47	0.883	1.088	1.094	2.70	0.789	1.064	1.065	2.80	0.754	1.058	1.057
	3.0	2.74	0.829	1.126	1.15	3.12	0.703	1.094	1.103	3.30	0.658	1.084	1.090
	3.5	2.89	0.804	1.145	1.18	3.36	0.663	1.108	1.122	3.59	0.615	1.097	1.107
	4.5	3.21	0.755	1.180	1.24	3.89	0.591	1.135	1.163	4.22	0.536	1.122	1.142
	5.5	3.56	0.709	1.211	1.311	4.50	0.526	1.160	1.205	4.97	0.467	1.145	1.180
$f_{PDes}=5$	2.0	7.57	0.894	1.025	1.149	8.21	0.799	1.020	1.109	8.52	0.763	1.018	1.097
	3.0	8.52	0.847	1.035	1.236	9.60	0.718	1.028	1.172	10.12	0.671	1.026	1.153
	3.5	9.03	0.825	1.040	1.283	10.37	0.680	1.032	1.205	11.03	0.629	1.029	1.182
	4.5	10.17	0.782	1.048	1.381	12.12	0.611	1.039	1.274	13.10	0.553	1.036	1.243
	5.5	11.45	0.742	1.054	1.489	14.16	0.550	1.045	1.348	15.57	0.487	1.042	1.308
$f_{PDes}=10$	2.0	14.01	0.898	1.013	1.156	15.16	0.803	1.010	1.116	15.71	0.767	1.009	1.104
	3.0	15.83	0.852	1.018	1.247	17.77	0.723	1.015	1.183	18.72	0.676	1.014	1.164
	3.5	16.82	0.831	1.020	1.295	19.24	0.686	1.017	1.218	20.44	0.634	1.015	1.195
	4.5	19.02	0.789	1.024	1.398	22.56	0.618	1.020	1.291	24.36	0.559	1.019	1.260
	5.5	21.50	0.75	1.028	1.509	26.46	0.556	1.023	1.369	29.03	0.493	1.022	1.329
$f_{PDes}=50$	2.0	65.56	0.901	1.003	1.161	70.81	0.807	1.002	1.122	73.33	0.771	1.002	1.110
	3.0	74.40	0.857	1.004	1.255	83.29	0.728	1.003	1.192	87.66	0.680	1.003	1.173
	3.5	79.26	0.836	1.004	1.305	90.34	0.691	1.003	1.229	95.84	0.639	1.003	1.205
	4.5	89.96	0.795	1.005	1.410	106.28	0.623	1.004	1.305	114.58	0.565	1.004	1.274
	5.5	102.12	0.756	1.006	1.524	125.04	0.563	1.005	1.387	136.99	0.498	1.005	1.346

Table C-9: Evaluated Nominal Resistance Factor, φ_y, for γ_A=1.1 and γ_{PDes}=1.2 for g_3

	β	Carbon Steel					Stainless Steel				
		R. T.	200°F	400°F	600°F	800°F	R. T.	200°F	400°F	600°F	800°F
f_{PDes}=0.5	2.0	0.94*	0.85	0.73	0.63	0.59	0.93*	0.89	0.73	0.64	0.60
	3.0	0.93	0.76	0.63	0.54	0.51	0.86	0.75	0.61	0.55	0.51
	3.5	0.88	0.73	0.58	0.50	0.47	0.79	0.69	0.57	0.50	0.47
	4.5	0.80	0.66	0.50	0.44	0.41	0.67	0.59	0.48	0.43	0.40
	5.5	0.72	0.59	0.44	0.38	0.35	0.57	0.50	0.41	0.36	0.34
f_{PDes}=1	2.0	0.96*	0.87	0.74	0.64	0.60	0.95*	0.90	0.74	0.66	0.62
	3.0	0.95	0.78	0.64	0.55	0.52	0.88	0.77	0.63	0.56	0.52
	3.5	0.90	0.74	0.60	0.51	0.48	0.81	0.70	0.58	0.51	0.48
	4.5	0.81	0.67	0.51	0.44	0.41	0.69	0.60	0.49	0.44	0.41
	5.5	0.73	0.60	0.44	0.38	0.36	0.58	0.51	0.42	0.37	0.35
f_{PDes}=5	2.0	0.97*	0.87	0.75	0.65	0.61	0.96*	0.92	0.75	0.67	0.63
	3.0	0.94	0.78	0.64	0.55	0.52	0.88	0.77	0.63	0.56	0.53
	3.5	0.89	0.73	0.60	0.51	0.48	0.81	0.71	0.58	0.51	0.48
	4.5	0.79	0.65	0.51	0.44	0.41	0.68	0.60	0.49	0.43	0.41
	5.5	0.70	0.58	0.44	0.38	0.35	0.57	0.50	0.41	0.36	0.34
f_{PDes}=10	2.0	0.97*	0.87	0.75	0.65	0.60	0.96	0.92	0.75	0.67	0.63
	3.0	0.94	0.77	0.64	0.55	0.52	0.88	0.77	0.63	0.56	0.52
	3.5	0.88	0.72	0.59	0.51	0.48	0.81	0.70	0.58	0.51	0.48
	4.5	0.78	0.64	0.51	0.44	0.41	0.68	0.59	0.48	0.43	0.40
	5.5	0.69	0.57	0.43	0.37	0.35	0.57	0.50	0.41	0.36	0.34
f_{PDes}=50	2.0	0.97*	0.87	0.75	0.65	0.60	0.96	0.92	0.75	0.67	0.62
	3.0	0.93	0.76	0.64	0.55	0.51	0.88	0.77	0.63	0.56	0.52
	3.5	0.87	0.72	0.59	0.51	0.47	0.80	0.70	0.57	0.51	0.48
	4.5	0.77	0.63	0.50	0.43	0.40	0.67	0.59	0.48	0.43	0.40
	5.5	0.68	0.56	0.43	0.37	0.34	0.56	0.49	0.40	0.36	0.33

* For these factors γ_A=1.0 and γ_{PD}=1.1, R. T.=Room Temperature

C.4. Performance Function g_4

Table C-10 gives the mean load and resistance factors for the performance function g_4. In this table, μ_{fy} is the converged mean value of the steel resistance. Table C-11 shows the evaluated adjusted nominal resistance factors for γ_A=1.1 and γ_{Pmax}=1.2.

Table C-10: Mean Load and Resistance Factors for Different Operating Temperature, T, for g_4

	β	Carbon Steel ($T \le 200^oF$)				Carbon Steel ($T > 200^oF$)				Stainless Steel (for any T)			
		μ_{fy}	ϕ'_y	γ'_A	γ'_{Pmax}	μ_{fy}	ϕ'_y	γ'_A	γ'_{Pmax}	μ_{fy}	ϕ'_y	γ'_A	γ'_{Pmax}
f_{Pmax}=0.5	2.0	1.87	0.889	1.108	1.098	2.03	0.794	1.083	1.057	2.11	0.758	1.075	1.046
	3.0	2.09	0.843	1.149	1.221	2.36	0.711	1.118	1.119	2.49	0.665	1.108	1.097
	3.5	2.21	0.824	1.164	1.317	2.55	0.674	1.134	1.162	2.71	0.623	1.123	1.130
	4.5	2.50	0.794	1.180	1.605	2.97	0.609	1.161	1.293	3.21	0.549	1.150	1.225
f_{Pmax}=1	2.0	2.51	0.900	1.071	1.187	2.71	0.802	1.058	1.116	2.81	0.765	1.054	1.097
	3.0	2.86	0.870	1.086	1.405	3.19	0.732	1.078	1.255	3.35	0.681	1.073	1.210
	3.5	3.08	0.858	1.089	1.551	3.47	0.704	1.084	1.357	3.67	0.647	1.080	1.293
	4.5	3.60	0.834	1.093	1.907	4.14	0.657	1.090	1.629	4.43	0.590	1.089	1.527
f_{Pmax}=3	2.0	5.21	0.921	1.026	1.258	5.57	0.826	1.024	1.191	5.75	0.787	1.023	1.167
	3.0	6.19	0.898	1.029	1.510	6.75	0.773	1.028	1.397	7.04	0.722	1.028	1.352
	3.5	6.80	0.887	1.030	1.668	7.48	0.751	1.030	1.529	7.85	0.694	1.029	1.473
	4.5	8.28	0.864	1.031	2.043	9.30	0.706	1.031	1.846	9.84	0.643	1.031	1.766
f_{PDes}= 5	2.0	7.95	0.926	1.016	1.269	8.46	0.834	1.015	1.208	8.72	0.796	1.014	1.185
	3.0	9.56	0.904	1.018	1.526	10.37	0.784	1.017	1.423	10.80	0.734	1.017	1.381
	3.5	10.57	0.893	1.018	1.685	11.57	0.762	1.018	1.559	12.10	0.707	1.018	1.507
	4.5	13.02	0.870	1.019	2.063	14.54	0.717	1.019	1.881	15.35	0.655	1.018	1.807
f_{PDes}= 10	2.0	14.81	0.930	1.008	1.276	15.71	0.841	1.007	1.220	16.18	0.803	1.007	1.198
	3.0	18.01	0.909	1.009	1.535	19.46	0.793	1.009	1.442	20.23	0.743	1.009	1.402
	3.5	20.01	0.898	1.009	1.696	21.82	0.770	1.009	1.580	22.78	0.716	1.009	1.51
	4.5	24.88	0.875	1.009	2.076	27.67	0.726	1.009	1.906	29.17	0.664	1.009	1.836
f_{PDes} = 50	2.0	69.75	0.933	1.002	1.281	73.80	0.847	1.002	1.230	75.90	0.809	1.001	1.209
	3.0	85.64	0.912	1.002	1.542	92.26	0.800	1.002	1.455	95.77	0.751	1.002	1.418
	3.5	95.57	0.902	1.002	1.703	103.89	0.777	1.002	1.56	108.34	0.724	1.002	1.550
	4.5	119.80	0.879	1.002	2.086	132.83	0.732	1.002	1.925	139.84	0.672	1.002	1.858

Table C-11: Evaluated Nominal Resistance Factor, φ_y, for γ_A=1.1 and γ_{Pmax}=1.2 for g_4

	β	Carbon Steel					Stainless Steel				
		R. T.	200°F	400°F	600°F	800°F	R. T.	200°F	400°F	600°F	800°F
f_{Pmax}=0.5	2.0	0.95*	0.86	0.74	0.64	0.60	0.94*	0.90	0.74	0.66	0.62
	3.0	0.94	0.77	0.64	0.55	0.51	0.88	0.76	0.63	0.56	0.52
	3.5	0.89	0.73	0.59	0.51	0.48	0.81	0.70	0.58	0.51	0.48
	4.5	0.78	0.64	0.51	0.44	0.41	0.68	0.59	0.49	0.43	0.40
f_{Pmax}=1	2.0	0.97*	0.88	0.76	0.65	0.61	0.97*	0.93	0.76	0.67	0.63
	3.0	0.93	0.77	0.64	0.56	0.52	0.89	0.78	0.63	0.56	0.53
	3.5	0.87	0.71	0.59	0.51	0.48	0.81	0.71	0.58	0.52	0.48
	4.5	0.74	0.61	0.50	0.43	0.40	0.67	0.59	0.48	0.43	0.40
f_{Pmax}=3	2.0	0.97*	0.87	0.76	0.66	0.61	0.98*	0.94	0.77	0.68	0.61
	3.0	0.89	0.73	0.63	0.54	0.51	0.84	0.76	0.63	0.56	0.50
	3.5	0.78	0.67	0.57	0.49	0.46	0.75	0.69	0.56	0.50	0.45
	4.5	0.64	0.55	0.46	0.39	0.37	0.60	0.55	0.45	0.40	0.36
f_{Pmax}=5	2.0	0.97*	0.87	0.76	0.66	0.61	0.98*	0.94	0.77	0.68	0.64
	3.0	0.88	0.72	0.62	0.54	0.50	0.87	0.76	0.62	0.55	0.51
	3.5	0.79	0.65	0.56	0.48	0.45	0.77	0.67	0.55	0.49	0.46
	4.5	0.64	0.53	0.44	0.38	0.36	0.61	0.53	0.43	0.39	0.36
f_{Pmax}=10	2.0	0.96*	0.86	0.76	0.66	0.61	0.98*	0.93	0.76	0.68	0.64
	3.0	0.86	0.71	0.61	0.53	0.49	0.86	0.75	0.61	0.54	0.51
	3.5	0.78	0.64	0.55	0.47	0.44	0.76	0.66	0.54	0.48	0.45
	4.5	0.62	0.51	0.43	0.37	0.35	0.59	0.52	0.42	0.38	0.35
f_{Pmax}=50	2.0	0.95*	0.86	0.76	0.65	0.61	0.98*	0.93	0.76	0.68	0.63
	3.0	0.85	0.70	0.61	0.52	0.49	0.85	0.74	0.60	0.54	0.50
	3.5	0.76	0.63	0.54	0.46	0.43	0.75	0.65	0.53	0.47	0.44
	4.5	0.61	0.50	0.42	0.36	0.34	0.58	0.51	0.41	0.37	0.34

* γ_A=1.0 and γ_{Pmax}=1.1

C.5. Performance Function g_6

Table C-12 gives the calculated mean load and resistance factors for performance function g_6. In this table, μ_{fy} is the converged mean value of the steel resistance. Table C-13 presents the adjusted nominal resistance factors for nominal load factors γ_A=1.1 and γ_M=γ_{PB}=1.2.

Table C-12a: Calculated Mean Load and Resistance Factors for Carbon Steel, $T \leq 200^oF$ for g_6

	β	Carbon Steel $T \leq 200^oF$														
		f_M=0.5					f_M=1.0					f_M=2.0				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M
f_{PB}=0.5	2	2.47	0.88	1.088	1.073	1.101	3.11	0.888	1.065	1.050	1.173	4.46	0.900	1.040	1.026	1.230
	3	2.74	0.83	1.127	1.117	1.166	3.48	0.840	1.092	1.078	1.288	5.06	0.858	1.054	1.040	1.381
	3.5	2.88	0.80	1.146	1.140	1.202	3.68	0.817	1.104	1.091	1.353	5.39	0.838	1.060	1.046	1.466
	4.5	3.20	0.75	1.181	1.187	1.278	4.11	0.774	1.125	1.114	1.500	6.14	0.800	1.070	1.055	1.657
f_{PB}=1	2	3.09	0.85	1.068	1.129	1.073	3.72	0.886	1.056	1.099	1.139	5.04	0.896	1.037	1.059	1.208
	3	3.44	0.83	1.098	1.209	1.117	4.14	0.836	1.079	1.157	1.229	5.68	0.851	1.051	1.089	1.346
	3.5	3.63	0.81	1.112	1.253	1.139	4.38	0.812	1.090	1.186	1.278	6.04	0.830	1.057	1.103	1.423
	4.5	4.04	0.76	1.136	1.350	1.184	4.88	0.767	1.110	1.247	1.387	6.82	0.790	1.068	1.126	1.599
f_{PB}=3	2	5.72	0.90	1.032	1.200	1.025	6.30	0.895	1.030	1.184	1.061	7.53	0.893	1.026	1.150	1.124
	3	6.48	0.85	1.043	1.325	1.040	7.10	0.850	1.041	1.300	1.094	8.46	0.846	1.036	1.241	1.198
	3.5	6.89	0.83	1.049	1.393	1.046	7.54	0.828	1.046	1.364	1.109	8.97	0.823	1.041	1.290	1.236
	4.5	7.82	0.80	1.057	1.544	1.058	8.51	0.787	1.055	1.504	1.137	10.08	0.781	1.049	1.396	1.315
f_{PB}=5	2	8.40	0.90	1.020	1.226	1.000	8.97	0.902	1.019	1.207	1.034	10.14	0.898	1.018	1.186	1.078
	3	9.59	0.86	1.027	1.365	1.005	10.19	0.859	1.027	1.336	1.053	11.46	0.853	1.025	1.302	1.120
	3.5	10.25	0.84	1.030	1.441	1.006	10.87	0.839	1.030	1.406	1.061	12.19	0.832	1.028	1.366	1.140
	4.5	11.73	0.81	1.035	1.606	1.009	12.38	0.800	1.035	1.561	1.074	13.80	0.791	1.033	1.507	1.176
f_{PB}=10	2	15.13	0.91	1.010	1.234	0.991	15.68	0.908	1.010	1.223	1.012	16.81	0.905	1.010	1.214	1.035
	3	17.42	0.87	1.014	1.377	0.992	18.00	0.868	1.014	1.360	1.021	19.20	0.864	1.014	1.346	1.054
	3.5	18.70	0.85	1.015	1.455	0.992	19.30	0.849	1.015	1.434	1.024	20.53	0.844	1.015	1.419	1.062
	4.5	21.56	0.81	1.018	1.624	0.993	22.19	0.812	1.018	1.598	1.030	23.49	0.806	1.018	1.577	1.076
f_{PB}=50	2	69.06	0.91	1.002	1.215	1.011	69.60	0.915	1.002	1.234	0.994	70.69	0.914	1.002	1.232	0.998
	3	80.21	0.88	1.003	1.349	1.020	80.78	0.877	1.003	1.376	0.995	81.92	0.876	1.003	1.374	1.002
	3.5	86.45	0.86	1.003	1.422	1.024	87.03	0.858	1.003	1.454	0.996	88.19	0.857	1.003	1.452	1.003
	4.5	100.44	0.82	1.004	1.581	1.030	101.05	0.823	1.004	1.623	0.997	102.27	0.821	1.004	1.620	1.005

Table C-12b: Mean Load and Resistance Factors for Carbon Steel, T>200°F for g_6

	β	Carbon Steel, T>200°F														
		f_M=0.5					f_M=1.0					f_M=2.0				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M
f_{PB}=0.5	2	2.69	0.789	1.064	1.049	1.068	3.38	0.794	1.050	1.035	1.119	4.82	0.805	1.032	1.019	1.169
	3	3.12	0.703	1.094	1.080	1.111	3.93	0.710	1.071	1.056	1.195	5.66	0.727	1.045	1.031	1.278
	3.5	3.35	0.663	1.108	1.095	1.133	4.24	0.672	1.081	1.066	1.237	6.14	0.691	1.051	1.036	1.338
	4.5	3.88	0.591	1.135	1.127	1.181	4.93	0.602	1.100	1.086	1.329	7.23	0.626	1.061	1.046	1.471
f_{PB}=1	2	3.37	0.790	1.051	1.088	1.049	4.05	.792	1.042	1.069	1.095	5.46	0.800	1.029	1.044	1.149
	3	3.91	0.706	1.074	1.142	1.081	4.70	0.708	1.061	1.110	1.155	6.39	0.720	1.042	1.068	1.245
	3.5	4.21	0.667	1.085	1.171	1.096	5.06	0.669	1.069	1.131	1.188	6.91	0.683	1.047	1.080	1.298
	4.5	4.87	0.595	1.105	1.232	1.128	5.88	0.598	1.086	1.174	1.257	8.09	0.616	1.057	1.101	1.415
f_{PB}=3	2	6.19	0.804	1.025	1.147	1.018	6.83	0.800	1.023	1.133	1.044	8.17	0.798	1.020	1.108	1.089
	3	7.26	0.725	1.036	1.237	1.030	7.99	0.720	1.033	1.215	1.071	9.54	0.716	1.028	1.172	1.143
	3.5	7.87	0.688	1.040	1.286	1.036	8.64	0.683	1.038	1.260	1.083	10.30	0.679	1.032	1.207	1.170
	4.5	9.25	0.622	1.048	1.392	1.046	10.12	0.615	1.046	1.356	1.107	12.03	0.610	1.040	1.279	1.228
f_{PB}=5	2	9.06	0.810	1.016	1.016	1.007	9.68	0.807	1.016	1.155	1.025	10.98	0.803	1.014	1.136	1.058
	3	10.70	0.734	1.023	1.023	1.015	11.40	0.729	1.022	1.250	1.041	12.87	0.723	1.020	1.220	1.091
	3.5	11.63	0.699	1.026	1.026	1.018	12.37	0.693	1.025	1.301	1.048	13.93	0.688	1.023	1.265	1.107
	4.5	13.75	0.633	1.031	1.031	1.024	14.58	0.627	1.030	1.412	1.061	16.35	0.619	1.028	1.362	1.139
f_{PB}=10	2	16.25	0.817	1.009	1.009	0.999	16.86	0.815	1.009	1.173	1.008	18.12	0.811	1.008	1.163	1.027
	3	19.33	0.743	1.012	1.012	1.002	20.01	0.740	1.012	1.277	1.016	21.41	0.734	1.011	1.262	1.043
	3.5	21.09	0.708	1.013	1.013	1.004	21.80	0.705	1.013	1.334	1.019	23.28	0.699	1.013	1.316	1.050
	4.5	25.11	0.644	1.016	1.016	1.007	25.90	0.641	1.016	1.455	1.025	27.54	0.634	1.015	1.431	1.063
f_{PB}=50	2	73.92	0.824	1.002	1.002	0.991	74.52	0.823	1.002	1.187	0.993	75.73	0.822	1.002	1.185	0.997
	3	88.59	0.751	1.002	1.002	0.992	89.25	0.750	1.002	1.300	0.994	90.58	0.749	1.002	1.297	1.000
	3.5	96.98	0.717	1.003	1.003	0.992	97.67	0.717	1.003	1.360	0.995	99.07	0.715	1.003	1.356	1.001
	4.5	116.25	0.654	1.003	1.003	0.993	117.01	0.653	1.003	1.489	0.996	118.54	0.652	1.003	1.485	1.003

Table C-12c: Mean Load and Resistance Factors for Stainless Steel and any T for g_6

	β	Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{PB}	γ'_M
f_{PB}=0.5	2	2.80	0.754	1.058	1.043	1.059	3.51	0.758	1.045	1.031	1.104	4.99	0.769	1.029	1.017	1.150
	3	3.29	0.658	1.085	1.070	1.096	4.15	0.664	1.065	1.050	1.171	5.96	0.679	1.042	1.028	1.246
	3.5	3.58	0.614	1.097	1.083	1.116	4.52	0.622	1.074	1.059	1.207	6.52	0.639	1.047	1.033	1.299
	4.5	4.27	0.536	1.122	1.111	1.157	5.35	0.545	1.092	1.077	1.286	7.79	0.566	1.057	1.042	1.415
f_{PB}=1	2	3.50	0.756	1.046	1.077	1.043	4.20	0.757	1.038	1.061	1.083	5.66	0.764	1.027	1.039	1.132
	3	4.13	0.660	1.067	1.124	1.071	4.96	0.662	1.055	1.097	1.136	6.73	0.673	1.038	1.061	1.216
	3.5	4.48	0.617	1.077	1.149	1.085	5.40	0.619	1.063	1.115	1.164	7.34	0.632	1.043	1.072	1.262
	4.5	5.29	0.539	1.095	1.202	1.113	6.37	0.542	1.078	1.153	1.224	8.74	0.557	1.053	1.093	1.363
f_{PB}=3	2	6.41	0.768	1.023	1.131	1.015	7.08	0.764	1.021	1.118	1.039	8.47	0.763	1.018	1.095	1.079
	3	7.65	0.677	1.033	1.211	1.029	8.42	0.673	1.031	1.191	1.063	10.06	0.670	1.026	1.153	1.126
	3.5	8.35	0.636	1.037	1.254	1.032	9.19	0.631	1.035	1.230	1.075	10.96	0.628	1.030	1.183	1.151
	4.5	9.97	0.562	1.045	1.347	1.042	10.93	0.556	1.043	1.313	1.097	13.01	0.552	1.036	1.247	1.202
f_{PB}=5	2	9.37	0.774	1.015	1.147	1.006	10.03	0.771	1.014	1.139	1.022	11.38	0.767	1.013	1.122	1.051
	3	11.24	0.686	1.021	1.237	1.013	11.99	0.682	1.020	1.223	1.037	13.56	0.676	1.019	1.196	1.082
	3.5	12.32	0.646	1.024	1.285	1.016	13.12	0.641	1.023	1.269	1.044	14.80	0.635	1.021	1.235	1.097
	4.5	14.79	0.573	1.029	1.388	1.022	15.71	0.568	1.028	1.366	1.056	17.67	0.560	1.026	1.320	1.126
f_{PB}=10	2	16.80	0.781	1.008	1.161	0.998	17.44	0.778	1.008	1.156	1.007	18.75	0.775	1.0008	1.147	1.024
	3	20.28	0.695	1.011	1.258	1.001	21.01	0.692	1.011	1.250	1.014	22.50	0.686	1.011	1.236	1.039
	3.5	22.29	0.655	1.013	1.309	1.003	23.07	0.652	1.012	1.301	1.017	24.66	0.646	1.012	1.283	1.046
	4.5	26.94	0.583	1.015	1.420	1.006	27.82	0.580	1.015	1.409	1.023	29.62	0.574	1.014	1.386	1.058
f_{PB}=50	2	76.32	0.788	1.002	1.172	0.991	76.95	0.787	1.002	1.171	0.993	78.22	0.786	1.002	1.169	0.996
	3	92.80	0.703	1.002	1.275	0.992	93.51	0.702	1.002	1.273	0.994	94.93	0.701	1.002	1.270	0.999
	3.5	102.34	0.664	1.003	1.329	0.992	103.08	0.663	1.003	1328	0.995	104.59	0.662	1.003	1.324	1.000
	4.5	124.46	0.593	1.003	1.446	0.992	125.30	0.592	1.003	1.444	0.996	126.99	0.591	1.003	1.440	1.003

Table C-13a: Adjusted Nominal Resistance Factors for Carbon Steel and γ_A=1.1, γ_M=γ_{PB}=1.2 for g_6

	β	Carbon Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PB}=0.5	2	0.94[(1)]	0.89	0.76	0.66	0.61	0.94	0.90	0.77	0.66	0.62	0.92	0.89	0.77	0.66	0.62
	3	0.97	0.80	0.66	0.57	0.53	0.97	0.80	0.66	0.57	0.53	0.95	0.78	0.65	0.56	0.53
	3.5	0.93	0.76	0.61	0.53	0.49	0.92	0.76	0.61	0.53	0.49	0.89	0.73	0.60	0.52	0.49
	4.5	0.83	0.69	0.53	0.46	0.43	0.82	0.68	0.53	0.46	0.43	0.78	0.64	0.51	0.44	0.41
f_{PB}=1	2	0.94[(1)]	0.90	0.77	0.67	0.62	0.94	0.91	0.78	0.67	0.63	0.93	0.90	0.78	0.67	0.63
	3	0.98	0.81	0.67	0.57	0.54	0.99	0.81	0.67	0.58	0.54	0.97	0.80	0.67	0.57	0.54
	3.5	0.93	0.77	0.62	0.53	0.50	0.94	0.77	0.62	0.54	0.50	0.91	0.75	0.62	0.53	0.50
	4.5	0.84	0.69	0.53	0.46	0.43	0.84	0.69	0.54	0.46	0.43	0.81	0.67	0.53	0.45	0.42
f_{PB}=3	2	0.93[(1)]	0.90	0.78	0.67	0.62	0.93	0.91	0.78	0.68	0.63	0.94	0.92	0.79	0.68	0.64
	3	0.96	0.79	0.66	0.57	0.53	0.98	0.81	0.67	0.58	0.54	0.99	0.82	0.68	0.58	0.54
	3.5	0.91	0.75	0.61	0.53	0.49	0.92	0.76	0.62	0.53	0.50	0.93	0.77	0.63	0.54	0.50
	4.5	0.80	0.66	0.52	0.45	0.42	0.82	0.67	0.53	0.46	0.43	0.83	0.68	0.54	0.46	0.43
f_{PB}=5	2	0.91[(1)]	0.89	0.77	0.67	0.62	0.92	0.90	0.78	00.67	0.63	0.93	0.91	0.79	0.68	0.63
	3	0.95	0.78	0.65	0.56	0.53	0.96	0.79	0.66	0.56	0.53	0.98	0.81	0.67	0.58	0.54
	3.5	0.89	0.73	0.60	0.52	0.48	0.90	0.74	0.61	0.52	0.49	0.92	0.76	0.62	0.54	0.50
	4.5	0.78	0.64	0.51	0.44	0.41	0.79	0.65	0.52	0.43	0.42	0.81	0.67	0.53	0.46	0.43
f_{PB}=10	2	0.90[(1)]	0.88	0.77	0.66	0.62	0.91	0.89	0.77	0.66	0.62	0.92	0.90	0.78	0.67	0.63
	3	0.83	0.77	0.65	0.56	0.52	0.94	0.77	0.65	0.55	0.52	0.96	0.79	0.66	0.57	0.53
	3.5	0.87	0.71	0.59	0.51	0.48	0.88	0.72	0.60	0.50	0.48	0.89	0.74	0.61	0.52	0.49
	4.5	0.75	0.62	0.50	0.43	0.40	0.76	0.63	0.50	0.42	0.41	0.78	0.64	0.51	0.44	0.41
f_{PB}=50	2	0.89[(1)]	0.87	0.76	0.66	0.61	0.89	0.88	0.76	0.67	0.62	0.89	0.88	0.77	0.66	0.62
	3	0.91	0.75	0.64	0.55	0.51	0.92	0.75	0.64	0.57	0.51	0.92	0.76	0.64	0.55	0.52
	3.5	0.85	0.70	0.58	0.50	0.47	0.85	0.70	0.58	0.53	0.47	0.86	0.70	0.59	0.51	0.47
	4.5	0.73	0.60	0.49	0.42	0.39	0.73	0.60	0.49	0.45	0.39	0.74	0.61	0.49	0.42	0.39

(1) For these factors γ_A=γ_M=γ_{PB}=1

Table C-13b: Adjusted Nominal Resistance Factors for γ_A=1.1, γ_M=γ_{PB}=1.2 and Stainless Steel for g_6

	β	Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PB}=0.5	2	0.92(1)	0.93	0.76	0.68	0.63	0.93	0.94	0.77	0.68	0.64	0.92	0.94	0.77	0.68	0.64
	3	0.91	0.79	0.65	0.57	0.54	0.91	0.79	0.65	0.58	0.54	0.90	0.79	0.64	0.57	0.54
	3.5	0.83	0.73	0.59	0.53	0.50	0.83	0.73	0.60	0.53	0.50	0.82	0.72	0.64	0.52	0.49
	4.5	0.71	0.62	0.51	0.45	0.42	0.71	0.62	0.50	0.45	0.42	0.69	0.60	0.49	0.44	0.41
f_{PB}=1	2	0.93(1)	0.94	0.77	0.68	0.64	0.93	0.95	0.78	0.69	0.65	0.93	0.95	0.78	0.69	0.65
	3	0.91	0.80	0.65	0.58	0.54	0.92	0.80	0.66	0.58	0.55	0.92	0.80	0.65	0.58	0.54
	3.5	0.84	0.74	0.60	0.53	0.50	0.85	0.74	0.60	0.54	0.50	0.84	0.73	0.60	0.53	0.50
	4.5	0.71	0.62	0.51	0.45	0.42	0.72	0.63	0.51	0.46	0.43	0.70	0.62	0.50	0.45	0.42
f_{PB}=3	2	0.92(1)	0.95	0.78	0.69	0.65	0.93	0.96	0.78	0.70	0.65	0.93	0.96	0.79	0.70	0.66
	3	0.91	0.79	0.65	0.58	0.54	0.92	0.80	0.66	0.58	0.55	0.93	0.81	0.66	0.59	0.55
	3.5	0.83	0.73	0.60	0.53	0.50	0.84	0.74	0.60	0.54	0.50	0.85	0.74	0.61	0.54	0.51
	4.5	0.70	0.61	0.50	0.44	0.42	0.71	0.62	0.51	0.45	0.42	0.72	0.63	0.51	0.46	0.43
f_{PB}=5	2	0.90(1)	0.94	0.77	0.69	0.64	0.92	0.95	0.78	0.69	0.65	0.93	0.96	0.79	0.70	0.66
	3	0.90	0.79	0.64	0.57	0.54	0.91	0.80	0.65	0.58	0.54	0.92	0.81	0.66	0.59	0.55
	3.5	0.82	0.72	0.58	0.52	0.49	0.83	0.73	0.60	0.53	0.50	0.85	0.74	0.60	0.54	0.50
	4.5	0.69	0.60	0.48	0.44	0.41	0.70	0.61	0.50	0.44	0.41	0.71	0.62	0.51	0.45	0.42
f_{PB}=10	2	0.90(1)	0.94	0.77	0.68	0.64	0.91	0.95	0.77	0.69	0.64	0.92	0.95	0.78	0.69	0.65
	3	0.89	0.78	0.64	0.57	0.53	0.90	0.79	0.64	0.57	0.54	0.91	0.79	0.65	0.58	0.54
	3.5	0.81	0.71	0.59	0.52	0.48	0.82	0.71	0.58	0.52	0.49	0.83	0.73	0.59	0.53	0.49
	4.5	0.67	0.59	0.49	0.43	0.40	0.68	0.59	0.49	0.43	0.40	0.69	0.60	0.49	0.44	0.41
f_{PB}=50	2	0.89(1)	0.94	0.77	0.68	0.64	0.90	0.94	0.77	0.68	0.64	0.90	0.94	0.77	0.68	0.64
	3	0.88	0.77	0.63	0.56	0.52	0.88	0.77	0.63	0.56	0.53	0.89	0.77	0.63	0.56	0.53
	3.5	0.80	0.70	0.57	0.51	0.48	0.80	0.70	0.57	0.51	0.48	0.80	0.70	0.57	0.51	0.48
	4.5	0.66	0.57	0.47	0.42	0.39	0.66	0.58	0.47	0.42	0.39	0.66	0.58	0.47	0.42	0.39

(1) For these factors γ_A=γ_M=γ_{PB}=1

C.6. Performance Function g_7

Table C-14 provides the calculated mean load and resistance factors for performance function g_7. In this table, μ_{fy} is the converged mean value of the steel resistance. Table C-15 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1 and γ_O=1.5.

Table C-13b: Adjusted Nominal Resistance Factors for γ_A=1.1, γ_M=γ_{PB}=1.2 and Stainless Steel for g_6

	β	Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PB}=0.5	2	0.92(1)	0.93	0.76	0.68	0.63	0.93	0.94	0.77	0.68	0.64	0.92	0.94	0.77	0.68	0.64
	3	0.91	0.79	0.65	0.57	0.54	0.91	0.79	0.65	0.58	0.54	0.90	0.79	0.64	0.57	0.54
	3.5	0.83	0.73	0.59	0.53	0.50	0.83	0.73	0.60	0.53	0.50	0.82	0.72	0.64	0.52	0.49
	4.5	0.71	0.62	0.51	0.45	0.42	0.71	0.62	0.50	0.45	0.42	0.69	0.60	0.49	0.44	0.41
f_{PB}=1	2	0.93(1)	0.94	0.77	0.68	0.64	0.93	0.95	0.78	0.69	0.65	0.93	0.95	0.78	0.69	0.65
	3	0.91	0.80	0.65	0.58	0.54	0.92	0.80	0.66	0.58	0.55	0.92	0.80	0.65	0.58	0.54
	3.5	0.84	0.74	0.60	0.53	0.50	0.85	0.74	0.60	0.54	0.50	0.84	0.73	0.60	0.53	0.50
	4.5	0.71	0.62	0.51	0.45	0.42	0.72	0.63	0.51	0.46	0.43	0.70	0.62	0.50	0.45	0.42
f_{PB}=3	2	0.92(1)	0.95	0.78	0.69	0.65	0.93	0.96	0.78	0.70	0.65	0.93	0.96	0.79	0.70	0.66
	3	0.91	0.79	0.65	0.58	0.54	0.92	0.80	0.66	0.58	0.55	0.93	0.81	0.66	0.59	0.55
	3.5	0.83	0.73	0.60	0.53	0.50	0.84	0.74	0.60	0.54	0.50	0.85	0.74	0.61	0.54	0.51
	4.5	0.70	0.61	0.50	0.44	0.42	0.71	0.62	0.51	0.45	0.42	0.72	0.63	0.51	0.46	0.43
f_{PB}=5	2	0.90(1)	0.94	0.77	0.69	0.64	0.92	0.95	0.78	0.69	0.65	0.93	0.96	0.79	0.70	0.66
	3	0.90	0.79	0.64	0.57	0.54	0.91	0.80	0.65	0.58	0.54	0.92	0.81	0.66	0.59	0.55
	3.5	0.82	0.72	0.58	0.52	0.49	0.83	0.73	0.60	0.53	0.50	0.85	0.74	0.60	0.54	0.50
	4.5	0.69	0.60	0.48	0.44	0.41	0.70	0.61	0.50	0.44	0.41	0.71	0.62	0.51	0.45	0.42
f_{PB}=10	2	0.90(1)	0.94	0.77	0.68	0.64	0.91	0.95	0.77	0.69	0.64	0.92	0.95	0.78	0.69	0.65
	3	0.89	0.78	0.64	0.57	0.53	0.90	0.79	0.64	0.57	0.54	0.91	0.79	0.65	0.58	0.54
	3.5	0.81	0.71	0.59	0.52	0.48	0.82	0.71	0.58	0.52	0.49	0.83	0.73	0.59	0.53	0.49
	4.5	0.67	0.59	0.49	0.43	0.40	0.68	0.59	0.49	0.43	0.40	0.69	0.60	0.49	0.44	0.41
f_{PB}=50	2	0.89(1)	0.94	0.77	0.68	0.64	0.90	0.94	0.77	0.68	0.64	0.90	0.94	0.77	0.68	0.64
	3	0.88	0.77	0.63	0.56	0.52	0.88	0.77	0.63	0.56	0.53	0.89	0.77	0.63	0.56	0.53
	3.5	0.80	0.70	0.57	0.51	0.48	0.80	0.70	0.57	0.51	0.48	0.80	0.70	0.57	0.51	0.48
	4.5	0.66	0.57	0.47	0.42	0.39	0.66	0.58	0.47	0.42	0.39	0.66	0.58	0.47	0.42	0.39

(1) For these factors γ_A=γ_M=γ_{PB}=1

Table C-15a: Adjusted Nominal Resistance Factor for γ_A=1.1 and γ_O=1.5 and Carbon Steel for g_7

			Carbon Steel				
	f_O	β	R.T.	200°F	400°F	600°F	800°F
$COV(f_O)$=0.50	0.5	1.5	0.96[(1)]	0.79[(1)]	0.93	0.80	0.75
		2	0.95[(2)]	0.89	0.80	0.69	0.65
		3	0.67	0.55	0.50	0.43	0.40
	1	1.5	0.91[(1)]	0.75[(1)]	0.97	0.83	0.78
		2	0.87[(2)]	0.87	0.79	0.68	0.63
		3	0.58	0.47	0.43	0.37	0.35
	2	1.5	0.88[(1)]	0.72[(1)]	0.99	0.85	0.79
		2	0.81[(2)]	0.85	0.77	0.67	0.62
		3	0.52	0.43	0.39	0.34	0.31
	2.5	1.5	0.86[(1)]	0.71[(1)]	0.99	0.86	0.80
		2	0.80[(2)]	0.84	0.77	0.66	0.62
		3	0.51	0.42	0.38	0.33	0.31
$COV(f_O)$=0.80	0.5	1.5	0.91[(1)]	0.75[(1)]	0.90	0.78	0.72
		2	0.85[(2)]	0.80	0.73	0.63	0.59
		3	0.48	0.40	0.36	0.31	0.29
	1.0	1.5	0.87[(1)]	0.70[(1)]	0.91	0.78	0.73
		2	0.76	0.75	0.69	0.59	0.55
		3	0.40	0.33	0.30	0.26	0.24
	2	1.5	0.80[(1)]	0.72[(1)]	0.91	0.78	0.73
		2	0.69[(2)]	0.72	0.66	0.57	0.53
		3	0.35	0.29	0.26	0.23	0.21
	2.5	1.5	0.79[(1)]	0.65[(1)]	0.91	0.78	0.73
		2	0.67[(2)]	0.71	0.65	0.56	0.52
		3	0.34	0.28	0.25	0.22	0.20

[(1)] γ_A=1 and γ_O=0.9, [(2)] γ_A=1.1 and γ_O=1.1, R.T.=Room Temperature

Table C-15b: Adjusted Nominal Resistance Factor for γ_A=1.1 and γ_O=1.5 and Stainless Steel for g_7

	f_O	β	Stainless Steel				
			R.T.	200°F	400°F	600°F	800°F
COV(f_O)=0.50	0.5	1.5	1.01(1)	0.94(1)	0.90	0.80	0.75
		2	1.00(2)	1.00	0.78	0.69	0.65
		3	0.71	0.62	0.48	0.43	0.40
	1	1.5	0.98(1)	0.86(1)	0.95	0.85	0.80
		2	0.93(2)	0.95	0.78	0.69	0.65
		3	0.62	0.52	0.43	0.38	0.36
	2	1.5	0.94(1)	0.85(1)	0.99	0.88	0.82
		2	0.87(2)	0.95	0.77	0.69	0.64
		3	0.56	0.48	0.39	0.35	0.33
	2.5	1.5	0.93(1)	0.81(1)	1.00	0.89	0.83
		2	0.86(2)	0.94	0.77	0.69	0.64
		3	0.54	0.47	0.38	0.34	0.32
COV(f_O)=0.80	0.5	1.5	0.98(1)	0.85(1)	0.87	0.78	0.73
		2	0.91(2)	0.87	0.71	0.63	0.59
		3	0.45	0.43	0.35	0.31	0.29
	1.0	1.5	0.92(1)	0.80(1)	0.90	0.80	0.75
		2	0.82(2)	0.83	0.68	0.61	0.57
		3	0.43	0.36	0.30	0.26	0.25
	2	1.5	0.87(1)	0.76(1)	0.91	0.81	0.76
		2	0.74(2)	0.81	0.66	0.59	0.55
		3	0.37	0.32	0.26	0.23	0.22
	2.5	1.5	0.86(1)	0.75(1)	0.92	0.81	0.76
		2	0.73(2)	0.80	0.65	0.58	0.54
		3	0.36	0.31	0.26	0.23	0.21

(1) γ_A=1 and γ_O=0.9, (2) γ_A=1.1 and γ_O=1.1, R.T.=Room Temperature

C.7. Performance Function g_8

Table C-16 provides the calculated mean load and resistance factors for performance function g_8. In this table, μ_{fy} is the converged mean value of the steel resistance. Table C-17 presents the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PO}=1.2, and γ_O=1.5.

Table C-16a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F for g_8

	β	Carbon Steel for $T \leq 200^{o}$F														
		f_O=0.5					f_O=1					f_O=2				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	1.5	2.50	0.962	1.023	1.746	1.011	3.42	0.973	1.011	1.818	1.001	5.30	0.979	1.006	1.840	0.996
	2	2.95	0.966	1.017	2.660	1.006	4.34	0.974	1.008	2.721	0.999	7.14	0.978	1.004	2.741	0.995
	3.0	5.44	0.975	1.007	7.595	0.997	9.34	0.978	1.003	7.633	0.994	17.15	0.979	1.002	7.649	0.993
f_{PO}=1	1.5	3.03	0.954	1.024	1.669	1.033	3.94	0.970	1.011	1.797	1.011	5.81	0.977	1.006	1.833	1.001
	2	3.48	0.960	1.018	2.598	1.022	4.85	0.972	1.008	2.703	1.006	7.65	0.977	1.004	2.735	0.999
	3.0	5.95	0.973	1.007	7.562	1.003	9.85	0.977	1.003	7.621	0.997	17.66	0.979	1.002	7.644	0.994
f_{PO}=3	1.5	5.34	0.928	1.023	1.105	1.127	6.09	0.954	1.012	1.623	1.056	7.88	0.970	1.006	1.788	1.021
	2	5.73	0.922	1.023	1.748	1.130	6.97	0.960	1.009	2.566	1.039	9.71	0.972	1.004	2.696	1.013
	3.0	8.05	0.963	1.007	7.334	1.028	11.91	0.972	1.003	7.552	1.009	19.70	0.977	1.002	7.619	1.000
f_{PO}=5	1.5	7.80	0.928	1.015	0.944	1.150	8.38	0.937	1.012	1.278	1.113	10.02	0.962	1.006	1.708	1.043
	2	8.34	0.907	1.020	1.015	1.208	9.20	0.944	1.010	2.254	1.084	11.82	0.966	1.004	2.633	1.029
	3.0	10.23	0.953	1.007	6.887	1.058	14	0.968	1.003	7.445	1.021	21.75	0.975	1.002	7.586	1.006
f_{PO}= 10	1.5	14.02	0.931	1.008	0.867	1.162	14.51	0.931	1.008	0.950	1.155	15.69	0.940	1.006	1.307	1.113
	2	15.05	0.911	1.010	0.886	1.225	15.57	0.911	1.010	1.025	1.215	17.33	0.948	1.005	2.295	1.082
	3.0	17.34	0.871	1.014	0.925	1.364	19.40	0.955	1.004	6.948	1.057	26.97	0.969	1.002	7.461	1.021
f_{PO}= 50	1.5	64	0.935	1.002	0.822	1.169	64.44	0.935	1.002	0.832	1.168	65.34	0.934	1.002	0.856	1.167
	2	68.97	0.915	1.002	0.824	1.234	69.42	0.915	1.002	0.838	1.234	70.35	0.914	1.002	0.870	1.232
	3.0	80.11	0.877	1.003	0.829	1.377	80.59	0.877	1.003	0.848	1.376	81.58	0.876	1.003	0.896	1.374

Table C-16a: (Continued)

	β	Carbon Steel for $T \leq 200^{o}F$					
		f_O=2.5					
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	
f_{Po}= 0.5	1.5	6.24	0.98	1.004	1.843	0.995	
	2	8.54	0.979	1.003	2.744	0.994	
	3.0	21.06	0.98	1.001	7.652	0.993	
f_{PO}=1	1.5	6.75	0.978	1.004	1.838	0.999	
	2	9.05	0.978	1.003	2.740	0.997	
	3.0	21.56	0.979	1.001	7.648	0.994	
f_{PO}=3	1.5	8.81	0.972	1.005	1.808	1.015	
	2	11.10	0.974	1.003	2.713	1.009	
	3.0	23.60	0.978	1.001	7.630	0.998	
f_{PO}=5	1.5	10.92	0.966	1.005	1.757	1.032	
	2	13.19	0.969	1.003	2.672	1.021	
	3.0	25.65	0.976	1.001	7.606	1.003	
f_{PO}= 10	1.5	16.43	0.949	1.005	1.505	1.084	
	2	18.59	0.956	1.004	2.478	1.058	
	3.0	30.83	0.972	1.001	7.521	1.015	
f_{PO}= 50	1.5	65.80	0.934	1.002	0.869	1.166	
	2	70.83	0.914	1.002	0.888	1.231	
	3.0	82.11	0.876	1.003	0.927	1.372	

Table C-16b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_8

	β	Carbon Steel for T>200°F														
		f_O=0.5					f_O=1					f_O=2				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	1.5	2.58	0.903	1.024	1.604	1.012	3.51	0.931	1.011	1.753	1.001	5.40	0.945	1.006	1.801	0.996
	2	3.04	0.912	1.018	2.506	1.007	4.44	0.934	1.009	2.642	0.999	7.29	0.944	1.004	2.688	0.995
	3.0	5.57	0.934	1.007	7.398	0.997	9.54	0.943	1.003	7.490	0.994	17.49	0.947	1.002	7.529	0.993
f_{PO}=1	1.5	3.15	0.884	1.025	1.457	1.035	4.05	0.922	1.012	1.711	1.011	5.93	0.940	1.006	1.787	1.001
	2	3.60	0.896	1.019	2.370	1.024	4.98	0.927	1.009	2.603	1.006	7.81	0.941	1.004	2.674	0.999
	3.0	6.11	0.929	1.007	7.324	1.003	10.07	0.940	1.003	7.462	0.997	18.02	0.945	1.002	7.516	0.994
f_{PO}=3	1.5	5.65	0.852	1.019	0.999	1.100	6.34	0.883	1.012	1.409	1.059	8.11	0.922	1.006	1.701	1.022
	2	6.15	0.814	1.024	1.156	1.134	7.23	0.894	1.010	2.328	1.043	9.97	0.927	1.004	2.596	1.014
	3.0	8.32	0.904	1.007	6.855	1.030	12.22	0.929	1.003	7.313	1.009	20.13	0.940	1.002	7.459	1.000
f_{PO}=5	1.5	8.25	0.854	1.013	0.910	1.116	8.83	0.861	1.011	1.095	1.099	10.37	0.902	1.006	1.561	1.046
	2	8.98	0.813	1.016	0.956	1.161	9.69	0.842	1.012	1.609	1.108	12.20	0.911	1.005	2.474	1.032
	3.0	10.64	0.738	1.022	1.102	1.256	14.42	0.917	1.004	7.101	1.022	22.27	0.934	1.002	7.389	1.006
f_{PO}= 10	1.5	14.81	0.858	1.007	0.857	1.127	15.33	0.858	1.007	0.916	1.122	16.49	0.865	1.006	1.120	1.102
	2	16.16	0.818	1.009	0.872	1.177	16.71	0.818	1.008	0.965	1.170	18.19	0.854	1.006	1.749	1.103
	3.0	19.23	0.744	1.012	0.903	1.284	19.90	0.744	1.012	1.132	1.267	27.74	0.920	1.002	7.144	1.022
f_{PO}= 50	1.5	67.43	0.863	1.001	0.820	1.136	67.91	0.863	1.001	0.829	1.135	68.88	0.862	1.001	0.848	1.134
	2	73.82	0.824	1.002	0.823	1.188	74.32	0.824	1.002	0.834	1.187	75.35	0.823	1.002	0.860	1.185
	3.0	88.47	0.751	1.002	0.827	1.301	89.03	0.751	1.002	0.843	1.300	90.18	0.750	1.002	0.882	1.297

Table C-16b: (Continued)

	β	Carbon Steel for T>200°F				
		f_O=2.5				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	1.5	6.36	0.947	1.005	1.809	0.995
	2	8.71	0.946	1.003	2.696	0.994
	3.0	21.47	0.947	1.001	7.536	0.993
f_{PO}=1	1.5	6.89	0.944	1.005	1.798	0.999
	2	9.24	0.943	1.003	2.685	0.997
	3.0	21.99	0.946	1.001	7.526	0.994
f_{PO}=3	1.5	9.04	0.929	1.005	1.739	1.015
	2	11.38	0.932	1.003	2.630	1.009
	3.0	24.10	0.942	1.001	7.483	0.998
f_{PO}=5	1.5	11.26	0.914	1.005	1.648	1.033
	2	13.57	0.920	1.004	2.550	1.022
	3.0	26.23	0.938	1.001	7.432	1.003
f_{PO}= 10	1.5	17.18	0.876	1.005	1.277	1.085
	2	19.34	0.884	1.004	2.175	1.065
	3.0	31.65	0.926	1.001	7.263	1.015
f_{PO}= 50	1.5	69.38	0.862	1.001	0.858	1.133
	2	75.88	0.822	1.002	0.874	1.184
	3.0	90.77	0.749	1.002	0.906	1.295

Table C-16c: Mean Load and Resistance Factors for Stainless Steel and any T for g_8

	β	Stainless Steel for any T														
		f_O=0.5					f_O=1					f_O=2				
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	1.5	2.63	0.873	1.024	1.532	1.012	3.55	0.910	1.012	1.720	1.001	5.46	0.927	1.006	1.781	0.996
	2	3.09	0.884	1.019	2.422	1.007	4.50	0.913	1.009	2.600	0.999	7.36	0.926	1.004	2.660	0.995
	3.0	5.64	0.914	1.007	7.294	0.997	9.65	0.924	1.003	7.415	0.994	17.67	0.930	1.002	7.466	0.993
f_{PO}=1	1.5	3.22	0.850	1.025	1.360	1.035	4.11	0.898	1.012	1.666	1.012	6.00	0.922	1.006	1.763	1.001
	2	3.68	0.861	1.020	2.240	1.026	5.05	0.903	1.009	2.549	1.007	7.90	0.922	1.004	2.642	0.999
	3.0	6.19	0.906	1.007	7.198	1.003	10.18	0.921	1.003	7.377	0.997	18.21	0.928	1.002	7.449	0.994
f_{PO}=3	1.5	5.80	0.823	1.017	0.973	1.090	6.48	0.850	1.012	1.316	1.059	8.23	0.898	1.006	1.656	1.022
	2	6.36	0.776	1.022	1.087	1.123	7.38	0.859	1.010	2.191	1.045	10.11	0.903	1.04	2.542	1.014
	3.0	8.48	0.872	1.008	6.582	1.032	12.38	0.906	1.004	7.186	1.009	20.37	0.921	1.002	7.375	1.000
f_{PO}=5	1.5	8.47	0.825	1.012	0.900	1.105	9.06	0.830	1.010	1.051	1.091	10.56	0.872	1.006	1.488	1.046
	2	9.29	0.777	1.015	0.939	1.146	9.98	0.794	1.012	1.351	1.113	12.40	0.882	1.005	2.387	1.033
	3.0	11.17	0.690	1.021	1.053	1.232	14.64	0.890	1.004	6.913	1.023	22.55	0.913	1.002	7.285	1.006
f_{PO}= 10	1.5	15.19	0.829	1.006	0.853	1.116	15.72	0.828	1.006	0.906	1.111	16.90	0.834	1.005	1.073	1.095
	2	16.7	0.782	1.008	0.867	1.161	17.28	0.781	1.008	0.948	1.154	18.71	0.805	1.006	1.462	1.112
	3.0	20.18	0.696	1.011	0.896	1.258	20.88	0.696	1.011	1.076	1.244	28.16	0.894	1.002	6.972	1.023
f_{PO}= 50	1.5	69.11	0.834	1.001	0.820	1.124	69.61	0.833	1.001	0.828	1.124	70.61	0.833	1.001	0.845	1.122
	2	76.21	0.788	1.002	0.822	1.172	76.74	0.787	1.002	0.832	1.171	77.81	0.786	1.002	0.856	1.169
	3.0	92.68	0.703	1.002	0.826	1.275	93.27	0.703	1.002	0.841	1.274	94.50	0.702	1.002	0.877	1.271

Table C-16c: (Continued)

	β	Stainless Steel for any T					
		f_O=2.5					
		μ_{fy}	ϕ'_{fy}	γ'_A	γ'_O	γ'_{PO}	
f_{Po}= 0.5	1.5	6.42	0.931	1.005	1.791	0.995	
	2	8.80	0.929	1.003	2.671	0.994	
	3.0	21.69	0.931	1.001	7.475	0.993	
f_{PO}=1	1.5	6.96	0.926	1.005	1.778	0.999	
	2	9.34	0.926	1.003	2.657	0.997	
	3.0	22.22	0.929	1.001	7.462	0.994	
f_{PO}=3	1.5	9.16	0.907	1.005	1.703	1.016	
	2	11.52	0.911	1.004	2.586	1.010	
	3.0	24.37	0.924	1.001	7.406	0.998	
f_{PO}=5	1.5	11.44	0.887	1.005	1.592	1.034	
	2	13.77	0.895	1.004	2.484	1.023	
	3.0	26.55	0.918	1.001	7.340	1.003	
f_{PO}= 10	1.5	17.58	0.843	1.005	1.200	1.082	
	2	19.77	0.844	1.004	1.991	1.070	
	3.0	32.09	0.903	1.001	7.124	1.016	
f_{PO}= 50	1.5	71.12	0.832	1.001	0.855	1.121	
	2	78.36	0.786	1.002	0.869	1.168	
	3.0	95.13	0.701	1.002	0.899	1.269	

Table C-17a: Adjusted Nominal Resistance Factor for g_8 and Carbon Steel for γ_A=1.1, γ_{PO}=1.2 and γ_O=1.5

	β	Carbon Steel														
		f_O=0.5					f_O=1.0					f_O=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PO}= 0.5	1.5	0.96[(1)]	0.79[(1)]	0.92	0.79	0.74	0.90[(1)]	0.74[(1)]	0.92	0.80	0.74	0.84[(1)]	0.69[(1)]	0.92	0.80	0.74
	2	0.81[(1)]	0.86	0.78	0.67	0.63	0.71[(1)]	0.80	0.73	0.63	0.59	0.62[(1)]	0.75	0.68	0.59	0.55
	3.0	0.57	0.47	0.43	0.37	0.34	0.45	0.37	0.34	0.29	0.27	0.38	0.31	0.29	0.25	0.23
f_{PO}=1	1.5	0.99[(1)]	0.81[(1)]	0.93	0.80	0.75	0.93[(1)]	0.77[(1)]	0.94	0.81	0.75	0.87[(1)]	0.71[(1)]	0.93	0.80	0.75
	2	0.86[(1)]	0.90	0.81	0.70	0.65	0.76[(1)]	0.84	0.76	0.66	0.61	0.66[(1)]	0.77	0.71	0.61	0.57
	3.0	0.64	0.53	0.48	0.41	0.39	0.50	0.41	0.38	0.32	0.30	0.41	0.34	0.31	0.26	0.25
f_{PO}=3	1.5	1.01[(1)]	0.83[(1)]	0.91	0.78	0.73	0.99[(1)]	0.82[(1)]	0.95	0.82	0.76	0.94[(1)]	0.77[(1)]	0.95	0.82	0.77
	2	0.94[(1)]	0.96	0.83	0.72	0.67	0.87[(1)]	0.92	0.83	0.71	0.67	0.76[(1)]	0.85	0.78	0.67	0.62
	3.0	0.83	0.68	0.62	0.53	0.50	0.65	0.54	0.49	0.42	0.39	0.51	0.42	0.38	0.33	0.31
f_{PO}=5	1.5	0.99[(1)]	0.82[(1)]	0.89	0.77	0.71	1.01[(1)]	0.83[(1)]	0.93	0.80	0.75	0.98[(1)]	0.80[(1)]	0.96	0.83	0.77
	2	0.93[(1)]	0.94	0.82	0.70	0.66	0.92[(1)]	0.95	0.85	0.73	0.68	0.83[(1)]	0.90	0.81	0.70	0.66
	3.0	0.93	0.77	0.69	0.59	0.55	0.76	0.63	0.57	0.49	0.46	0.59	0.49	0.45	0.38	0.36
f_{PO}=10	1.5	0.98[(1)]	0.80[(1)]	0.87	0.75	0.70	0.99[(1)]	0.82[(1)]	0.89	0.77	0.72	1.00[(1)]	0.83[(1)]	0.94	0.81	0.75
	2	0.91[(1)]	0.91	0.79	0.68	0.64	0.92[(1)]	0.94	0.82	0.71	0.66	0.91[(1)]	0.95	0.85	0.73	0.68
	3.0	0.96	0.79	0.67	0.57	0.54	0.92	0.75	0.69	0.59	0.55	0.31	0.61	0.56	0.48	0.45
f_{PO}=50	1.5	0.96[(1)]	0.79[(1)]	0.84	0.73	0.68	0.96[(1)]	0.79[(1)]	0.85	0.73	0.68	0.97[(1)]	0.80[(1)]	0.86	0.74	0.69
	2	0.89[(1)]	0.88	0.77	0.66	0.62	0.89[(1)]	0.89	0.78	0.67	0.62	0.90[(1)]	0.90	0.79	0.68	0.63
	3.0	0.92	0.76	0.64	0.55	0.52	0.93	0.76	0.65	0.56	0.52	0.95	0.78	0.66	0.57	0.53

(1) For these factors γ_A=γ_{PB}=1 and γ_O=0.9

Table C-17a: (Continued)

	β	Carbon Steel					
		f_O=2.5					
		R.T.	200°F	400°F	600°F	800°F	
f_{PO}= 0.5	1.5	0.82(1)	0.67(1)	0.92	0.79	0.74	
	2	0.60(1)	0.73	0.67	0.58	0.54	
	3.0	0.36	0.30	0.27	0.24	0.22	
f_{PO}=1	1.5	0.85(1)	0.70(1)	0.93	0.80	0.75	
	2	0.63(1)	0.76	0.69	0.60	0.56	
	3.0	0.39	0.32	0.29	0.25	0.23	
f_{PO}=3	1.5	0.92(1)	0.76(1)	0.95	0.82	0.77	
	2	0.73(1)	0.83	0.76	0.65	0.61	
	3.0	0.47	0.39	0.36	0.31	0.29	
f_{PO}=5	1.5	0.96(1)	0.79(1)	0.96	0.83	0.77	
	2	0.79(1)	0.88	0.80	0.69	0.64	
	3.0	0.55	0.45	0.41	0.36	0.33	
f_{PO}=10	1.5	1.00(1)	0.82(1)	0.95	0.82	0.76	
	2	0.88(1)	0.94	0.84	0.73	0.68	
	3.0	0.69	0.57	0.51	0.44	0.41	
f_{PO}=50	1.5	0.97(1)	0.80(1)	0.87	0.75	0.70	
	2	0.90(1)	0.91	0.79	0.68	0.64	
	3.0	0.95	0.78	0.66	0.57	0.53	

(1) For these factors $\gamma_A=\gamma_{PB}=1$ and $\gamma_O=0.9$

Table C-17b: Adjusted Nominal Resistance Factor for g_8 and Stainless Steel for γ_A=1.1, γ_{PO}=1.2 and γ_O=1.5

	β	Stainless Steel														
		f_O=0.5					f_O=1.0					f_O=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PO}= 0.5	1.5	1.02(1)	0.89(1)	0.93	0.83	0.78	0.97	0.84	0.95	0.84	0.79	0.91	0.79	0.94	0.84	0.79
	2	0.87(1)	0.97	0.80	0.71	0.66	0.76	0.91	0.75	0.66	0.62	0.67	0.86	0.70	0.62	0.58
	3.0	0.61	0.53	0.44	0.39	0.36	0.49	0.43	0.35	0.31	0.29	0.41	0.36	0.29	0.26	0.24
f_{PO}=1	1.5	1.04(1)	0.91(1)	0.94	0.84	0.78	1.00	0.87	0.96	0.85	0.80	0.94	0.82	0.95	0.85	0.80
	2	0.91(1)	1.01	0.82	0.73	0.69	0.81	0.95	0.78	0.69	0.65	0.71	0.89	0.72	0.64	0.60
	3.0	0.68	0.60	0.49	0.43	0.41	0.54	0.47	0.39	0.34	0.32	0.44	0.38	0.31	0.28	0.26
f_{PO}=3	1.5	1.03(1)	0.90(1)	0.91	0.81	0.76	1.04	0.91	0.96	0.85	0.80	1.00	0.88	0.97	0.86	0.81
	2	0.94(1)	1.02	0.83	0.74	0.69	0.91	1.03	0.84	0.75	0.70	0.82	0.97	0.79	0.70	0.66
	3.0	0.88	0.76	0.63	0.56	0.52	0.70	0.61	0.50	0.45	0.42	0.55	0.48	0.39	0.35	0.33
f_{PO}=5	1.5	1.02(1)	0.89(1)	0.89	0.79	0.75	1.04	0.91	0.94	0.83	0.78	1.03	0.90	0.97	0.86	0.81
	2	0.93(1)	1.0	0.82	0.72	0.68	0.94	1.04	0.85	0.75	0.71	0.88	1.01	0.83	0.74	0.69
	3.0	0.95	0.83	0.68	0.60	0.57	0.81	0.71	0.58	0.51	0.48	0.64	0.56	0.46	0.40	0.38
f_{PO}=10	1.5	1.01(1)	0.88(1)	0.87	0.78	0.73	1.02	0.89	0.90	0.80	0.75	1.04	0.91	0.94	0.84	0.79
	2	0.91(1)	0.97	0.79	0.71	0.66	0.93	1.00	0.82	0.73	0.68	0.94	1.04	0.85	0.76	0.71
	3.0	0.92	0.80	0.66	0.58	0.55	0.95	0.83	0.68	0.60	0.57	0.79	0.69	0.57	0.50	0.47
f_{PO}=50	1.5	0.99(1)	0.86(1)	0.85	0.76	0.71	0.99	0.87	0.86	0.76	0.71	1.00	0.87	0.87	0.77	0.73
	2	0.90(1)	0.94	0.77	0.69	0.64	0.90	0.95	0.78	0.69	0.65	0.91	0.96	0.79	0.70	0.66
	3.0	0.89	0.77	0.63	0.56	0.53	0.90	0.78	0.64	0.57	0.53	0.91	0.79	0.65	0.58	0.54

(1) For these factors γ_A=γ_{PB}=1 and γ_O=0.9

Table C-17b: (Continued)

	β	Stainless Steel					
		f_O=2.5					
		R.T.	200°F	400°F	600°F	800°F	
f_{PO}=0.5	1.5	0.89(1)	0.78(1)	0.94	0.84	0.79	
	2	0.65(1)	0.84	0.69	0.61	0.57	
	3.0	0.39	0.34	0.28	0.25	0.23	
f_{PO}=1	1.5	0.91(1)	0.80(1)	0.95	0.85	0.79	
	2	0.68(1)	0.87	0.71	0.63	0.59	
	3.0	0.42	0.36	0.30	0.27	0.25	
f_{PO}=3	1.5	0.98(1)	0.86(1)	0.97	0.86	0.81	
	2	0.78(1)	0.94	0.77	0.69	0.64	
	3.0	0.51	0.45	0.37	0.32	0.30	
f_{PO}=5	1.5	1.02(1)	0.89(1)	0.98	0.87	0.81	
	2	0.85(1)	0.99	0.81	0.72	0.68	
	3.0	0.59	0.51	0.42	0.37	0.35	
f_{PO}=10	1.5	1.04(1)	0.91(1)	0.96	0.85	0.80	
	2	0.93(1)	1.04	0.85	0.76	0.71	
	3.0	0.74	0.64	0.53	0.47	0.44	
f_{PO}=50	1.5	1.00(1)	0.88(1)	0.88	0.78	0.73	
	2	0.91(1)	0.97	0.80	0.71	0.66	
	3.0	0.92	0.80	0.66	0.58	0.55	

(1) $\gamma_A=\gamma_{PB}=1$ and $\gamma_O=0.9$

C.8. Performance Function g_9

Table C-18 gives the calculated mean load and resistance factors for performance function g_9. In this table, μ_{fy} is the converged mean value of the yield strength of steel. Table C-19 provides the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PO}=1.2, γ_M=1.2, and γ_O=1.5.

Table C-18a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F for g_9

	β=1.5	Carbon Steel, $T \leq 200^{o}$F																	
		f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
0.5	0.5	3.02	0.955	1.023	1.012	1.015	1.690	3.56	0.95	1.02	0.01	1.05	1.59	4.71	0.93	1.02	1.01	1.12	1.24
	1	3.93	0.970	1.011	1.001	1.001	1.801	4.45	0.97	1.01	1.00	1.01	1.78	5.52	0.96	1.01	1.00	1.04	1.69
	2	5.80	0.977	1.006	0.996	0.995	1.834	6.32	0.98	1.01	1.00	1.00	1.83	7.35	0.97	1.01	1.00	1.01	1.80
	2.5	6.74	0.978	1.004	0.995	0.994	1.839	7.25	0.98	1.00	1.00	1.00	1.83	8.28	0.97	1.00	1.00	1.01	1.82
1	0.5	3.56	0.947	1.024	1.034	1.02	1.60	4.10	0.94	1.02	1.03	1.05	1.49	5.26	0.93	1.02	1.03	1.11	1.18
	1	4.45	0.97	1.01	1.01	1.00	1.78	4.98	0.96	1.01	1.01	1.01	1.75	6.05	0.95	1.01	1.01	1.04	1.66
	2	6.32	0.98	1.01	1.00	1.00	1.83	6.83	0.97	1.01	1.00	1.00	1.82	7.87	0.97	1.01	1.00	1.01	1.80
	2.5	7.25	0.98	1.00	1.00	0.99	1.83	7.76	0.98	1.00	1.00	1.00	1.83	8.79	0.97	1.00	1.00	1.01	1.81
3	0.5	5.88	0.92	1.02	1.12	1.01	0.68	6.43	0.92	1.02	1.11	1.04	1.05	7.59	0.92	1.02	1.10	1.08	0.99
	1	6.61	0.95	1.01	1.06	1.00	1.59	7.14	0.95	1.01	1.06	1.02	1.56	8.24	0.94	1.01	1.06	1.05	1.44
	2	8.40	0.97	1.01	1.02	1.00	1.78	8.91	0.97	1.01	1.02	1.00	1.77	9.96	0.96	1.01	1.02	1.02	1.74
	2.5	9.32	0.97	1.00	1.01	0.99	1.80	9.83	0.97	1.00	1.01	1.00	1.80	10.87	0.97	1.00	1.02	1.01	1.78
5	0.5	8.34	0.93	1.02	1.15	1.01	0.94	8.88	0.92	1.01	1.14	1.02	0.93	10.01	0.92	1.01	1.13	1.05	0.92
	1	8.91	0.93	1.01	1.11	1.00	1.25	9.45	0.93	1.01	1.11	1.02	1.22	10.56	0.93	1.01	1.11	1.04	1.16
	2	10.54	0.96	1.01	1.04	1.00	1.70	11.06	0.96	1.01	1.04	1.00	1.68	12.11	0.95	1.01	1.04	1.02	1.65
	2.5	11.43	0.97	1.00	1.03	0.99	1.75	11.95	0.96	1.00	1.03	1.00	1.74	13.00	0.96	1.00	1.03	1.01	1.72
10	0.5	14.56	0.93	1.01	1.16	1.00	0.87	15.10	0.93	1.01	1.16	1.01	0.87	16.19	0.93	1.01	1.15	1.02	0.86
	1	15.04	0.93	1.01	1.15	1.00	0.95	15.58	0.93	1.01	1.15	1.01	0.94	16.68	0.93	1.01	1.14	1.02	0.94
	2	16.21	0.94	1.01	1.11	1.00	1.29	16.75	0.94	1.01	1.11	1.00	1.28	17.83	0.93	1.01	1.11	1.02	1.25
	2.5	16.96	0.95	1.00	1.08	0.99	1.49	17.48	0.95	1.00	1.08	1.00	1.48	18.53	0.94	1.00	1.08	1.01	1.45
50	0.5	64.53	0.93	1.00	1.17	0.99	0.82	65.06	0.93	1.00	1.17	0.99	0.82	66.12	0.93	1.00	1.17	1.00	0.82
	1	64.97	0.93	1.00	1.17	0.99	0.83	65.50	0.93	1.00	1.17	0.99	0.83	66.56	0.93	1.00	1.17	1.00	0.83
	2	65.87	0.93	1.00	1.17	0.99	0.86	66.40	0.93	1.00	1.17	0.99	0.86	67.47	0.93	1.00	1.16	1.00	0.86
	2.5	66.33	0.93	1.00	1.17	0.99	0.87	66.86	0.93	1.00	1.16	0.99	0.87	67.93	0.93	1.00	1.16	1.00	0.87

Table C-18a: (Continued)

		β=2.5	Carbon Steel, $T \leq 200^oF$																	
			f_M=0.5						f_M=1.0						f_M=2.0					
		fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
f_{Po}	0.5	0.5	4.30	0.97	1.01	1.00	1.00	4.30	4.82	0.96	1.01	1.00	1.01	4.24	5.90	0.95	1.01	1.00	1.05	4.06
		1	6.54	0.97	1.01	1.00	1.00	4.37	7.05	0.97	1.01	1.00	1.00	4.35	8.09	0.97	1.01	1.00	1.01	4.31
		2	11.03	0.98	1.00	0.99	0.99	4.40	11.54	0.98	1.00	0.99	1.00	4.39	12.56	0.98	1.00	0.99	1.00	4.37
		2.5	13.28	0.98	1.00	0.99	0.99	4.40	13.78	0.98	1.00	0.99	0.99	4.40	14.80	0.98	1.00	0.99	1.00	4.38
	1	0.5	4.82	0.96	1.01	1.01	1.00	4.25	5.35	0.96	1.01	1.01	1.02	4.19	643	0.95	1.01	1.01	1.05	3.98
		1	7.05	0.97	1.01	1.00	1.00	4.35	7.56	0.97	1.01	1.00	1.00	4.34	8.61	0.97	1.01	1.00	1.01	4.29
		2	11.54	0.98	1.00	1.00	0.99	4.39	12.05	0.98	1.00	1.00	1.00	4.38	13.07	0.97	1.00	1.00	1.00	4.37
		2.5	13.79	0.98	1.00	1.00	0.99	4.40	14.29	0.98	1.00	1.00	0.99	4.39	15.31	0.98	1.00	1.00	1.00	4.38
	3	0.5	6.99	0.95	1.01	1.06	1.00	3.82	7.53	0.94	1.01	1.06	1.02	3.71	8.64	0.93	1.01	1.07	1.06	3.32
		1	9.14	0.97	1.01	1.02	1.00	4.25	9.66	0.96	1.01	1.02	1.00	4.23	10.70	0.96	1.01	1.02	1.02	4.17
		2	13.59	0.97	1.00	1.01	0.99	4.36	14.10	0.97	1.00	1.01	1.00	4.35	15.13	0.97	1.00	1.01	1.00	4.33
		2.5	15.83	0.98	1.00	1.00	0.99	4.37	16.34	0.97	1.00	1.00	0.99	4.37	17.36	0.97	1.00	1.00	1.00	4.35
	5	0.5	9.50	0.88	1.02	1.26	1.01	1.11	10.08	0.88	1.02	1.25	1.04	1.09	11.30	0.87	1.02	1.23	1.09	1.05
		1	11.29	0.96	1.01	1.04	1.00	4.07	11.81	0.95	1.01	1.05	1.00	4.04	12.87	0.95	1.01	1.05	1.02	3.96
		2	15.67	0.97	1.00	1.02	0.99	4.31	16.18	0.97	1.00	1.02	1.00	4.30	17.22	0.97	1.00	1.02	1.00	4.28
		2.5	17.90	0.97	1.00	1.01	0.99	4.34	18.41	0.97	1.00	1.01	0.99	4.30	19.44	0.97	1.00	1.01	1.00	4.32
	10	0.5	16.71	0.89	1.01	1.29	1.00	0.90	17.28	0.89	1.01	1.28	1.02	0.90	18.45	0.88	1.01	1.27	1.04	0.90
		1	17.27	0.89	1.01	1.27	1.00	1.14	17.84	0.89	1.01	1.27	1.02	1.13	19.00	0.88	1.01	1.26	1.04	1.11
		2	21.01	0.96	1.00	1.04	0.99	4.11	21.53	0.96	1.00	1.04	1.00	4.10	22.57	0.96	1.00	1.04	1.00	4.07
		2.5	23.17	0.96	1.00	1.03	0.99	4.21	23.69	0.96	1.00	1.03	0.99	4.20	24.72	0.96	1.00	103	1.00	4.19
	50	0.5	74.88	0.90	1.00	1.30	0.99	0.83	75.44	0.90	1.00	1.30	0.99	0.83	76.55	0.89	1.00	1.30	1.00	0.83
		1	75.35	0.90	1.00	1.30	0.99	0.84	75.90	0.89	1.00	1.30	0.99	0.84	77.02	0.89	1.00	1.30	1.00	0.84
		2	76.31	0.89	1.00	1.30	0.99	0.88	76.87	0.89	1.00	1.30	0.99	0.88	77.98	0.89	1.00	1.30	1.00	0.88
		2.5	76.81	0.89	1.00	1.30	0.99	0.91	77.37	0.89	1.00	1.30	0.99	0.91	78.48	0.89	1.00	1.30	1.00	0.91

Table C-18b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_9

	β=1.5	Carbon Steel, T>200°F																	
		f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
0.5	0.5	3.14	0.88	1.02	1.01	1.02	1.48	3.73	0.87	1.02	1.01	1.05	1.31	4.99	0.85	1.02	1.01	1.10	1.06
	1	4.04	0.92	1.01	1.00	1.00	1.72	4.59	0.91	1.01	1.00	1.02	1.66	5.73	0.89	1.01	1.00	1.05	1.51
	2	5.93	0.94	1.01	1.00	1.00	179	6.46	0.94	1.01	1.00	1.00	1.77	7.55	0.93	1.01	1.00	1.02	1.73
	2.5	6.88	0.94	1.00	1.04	0.99	1.80	7.41	0.94	1.00	1.00	1.00	1.79	8.48	0.93	1.00	1.00	1.01	1.76
1	0.5	3.73	0.87	1.02	1.01	1.02	1.33	4.33	0.85	1.02	1.03	1.05	1.19	5.59	0.85	1.02	1.03	1.09	1.02
	1	4.59	0.91	1.01	1.00	1.00	1.67	5.15	0.90	1.01	1.01	1.02	1.61	6.30	0.88	1.01	1.01	1.05	1.45
	2	6.46	0.94	1.01	1.00	1.00	1.77	7.00	0.93	1.01	1.00	1.00	1.75	8.09	0.92	1.01	1.00	1.02	1.71
	2.5	7.41	0.94	1.00	1.09	0.99	1.79	7.94	0.94	1.00	1.00	1.00	1.78	9.02	0.93	1.00	1.00	1.01	1.74
3	0.5	6.24	0.85	1.02	1.06	1.01	0.98	6.84	0.84	1.02	1.09	1.03	0.96	8.08	0.84	1.01	1.07	1.06	0.93
	1	6.91	0.87	1.01	1.02	1.00	1.35	7.49	0.87	1.01	1.06	1.02	1.26	8.69	0.86	1.01	1.06	1.04	1.16
	2	8.65	0.92	1.01	1.02	1.00	1.68	9.19	0.91	1.01	1.02	1.00	1.66	10.30	0.90	1.01	1.02	1.02	1.60
	2.5	9.57	0.93	1.00	1.11	0.99	1.73	10.11	0.92	1.00	1.02	1.00	1.71	11.20	0.91	1.00	1.02	1.01	1.67
5	0.5	8.84	0.85	1.01	1.10	1.00	0.91	9.43	0.85	1.01	1.10	1.02	0.90	10.64	0.85	1.01	1.09	1.04	0.89
	1	9.41	0.86	1.01	1.05	1.00	1.07	10.00	0.85	1.01	1.09	1.01	1.05	11.20	0.85	1.01	1.08	1.03	1.01
	2	10.92	0.90	1.01	1.03	1.00	1.54	11.48	0.89	1.01	1.05	1.00	1.51	12.62	0.88	1.01	1.05	1.02	1.44
	2.5	11.80	0.91	1.00	1.12	0.99	1.63	12.35	0.91	1.00	1.03	1.00	1.61	13.46	0.90	1.00	1.03	1.01	1.56
10	0.5	15.39	0.86	1.01	1.12	1.00	0.86	15.97	0.85	1.01	1.12	1.00	0.85	17.16	0.85	1.01	1.11	1.02	0.85
	1	15.90	0.86	1.01	1.10	1.00	0.91	16.49	0.85	1.01	1.12	1.00	0.91	17.67	0.85	1.01	1.11	1.02	0.90
	2	17.07	0.86	1.01	1.08	1.00	1.11	17.65	0.86	1.01	1.10	1.00	1.10	18.82	0.86	1.01	1.10	1.01	1.07
	2.5	17.75	0.87	1.00	1.13	0.99	1.26	18.32	0.87	1.00	1.08	1.00	1.24	19.48	0.87	1.00	1.08	1.01	1.20
50	0.5	68.01	0.86	1.00	1.13	0.99	0.82	68.58	0.86	1.00	1.13	0.99	0.82	69.73	0.86	1.00	1.13	1.00	0.82
	1	68.48	0.86	1.00	1.13	0.99	0.83	69.06	0.86	1.00	1.13	0.99	0.83	70.21	0.86	1.00	1.13	1.00	0.83
	2	69.46	0.86	1.00	1.13	0.99	0.85	70.03	0.86	1.00	1.13	0.99	0.85	71.19	0.86	1.00	1.13	1.00	0.85
	2.5	69.95	0.86	1.00	1.13	0.99	0.86	70.53	0.86	1.00	1.13	0.99	0.86	71.68	0.86	1.00	1.13	0.99	0.86

Tble C-18b: (Continued)

	β=2.5	Carbon Steel, T>200°F																	
		f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
0.5	0.5	4.43	0.91	1.01	1.00	1.00	4.08	4.99	0.90	1.01	1.00	1.02	3.96	6.15	0.88	1.01	1.00	1.05	3.55
	1	6.70	0.93	1.01	1.00	1.00	4.25	7.23	0.93	1.01	1.00	1.00	4.21	8.32	0.92	1.01	1.00	1.02	4.12
	2	11.26	0.94	1.00	0.99	0.99	4.31	11.79	0.94	1.00	0.99	1.00	4.30	12.85	0.94	1.00	0.99	1.00	4.26
	2.5	13.55	0.94	1.00	0.99	0.99	4.32	14.07	0.94	1.00	0.99	0.99	4.31	15.13	0.94	1.00	0.99	1.00	4.29
1	0.5	4.99	0.90	1.01	1.01	1.00	3.97	5.55	0.89	1.01	1.01	1.02	3.82	6.73	0.86	1.01	1.02	1.06	3.32
	1	7.23	0.93	1.01	1.00	1.00	4.21	7.77	0.92	1.01	1.00	1.00	4.17	8.87	0.91	1.01	1.00	1.02	4.07
	2	11.79	0.94	1.00	1.00	0.99	4.30	12.32	0.94	1.00	1.00	1.00	4.28	13.38	0.93	1.00	1.00	1.00	4.25
	2.5	14.07	0.94	1.00	1.00	0.99	4.31	14.60	0.94	1.00	1.00	0.99	4.30	15.66	0.94	1.00	1.00	1.00	4.28
3	0.5	7.37	0.83	1.02	1.09	1.01	2.68	8.02	0.77	1.02	1.14	1.05	1.31	9.43	0.76	1.02	1.13	1.10	1.10
	1	9.43	0.91	1.01	1.02	1.01	4.00	9.98	0.90	1.01	1.02	1.00	3.94	11.11	0.89	1.01	1.02	1.02	3.80
	2	13.93	0.93	1.00	1.01	0.99	4.23	14.46	0.93	1.00	1.01	1.00	4.21	15.54	0.92	1.00	1.01	1.00	4.17
	2.5	16.20	0.94	1.00	1.00	0.99	4.26	16.73	0.93	1.00	1.00	0.99	4.25	17.80	0.93	1.00	1.00	1.00	4.22
5	0.5	10.42	0.77	1.02	1.20	1.01	1.00	11.08	0.77	1.02	1.19	1.03	0.99	12.46	0.76	1.02	1.17	1.07	0.96
	1	11.74	0.88	1.01	1.05	1.00	3.62	12.31	0.88	1.01	1.05	1.00	3.52	13.48	0.86	1.01	1.06	1.02	0.27
	2	16.11	0.92	1.00	1.02	0.99	4.13	16.65	0.92	1.00	1.02	1.00	4.11	17.74	0.91	1.00	1.02	1.00	4.06
	2.5	18.36	0.93	1.00	1.01	0.99	4.20	18.90	0.93	1.00	1.01	0.99	4.18	19.98	0.92	1.00	1.01	1.00	4.15
10	0.5	18.27	0.78	1.01	1.22	1.00	0.89	18.91	0.77	1.01	1.22	1.01	0.88	20.24	0.77	1.01	1.21	1.03	0.88
	1	18.87	0.78	1.01	1.21	1.00	1.02	19.52	0.77	1.01	1.21	1.01	1.02	20.85	0.77	1.01	1.20	1.03	1.00
	2	21.80	0.89	1.00	1.05	0.99	3.73	22.35	0.89	1.00	1.05	1.00	3.70	23.48	0.88	1.00	1.05	1.00	3.61
	2.5	23.93	0.91	1.00	1.03	0.99	3.95	24.48	0.90	1.00	1.03	0.99	0.92	25.59	0.90	1.00	1.04	1.00	3.88
50	0.5	81.44	0.79	1.00	1.24	0.99	0.82	82.07	0.79	1.00	1.24	0.99	0.82	83.34	0.78	1.00	1.24	1.00	0.82
	1	81.97	0.79	1.00	1.24	0.99	0.84	82.60	0.78	1.00	1.24	0.99	0.84	83.87	0.78	1.00	1.24	1.00	0.84
	2	83.06	0.78	1.00	1.24	0.99	0.87	83.69	0.78	1.00	1.24	0.99	0.87	84.96	0.78	1.00	1.24	1.00	0.87
	2.5	83.62	0.78	1.00	1.24	0.99	0.89	84.25	0.78	1.00	1.24	0.99	0.89	85.52	0.78	1.00	1.23	1.00	0.89

Table C-18c: Mean Load and Resistance Factors for Stainless Steel and any T for g_9

		β=1.5	Stainless Steel for any T																	
			f_M=0.5						f_M=1.0						f_M=2.0					
		fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
f_{Po}	0.5	0.5	3.21	0.85	1.02	1.01	1.02	1.38	3.82	0.83	1.02	1.01	1.05	1.22	5.12	0.82	1.02	1.01	1.09	1.02
		1	4.10	0.90	1.01	1.00	1.00	1.67	4.67	0.89	1.01	1.00	1.02	1.61	5.85	0.86	1.01	1.00	1.05	1.43
		2	6.00	0.92	1.01	1.00	1.00	1.76	6.54	0.92	1.01	1.00	1.00	1.74	7.65	0.90	1.01	1.00	1.02	1.69
		2.5	6.96	0.93	1.00	1.00	0.99	1.78	7.50	0.92	1.00	1.00	1.00	1.76	8.59	0.91	1.00	1.00	1.01	1.73
	1	0.5	3.82	0.83	1.02	1.03	1.02	1.23	4.44	0.82	1.02	1.03	1.04	1.11	5.74	0.82	1.02	1.02	1.08	0.99
		1	4.67	0.89	1.01	1.01	1.00	1.61	5.24	0.87	1.01	1.01	1.02	1.54	6.44	0.85	1.01	1.01	1.05	1.35
		2	6.54	0.92	1.01	1.00	1.00	1.74	7.09	0.91	1.01	1.00	1.00	1.72	8.21	0.90	1.01	1.00	1.02	1.66
		2.5	7.50	0.92	1.00	1.00	0.99	1.76	8.04	0.92	1.00	1.00	1.00	1.75	9.14	0.91	1.00	1.00	1.01	1.71
	3	0.5	6.41	0.82	1.02	1.08	1.01	0.96	7.03	0.82	1.02	1.08	1.02	0.94	8.31	0.81	1.01	1.06	1.05	0.91
		1	7.07	0.84	1.01	1.06	1.00	1.25	7.67	0.83	1.01	1.06	1.02	1.19	8.92	0.82	1.01	1.05	1.04	1.10
		2	8.78	0.89	1.01	1.02	1.00	1.63	9.34	0.89	1.01	1.02	1.00	1.60	10.49	0.87	1.01	1.02	1.02	1.53
		2.5	9.71	0.90	1.00	1.02	0.99	1.68	10.26	0.90	1.00	1.02	1.00	1.66	11.38	0.89	1.00	1.02	1.01	1.62
	5	0.5	9.08	0.82	1.01	1.10	1.00	0.89	9.69	0.82	1..01	1.09	1.01	0.89	10.94	0.82	1.01	1.08	1.03	0.88
		1	9.66	0.83	1.01	1.09	1.00	1.03	10.27	0.82	1.01	1.08	1.01	1.01	11.51	0.82	1.01	1.08	1.03	0.98
		2	11.14	0.87	1.01	1.05	1.00	1.46	11.71	0.86	1.01	1.05	1.00	1.42	12.89	0.85	1.01	1.05	1.02	1.34
		2.5	12.00	0.88	1.00	1.03	0.99	1.57	12.57	0.88	1.00	1.03	1.00	1.54	13.72	0.87	1.00	1.03	1.01	1.49
	10	0.5	15.79	0.83	1.01	1.11	1.00	0.85	16.40	0.82	1.01	1.11	1.00	0.85	17.62	0.82	1.01	1.10	1.01	0.85
		1	16.32	0.83	1.01	1.11	1.00	0.90	16.93	0.82	1.01	1.11	1.00	0.90	18.15	0.82	1.01	1.10	1.01	0.89
		2	17.50	0.83	1.01	1.09	0.99	1.06	18.10	0.83	1.01	1.09	1.00	1.05	19.31	0.83	1.01	1.09	1.01	1.03
		2.5	18..17	0.84	1.00	1.08	0.99	1.18	18.76	0.84	1.00	1.08	1.00	1.17	19.96	0.83	1.00	1.08	1.01	1.13
	50	0.5	69.71	0.83	1.00	1.12	0.99	0.82	70.30	0.83	1.00	1.12	0.99	0.82	71.50	0.83	1.00	1.12	0.99	0.82
		1	70.20	0.83	1.00	1.12	0.99	0.83	70.80	0.83	1.00	1.12	0.99	0.83	71.99	0.83	1.00	1.12	0.99	0.83
		2	71.21	0.83	1.00	1.12	0.99	0.85	71.80	0.83	1.00	1.12	0.99	0.84	73.00	0.83	1.00	1.12	0.99	0.84
		2.5	71.72	0.83	1.00	1.12	0.99	0.85	72.31	0.83	1.00	1.12	0.99	0.85	73.51	0.83	1.00	1.12	0.99	0.85

Table C-18c: (Continued)

		β=2.5	Stainless Steel for any T																	
			f_M=0.5						f_M=1.0						f_M=2.0					
		fo	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fy}	γ'_A	γ'_{Po}	γ'_M	γ'_o
f_{Po}	0.5	0.5	4.51	0.89	1.01	1.00	1.00	3.97	5.08	0.87	1.01	1.00	1.02	3.80	6.29	0.83	1.01	1.00	1.06	3.21
		1	6.78	0.91	1.01	1.00	1.00	4.19	7.33	0.91	1.01	1.00	1.00	4.14	8.45	0.89	1.01	1.00	1.02	4.01
		2	11.39	0.92	1.00	0.99	0.99	4.27	11.92	0.92	1.00	0.99	1.00	4.25	13.01	0.92	1.00	0.99	1.00	4.21
		2.5	13.69	0.93	1.00	0.99	0.99	4.28	14.23	0.92	1.00	0.99	0.99	4.27	15.31	0.92	1.00	0.99	1.00	4.24
	1	0.5	5.08	0.87	1.01	1.01	1.00	3.81	5.66	0.86	1.01	1.01	1.02	3.61	6.91	0.80	1.02	1.002	1.07	2.75
		1	7.33	0.91	1.01	1.00	1.00	4.14	7.88	0.90	1.01	1.00	1.00	4.09	9.01	0.89	1.01	1.00	1.02	3.95
		2	11.92	0.92	1.00	1.00	0.99	4.25	12.46	0.92	1.00	1.00	1.00	4.23	13.55	0.91	1.00	1.00	1.00	4.19
		2.5	14.23	0.92	1.00	1.00	0.99	4.27	14.7	0.92	1.00	1.00	0.99	4.25	15.85	0.92	1.00	1.00	1.00	4.22
	3	0.5	7.66	0.73	1.02	1.14	1.02	1.25	8.37	0.72	1.02	1.13	1.04	1.15	9.86	0.72	1.02	1.11	1.09	1.04
		1	9.60	0.88	1.01	1.02	1.00	3.86	10.17	0.87	1.01	1.02	1.00	3.78	11.34	0.86	1.01	1.03	1.02	3.58
		2	14.11	0.91	1.00	1.01	0.99	4.16	14.66	0.91	1.00	1.01	1.00	4.14	15.76	0.90	1.00	1.01	1.00	4.08
		2.5	16.40	0.92	1.00	1.00	0.99	4.20	16.95	0.91	1.00	1.00	0.99	4.19	18.04	0.91	1.00	1.00	1.00	4.15
	5	0.5	10.87	0.73	1.02	1.18	1.01	0.98	11.57	0.72	1.02	1.17	1.03	0.96	13.02	0.72	1.02	1.15	1.06	0.94
		1	12.01	0.84	1.01	1.06	1.00	3.33	12.60	0.83	1.01	1.06	1.01	3.17	13.85	0.80	1.01	1.07	1.03	2.63
		2	16.35	0.90	1.00	1.02	0.99	4.04	16.91	0.89	1.00	1.02	1.00	4.01	18.03	0.89	1.00	1.02	1.00	3.94
		2.5	18.62	0.91	1.00	1.01	0.99	4.12	19.17	0.90	1.00	1.01	0.99	4.10	20.27	0.90	1.00	1.01	1.00	4.05
	10	0.5	19.03	0.73	1.01	1.20	1.00	0.88	19.72	0.73	1.01	1.20	1.01	0.88	21.11	0.73	1.01	1.10	1.03	0.87
		1	19.66	0.73	1.01	1.19	1.00	0.99	20.35	0.73	1.01	1.19	1.01	0.99	21.75	0.73	1.01	1.18	1.03	0.98
		2	22.24	0.86	1.00	1.05	0.99	3.50	22.82	0.85	1.00	1.05	1.00	3.45	24.01	0.84	1.00	1.06	1.00	3.32
		2.5	24..36	0.88	1.00	1.04	0.99	3.80	24.92	0.87	1.00	1.04	0.99	3.76	26.07	0.87	1.00	1.04	1.00	3.70
	50	0.5	84.71	0.74	1.00	1.22	0.99	0.82	85.37	0.74	1.00	1.22	0.99	0.82	86.72	0.74	1.00	1.22	1.00	0.82
		1	85.27	0.74	1.00	1.22	0.99	0.84	85.93	0.74	1.00	1.22	0.99	0.84	87.28	0.74	1.00	1.22	1.00	0.84
		2	86.41	0.74	1.00	1.22	0.99	0.87	87.08	0.74	1.00	1.22	0.99	0.87	88.42	0.74	1.00	1.21	1.00	0.87
		2.5	87.00	0.74	1.00	1.22	0.99	0.88	87.67	0.74	1.00	1.22	0.99	0.88	89.02	0.74	1.00	1.21	1.00	0.88

Table C-19a: Adjusted Nominal Resistance Factors for Carbon Steel and γ_A=1.1, γ_{PO}=γ_M=1.2, γ_O=1.5 for g_9

	β=1.5	Carbon Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
f_{Po}	fo	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
0.5	0.5	0.98[1]	0.81[1]	0.92	0.80	0.74	0.99[1]	0.82[1]	0.92	0.79	0.74	0.99[1]	0.81[1]	0.89	0.77	0.72
	1	0.93[1]	0.76[1]	0.93	0.80	0.75	0.95[1]	0.78[1]	0.93	0.81	0.75	0.97[1]	0.80[1]	0.93	0.80	0.75
	2	0.86[1]	0.71[1]	0.93	0.80	0.75	0.88[1]	0.72[1]	0.93	0.80	0.75	0.91[1]	0.75[1]	0.94	0.81	0.75
	2.5	0.84[1]	0.81[1]	0.93	0.80	0.75	0.86[1]	0.71[1]	0.93	0.80	0.75	0.89[1]	0.73[1]	0.94	0.81	0.75
1	0.5	1.00[1]	0.82[1]	0.92	0.80	0.74	1.01[1]	0.83[1]	0.92	0.79	0.74	1.00[1]	0.82[1]	0.90	0.77	0.72
	1	0.95[1]	0.78[1]	0.94	0.81	0.76	0.96[1]	0.79[1]	0.94	0.81	0.76	0.98[1]	0.81[1]	0.93	0.81	0.75
	2	0.89[1]	0.73[1]	0.94	0.81	0.75	0.90[1]	0.74[1]	0.94	0.81	0.76	0.93[1]	0.76[1]	0.94	0.81	0.75
	2.5	0.87[1]	0.71[1]	0.93	0.81	0.75	0.88[1]	0.73[1]	0.94	0.81	0.75	0.91[1]	0.75[1]	0.94	0.81	0.76
3	0.5	1.01[1]	0.83[1]	0.90	0.78	0.73	1.01[1]	0.83[1]	0.90	0.78	0.73	1.01[1]	0.83[1]	0.89	0.77	0.72
	1	1.00[1]	0.82[1]	0.94	0.81	0.76	1.01[1]	0.83[1]	0.94	0.81	0.76	1.01[1]	0.83[1]	0.93	0.80	0.75
	2	0.95[1]	0.78[1]	0.95	0.82	0.77	0.96[1]	0.79[1]	0.96	0.82	0.77	0.97[1]	0.80[1]	0.95	0.82	0.77
	2.5	0.93[1]	0.76[1]	0.95	0.82	0.77	0.94[1]	0.77[1]	0.95	0.82	0.77	0.95[1]	0.78[1]	0.95	0.82	0.77
5	0.5	1.00[1]	0.82[1]	0.89	0.75	0.71	1.00[1]	0.82[1]	0.89	0.76	0.71	1.00[1]	0.82[1]	0.88	0.76	0.71
	1	1.01[1]	0.83[1]	0.93	0.80	0.75	1.01[1]	0.83[1]	0.92	0.80	0.74	1.01[1]	0.83[1]	0.92	0.79	0.74
	2	0.98[1]	0.81[1]	0.93	0.83	0.77	0.99[1]	0.81[1]	0.96	0.82	0.77	0.99[1]	0.82[1]	0.95	0.82	0.77
	2.5	0.97[1]	0.79[1]	0.96	0.83	0.77	0.97[1]	0.80[1]	0.96	0.83	0.77	0.98[1]	0.81[1]	0.96	0.83	0.77
10	0.5	0.98[1]	0.81[1]	0.87	0.75	0.70	0.98[1]	0.81[1]	0.87	0.75	0.70	0.99[1]	0.81[1]	0.87	0.75	0.70
	1	0.99[1]	0.82[1]	0.89	0.77	0.72	1.00[1]	0.82[1]	0.89	0.77	0.72	1.00[1]	0.82[1]	0.89	0.77	0.72
	2	1.01[1]	0.83[1]	0.93	0.81	0.75	1.00[1]	0.83[1]	0.93	0.80	0.75	1.01[1]	0.83[1]	0.93	0.80	0.75
	2.5	1.00[1]	0.82[1]	0.95	0.82	0.70	1.00[1]	0.83[1]	0.95	0.82	0.76	1.01[1]	0.83[1]	0.94	0.81	0.76
50	0.5	0.96[1]	0.79[1]	0.84	0.73	0.68	0.96[1]	0.79[1]	0.84	0.73	0.68	0.96[1]	0.79[1]	0.84	0.73	0.68
	1	0.96[1]	0.79[1]	0.85	0.73	0.68	0.96[1]	0.79[1]	0.85	0.73	0.68	0.96[1]	0.79[1]	0.85	0.73	0.68
	2	0.97[1]	0.80[1]	0.86	0.74	0.69	0.97[1]	0.80[1]	0.86	0.75	0.69	0.97[1]	0.80[1]	0.86	0.74	0.69
	2.5	0.97[1]	0.80[1]	0.87	0.75	0.70	0.97[1]	0.80[1]	0.87	0.76	0.70	0.98[1]	0.80[1]	0.87	0.75	0.70

[1] γ_A=γ_M=γ_{PO}=1.0, γ_O=0.9

Table C-19a: (Continued)

	β=2.5	Carbon Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
f_{Po}	fo	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
0.5	0.5	0.88	0.72	0.65	0.56	0.53	0.92	0.76	0.69	0.59	0.55	0.98	0.81	0.73	0.63	0.58
	1	0.75	0.62	0.56	0.48	0.45	0.78	0.65	0.59	0.51	0.48	0.86	0.70	0.64	0.55	0.52
	2	0.65	0.53	0.49	0.42	0.39	0.72	0.56	0.51	0.44	0.41	0.75	0.60	0.55	0.47	0.44
	2.5	0.62	0.51	0.47	0.41	0.38	0.71	0.54	0.49	0.42	0.39	0.73	0.57	0.53	0.45	0.42
1	0.5	0.93	0.76	0.69	0.60	0.56	0.96	0.79	0.72	0.62	0.58	1.01	0.83	0.75	0.64	0.60
	1	0.80	0.65	0.60	0.51	0.48	0.83	0.68	0.62	0.54	0.50	0.89	0.73	0.66	0.57	0.53
	2	0.68	0.56	0.51	0.44	0.41	0.71	0.58	0.53	0.46	0.43	0.76	0.62	0.57	0.49	0.46
	2.5	0.65	0.54	0.49	0.42	0.47	0.68	0.56	0.51	0.44	0.41	0.72	0.59	0.54	0.47	0.44
3	0.5	1.05	0.86	0.77	0.66	0.62	1.06	0.88	0.77	0.66	0.62	1.08	0.89	0.76	0.66	0.62
	1	0.93	0.66	0.69	0.60	0.56	0.95	0.78	0.71	0.61	0.57	0.98	0.81	0.73	0.63	0.59
	2	0.79	0.65	0.59	0.51	0.48	0.81	0.67	0.61	0.52	0.49	0.84	0.69	0.63	0.54	0.51
	2.5	0.75	0.62	0.56	0.49	0.45	0.77	0.63	0.58	0.50	0.46	0.80	0.66	0.60	0.52	0.48
5	0.5	1.07	0.88	0.75	0.65	0.61	1.08	0.89	0.76	0.65	0.61	1.08	0.89	0.76	0.65	0.61
	1	1.00	0.83	0.74	0.64	0.60	1.02	0.84	0.75	0.65	0.60	1.04	0.85	0.76	0.66	0.61
	2	0.87	0.71	0.65	0.56	0.52	0.88	0.73	0.66	0.57	0.53	0.91	0.75	0.68	0.58	0.55
	2.5	0.82	0.68	0.62	0.53	0.50	0.84	0.69	0.63	0.54	0.50	0.86	0.71	0.65	0.56	0.52
10	0.5	1.04	0.85	0.73	0.63	0.59	1.04	0.86	0.73	0.63	0.59	1.05	0.86	0.74	0.63	0.59
	1	1.07	0.88	0.75	0.65	0.61	1.07	0.88	0.75	0.65	0.61	1.08	0.89	0.76	0.65	0.61
	2	0.99	0.81	0.73	0.63	0.59	0.99	0.82	0.74	0.64	0.59	1.01	0.83	0.75	0.64	0.60
	2.5	0.94	0.78	0.70	0.61	0.57	0.95	0.78	0.71	0.66	0.57	0.97	0.79	0.72	0.62	0.58
50	0.5	0.99	0.82	0.70	0.61	0.57	1.00	0.82	0.70	0.61	0.57	1.00	0.82	0.71	0.61	0.57
	1	1.00	0.83	0.71	0.61	0.57	1.00	0.83	0.71	0.61	0.57	1.01	0.83	0.71	0.61	0.57
	2	1.02	0.84	0.72	0.62	0.58	1.02	0.84	0.72	0.62	0.58	1.02	0.84	0.72	0.62	0.58
	2.5	1.03	0.85	0.73	0.63	0.58	1.03	0.85	0.73	0.63	0.59	1.03	0.85	0.73	0.63	0.59

Table C-19b: Adjusted Nominal Resistance Factors for Stainless Steel and γ_A=1.1, γ_{PO}=γ_M=1.2, γ_O=1.5 for g_9

		Stainless Steel														
	β=1.5	f_M=0.5					f_M=1.0					f_M=2.0				
f_{Po}	*fo*	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
0.5	0.5	1.03[1]	0.90[1]	0.93	0.83	0.78	1.03[1]	0.90[1]	0.93	0.82	0.77	1.02[1]	0.89[1]	0.90	0.80	0.75
	1	0.99[1]	0.87[1]	0.95	0.85	0.79	1.01[1]	0.88[1]	0.95	0.84	0.79	1.02[1]	0.89	0.94	0.84	0.79
	2	0.93[1]	0.81[1]	0.95	0.84	0.79	0.95[1]	0.83[1]	0.95	0.85	0.79	0.98[1]	0.85	0.96	0.85	0.80
	2.5	0.91[1]	0.79[1]	0.95	0.84	0.79	0.93[1]	0.81[1]	0.95	0.85	0.79	0.96[1]	0.84	0.96	0.85	0.80
1	0.5	1.04[1]	0.91[1]	0.93	0.83	0.78	1.04[1]	0.90[1]	0.92	0.82	0.77	1.02[1]	0.89	0.90	0.80	0.75
	1	1.01[1]	0.88[1]	0.96	0.85	0.80	1.02[1]	089[1]	0.96	0.85	0.80	1.03[1]	0.90	0.95	0.84	0.79
	2	0.95[1]	0.83[1]	0.96	0.85	0.80	0.97[1]	0.85[1]	0.96	0.85	0.80	0.99[1]	0.96	0.96	0.85	0.80
	2.5	0.93[1]	0.81[1]	0.96	0.85	0.80	0.95[1]	0.83[1]	0.96	0.85	0.80	0.97[1]	0.85	0.96	0.85	0.80
3	0.5	1.03[1]	0.90[1]	0.91	0.81	0.76	1.03[1]	0.90[1]	0.91	0.81	0.76	1.02[1]	0.89	0.90	0.80	0.75
	1	1.04[1]	0.91[1]	0.95	0.85	0.79	1.04[1]	0.91[1]	0.95	0.84	0.79	1.04[1]	0.91	0.94	0.83	0.78
	2	1.01[1]	0.88[1]	0.97	0.86	0.81	1.02[1]	0.89[1]	0.97	0.86	0.81	1.03[1]	0.90	0.97	0.86	0.81
	2.5	0.99[1]	0.87[1]	0.97	0.86	0.81	1.00[1]	0.87[1]	0.97	0.86	0.81	1.01[1]	0.89	0.97	0.86	0.81
5	0.5	1.02[1]	0.89[1]	0.89	0.79	0.74	1.02[1]	0.89[1]	0.89	0.79	0.74	1.02	0.89	0.89	0.79	0.74
	1	1.04[1]	0.91[1]	0.93	0.83	0.78	1.04[1]	0.91[1]	0.93	0.83	0.78	1.04	0.90	0.92	0.82	0.77
	2	1.04[1]	0.90[1]	0.97	0.86	0.81	1.04[1]	0.91[1]	0.97	0.86	0.81	1.04	0.91	0.96	0.86	0.80
	2.5	1.03[1]	0.89[1]	0.98	0.87	0.81	1.03[1]	0.90[1]	0.97	0.87	0.81	1.03	0.90	0.97	0.86	0.81
10	0.5	1.01[1]	0.88[1]	0.87	0.78	0.73	1.01[1]	0.88[1]	0.87	0.78	0.73	1.01	0.88	0.88	0.78	0.73
	1	1.02[1]	0.89[1]	0.90	0.80	0.75	1.02[1]	0.8[1]9	0.90	0.80	0.77	1.02	0.89	0.90	0.80	0.75
	2	1.04[1]	0.91[1]	0.94	0.84	0.79	1.04[1]	0.91[1]	0.94	0.84	0.78	1.04	0.91	0.94	0.83	0.78
	2.5	1.04[1]	0.91[1]	0.96	0.85	0.80	1.04[1]	0.91[1]	0.96	0.85	0.80	1.04	0.91	0.95	0.85	0.79
50	0.5	0.99[1]	0.86[1]	0.85	0.76	0.71	0.99[1]	0.86[1]	0.85	0.76	0.71	0.99	0.87	0.85	0.76	0.71
	1	0.99[1]	0.87[1]	0.86	0.76	0.71	0.99[1]	0.87[1]	0.86	0.76	0.71	0.99	0.87	0.86	0.76	0.72
	2	1.00[1]	0.87[1]	0.87	0.77	0.73	1.00[1]	0.87[1]	0.87	0.77	0.73	1.00	0.87	0.87	0.77	0.73
	2.5	1.00[1]	0.88[1]	0.88	0.78	0.73	1.00[1]	0.88[1]	0.88	0.79	0.73	1.00	0.88	0.88	0.78	0.73

(1) γ_A=γ_M=γ_{PO}=1.0, γ_O=0.9

Table C-19b: (Continued)

	β=2.5	Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
	fo	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
f_{Po} = 0.5	0.5	0.93	0.81	0.66	0.59	0.55	0.98	0.85	0.70	0.62	0.58	1.03	0.90	0.73	0.65	0.61
	1	0.80	0.70	0.57	0.51	0.48	0.85	0.74	0.61	0.54	0.50	0.91	0.80	0.65	0.58	0.54
	2	0.70	0.61	0.50	0.44	0.42	0.73	0.61	0.52	0.47	0.44	0.79	0.69	0.56	0.50	0.47
	2.5	0.67	0.59	0.48	0.43	0.40	0.70	0.61	0.50	0.45	0.42	0.75	0.66	0.54	0.48	0.45
1	0.5	0.98	0.86	0.70	0.62	0.59	1.02	0.89	0.73	0.64	0.60	1.05	0.92	0.75	0.67	0.63
	1	0.85	0.74	0.61	0.54	0.51	0.89	0.78	0.64	0.56	0.53	0.95	0.83	0.68	0.60	0.56
	2	0.74	0.64	0.53	0.47	0.44	0.76	0.67	0.55	0.49	0.46	0.81	0.71	0.58	0.52	0.49
	2.5	0.71	0.62	0.50	0.45	0.42	0.73	0.64	0.52	0.46	0.43	0.78	0.68	0.55	0.49	0.46
3	0.5	1.07	0.93	0.76	0.68	0.64	1.07	0.93	0.76	0.68	0.64	1.06	0.92	0.76	0.67	0.63
	1	0.98	0.86	0.70	0.62	0.59	1.00	0.87	0.72	0.64	0.60	1.03	0.90	0.74	0.66	0.61
	2	0.85	0.74	0.61	0.54	0.50	0.87	0.76	0.62	0.55	0.52	0.90	0.79	0.64	0.57	0.54
	2.5	0.81	0.70	0.58	0.51	0.48	0.82	0.72	0.59	0.52	0.49	0.86	0.75	0.61	0.54	0.51
5	0.5	1.05	0.91	0.75	0.66	0.62	1.05	0.91	0.75	0.66	0.62	1.05	0.91	0.75	0.66	0.62
	1	1.05	0.92	0.75	0.67	0.63	1.06	0.93	0.76	0.67	0.63	1.07	0.94	0.77	0.68	0.64
	2	0.93	0.81	0.66	0.59	0.55	0.94	0.82	0.67	0.60	0.56	0.97	0.84	0.69	0.61	0.57
	2.5	0.88	0.77	0.63	0.56	0.52	0.89	0.89	0.64	0.57	0.53	0.92	0.80	0.66	0.58	0.55
10	0.5	1.02	0.89	0.73	0.64	0.60	1.02	0.89	0.73	0.65	0.61	1.02	0.89	0.73	0.65	0.61
	1	1.05	0.91	0.75	0.66	0.62	1.05	0.92	0.75	0.67	0.62	1.05	0.92	0.75	0.67	0.63
	2	1.04	0.91	0.74	0.66	0.62	1.05	0.91	0.75	0.66	0.62	1.06	0.92	0.75	0.67	0.63
	2.5	1.00	0.87	0.71	0.63	0.60	1.01	0.88	0.72	0.64	0.60	1.02	0.89	0.73	0.65	0.61
50	0.5	0.98	0.86	0.70	0.62	0.58	0.98	0.84	0.70	0.62	0.58	0.98	0.86	0.70	0.62	0.59
	1	0.99	0.86	0.71	0.63	0.59	0.99	0.85	0.71	0.63	0.59	0.99	0.87	0.71	0.63	0.59
	2	1.00	0.88	0.72	0.64	0.60	1.01	0.86	0.72	0.64	0.60	1.01	0.88	0.72	0.64	0.60
	2.5	1.01	0.88	0.72	0.64	0.60	1.01	0.87	0.72	0.64	0.60	1.01	0.89	0.72	0.64	0.60

C.9. Performance Function g_{11}

Table C-20 provides the calculated mean load and resistance factors for performance function g_{11}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-21 gives the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1 and γ_O=1.5.

Table C-20: Mean Partial Safety Factors for g_{11}

	β	Carbon Steel ($T \leq 200^oF$) & Stainless Steel				Carbon Steel ($T > 200^oF$)			
		μ_{fu}	ϕ'_u	γ'_A	γ'_O	μ_{fu}	ϕ'_u	γ'_A	γ'_O
f_O=0.5	1.5	1.96	0.983	1.023	1.813	2.00	0.953	1.023	1.758
	2	2.42	0.984	1.017	2.724	2.46	0.956	1.017	2.662
	3	4.90	0.987	1.007	7.662	4.97	0.964	1.007	7.564
f_O=1	1.5	2.89	0.987	1.011	1.844	2.93	0.964	1.011	1.815
	2	3.81	0.987	1.008	2.750	3.86	0.64	1.008	2.712
	3	8.79	0.988	1.003	7.678	8.90	0.967	1.003	7.599
f_O=2	1.5	4.77	0.989	1.006	1.853	4.82	0.969	1.006	1.834
	2	6.60	0.988	1.004	2.758	6.68	0.968	1.004	2.730
	3	16.56	0.989	1.002	7.684	16.75	0.969	1.002	7.614
f_O=2.5	1.5	5.70	0.989	1.004	1.855	5.77	0.971	1.004	1.837
	2	7.99	0.989	1.003	2.760	8.09	0.969	1.003	2.733
	3	20.45	0.989	1.001	7.685	20.68	0.969	1.001	7.617

Table C-21a: Adjusted Nominal Resistance Factor for γ_A=1.1 and γ_S=1.5 and Carbon Steel for g_{11}

		Carbon Steel				
f_O	β	R.T.	200°F	400°F	600°F	800°F
0.5	1.5	0.98[(1)]	0.89[(1)]	0.98[(1)]	0.92[(1)]	0.92
	2	1.00	0.91	1.00	0.94	0.75
	3	0.49	0.45	0.49	0.46	0.37
1	1.5	0.93[(1)]	0.85[(1)]	0.93[(1)]	0.88[(1)]	0.93
	2	0.92	0.85	0.94	0.88	0.71
	3	0.41	0.37	0.41	0.38	0.31
2	1.5	0.88[(1)]	0.81[(1)]	0.89[(1)]	0.84[(1)]	0.93
	2	0.89	0.81	0.89	0.84	0.67
	3	0.35	0.32	0.36	0.33	0.27
2.5	1.5	0.87[(1)]	0.80[(1)]	0.88[(1)]	0.70[(1)]	0.93
	2	0.88	0.80	0.88	0.83	0.66
	3	0.34	0.31	0.35	0.32	0.26

(1) γ_A=1.0 and γ_O=1.0, R.T.=Room Temperature

Table C-21b: Adjusted Nominal Resistance Factor for γ_A=1.1 and γ_O=1.5 and Stainless Steel for g_{11}

		Stainless Steel				
f_O	β	R.T.	200°F	400°F	600°F	800°F
0.5	1.5	0.96[(1)]	0.83[(1)]	0.94	0.94	0.91
	2	0.98	0.85	0.76	0.76	0.74
	3	0.48	0.42	0.38	0.38	0.36
1	1.5	0.91[(1)]	0.79[(1)]	0.94	0.94	0.91
	2	0.92	0.80	0.72	0.72	0.69
	3	0.40	0.35	0.31	0.31	0.30
2	1.5	0.87[(1)]	0.75[(1)]	0.94	0.94	0.91
	2	0.87	0.76	0.68	0.68	0.66
	3	0.35	0.30	0.27	0.27	0.26
2.5	1.5	0.86[(1)]	0.75[(1)]	0.94	0.94	0.91
	2	0.86	0.75	0.67	0.67	0.65
	3	0.34	0.29	0.26	0.26	0.25

(1) γ_A=1.0 and γ_O=1.0, R.T.=Room Temperature

C.10. Performance Function g_{12}

Table C-22 gives the calculated mean load and resistance factors for performance function g_{12}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-23 shows the evaluated adjusted nominal resistance factors for load factors γ_A=1.1, γ_{PO}=1.2, and γ_M=1.2.

Table C-22a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F and Stainless Steel for g_{12}

	β	Carbon Steel for $T \leq 200^{o}$F and Stainless Steel														
		f_O=0.5					f_O=1					f_O=2				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}
f_{Po}=0.5	2	2.93	0.981	1.017	2.700	1.006	4.31	0.985	1.008	2.742	0.999	7.10	0.988	1.004	2.755	0.995
	2.5	3.76	0.98	1.01	4.38	1.00	5.99	0.99	1.01	4.41	1.00	10.47	0.99	1.00	4.42	0.99
	3	5.41	0.986	1.007	7.647	0.997	9.29	0.987	1.003	7.672	0.994	17.06	0.988	1.002	7.682	0.993
f_{PO}=1	2	3.44	0.978	1.017	2.656	1.021	4.82	0.984	1.008	2.730	1.006	7.60	0.987	1.004	2.7561	0.999
	2.5	4.27	0.98	1.01	4.35	1.01	6.50	0.99	1.01	4.40	1.00	10.97	0.99	1.00	4.42	1.00
	3	5.91	0.984	1.007	7.625	1.033	9.79	0.987	1.003	7.664	0.997	17.56	0.988	1.002	7.679	0.994
f_{PO}=3	2	5.63	0.959	1.021	2.077	1.114	6.90	0.977	1.009	2.626	1.038	9.65	0.984	1.004	2.723	1.013
	2.5	6.39	0.97	1.01	4.05	1.06	8.56	0.98	1.01	4.33	1.02	13.00	0.99	1.00	4.40	1.01
	3	7.98	0.979	1.007	7.457	1.027	11.83	0.984	1.003	7.616	1.008	19.58	0.987	1.002	7.662	1.000
f_{PO}=5	2	8.15	0.942	1.021	1.047	1.228	9.08	0.969	1.009	2.390	1.079	11.72	0.981	1.004	2.674	1.029
	2.5	8.69	0.93	1.02	1.22	1.29	10.66	0.98	1.01	4.19	1.04	15.05	0.98	1.00	4.36	1.02
	3	10.11	0.974	1.007	7.116	1.056	13.89	0.982	1.003	7.535	1.021	21.62	0.986	1.002	7.638	1.006
f_{PO}=10	2	14.72	0.945	1.011	0.892	1.246	15.23	0.945	1.011	1.056	1.233	17.11	0.971	1.005	2.413	1.079
	3	15.73	0.93	1.01	0.91	1.32	16.28	0.93	1.01	1.25	1.29	20.38	0.98	1.00	4.21	1.04
	4.5	16.80	0.920	1.015	0.934	1.398	19.19	0.975	1.004	7.151	1.055	26.76	0.983	1.002	7.545	1.020
f_{PO}=50	2	67.56	0.948	1.002	0.825	1.253	68.00	0.948	1.002	0.840	1.252	68.90	0.948	1.002	0.873	1.251
	2.5	72.46	0.94	1.00	0.83	1.33	72.91	0.94	1.00	0.85	1.33	73.84	0.94	1.00	0.89	1.33
	3	77.73	0.924	1.003	0.830	1.409	78.19	0.924	1.003	0.850	1.408	79.13	0.924	1.003	0.902	1.405

Table C-22a: (Continued)

	β	Carbon Steel for $T \leq 200^{o}$F and Stainless Steel					
		f_O=2.5					
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}	
f_{Po}= 0.5	2	8.49	0.988	1.003	2.757	0.994	
	2.5	12.70	0.99	1.00	4.42	0.99	
	3	20.95	0.988	1.001	7.683	0.993	
f_{PO}=1	2	9.00	0.988	1.003	2.755	0.997	
	2.5	13.21	0.99	1.00	4.42	1.00	
	3	21.45	0.988	1.001	7.681	0.994	
f_{PO}=3	2	11.03	0.985	1.003	2.736	1.009	
	2.5	15.23	0.99	1.00	4.41	1.00	
	3	23.47	0.987	1.001	7.669	0.998	
f_{PO}=5	2	13.09	0.983	1.003	2.704	1.021	
	2.5	17.27	0.98	1.00	4.38	1.01	
	3	25.49	0.986	1.001	7.653	1.003	
f_{PO}= 10	2	18.39	0.976	1.004	2.552	1.056	
	3	22.47	0.98	1.00	4.28	1.03	
	4.5	30.61	0.984	1.001	7.590	1.014	
f_{PO}= 50	2	69.37	0.947	1.002	0.894	1.250	
	2.5	74.32	0.94	1.00	0.91	1.32	
	3	79.63	0.923	1.003	0.936	1.404	

Table C-22b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{12}

	β	Carbon Steel for T>200°F														
		f_O=0.5					f_O=1					f_O=2				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}	μ_{fy}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	2	2.98	0.947	1.017	2.607	1.066	4.38	0.960	1.009	2.694	0.999	7.19	0.966	1.004	2.723	0.995
	2.5	3.82	0.95	1.01	4.28	1.00	6.08	0.96	1.01	4.35	1.00	10.60	0.97	1.00	4.37	0.99
	3	5.48	0.961	1.007	7.527	0.997	9.41	0.966	1.003	7.584	0.994	17.27	0.968	1.002	7.607	0.993
f_{PO}=1	2	3.52	0.938	1.018	2.521	1.023	4.90	0.956	1.009	2.668	1.006	7.71	0.964	1.004	2.714	0.999
	2.5	4.35	0.95	1.01	4.22	1.01	6.60	0.96	1.01	4.33	1.00	11.11	0.97	1.00	4.37	1.00
	3	6.01	0.957	1.007	7.480	1.003	9.93	0.964	1.003	7.566	0.997	17.78	0.967	1.002	7.600	0.994
f_{PO}=3	2	5.87	0.876	1.025	1.381	1.144	7.06	0.937	1.009	2.487	1.040	9.80	0.956	1.004	2.662	1.014
	2.5	6.57	0.92	1.01	3.67	1.06	8.71	0.95	1.01	4.20	1.02	13.19	0.96	1.00	4.32	1.01
	3	8.14	0.943	1.007	7.174	1.028	12.01	0.957	1.003	7.470	1.009	19.85	0.964	1.002	7.564	1.000
f_{PO}=5	2	8.57	0.870	1.018	0.988	1.188	9.36	0.911	1.010	2.056	1.091	11.95	0.947	1.004	2.579	1.030
	2.5	9.23	0.84	1.02	1.07	1.24	10.91	0.94	1.01	3.96	1.05	15.30	0.95	1.00	4.26	1.02
	3	9.95	0.816	1.025	1.250	1.294	14.14	0.950	1.003	7.328	1.021	21.93	0.961	1.002	7.518	1.006
f_{PO}= 10	2	15.45	0.874	1.010	0.880	1.205	15.98	0.874	1.009	0.998	1.196	17.61	0.917	1.005	2.128	1.088
	3	16.68	0.85	1.01	0.90	1.27	17.26	0.85	1.01	1.09	1.25	20.74	0.94	1.00	4.00	1.05
	4.5	18.01	0.820	1.013	0.916	1.330	18.65	0.823	1.012	1.345	1.299	27.23	0.952	1.002	7.354	1.021
f_{PO}= 50	2	70.70	0.879	1.002	0.824	1.215	71.17	0.879	1.002	0.836	1.214	72.14	0.878	1.002	0.866	1.213
	2.5	76.63	0.85	1.00	0.83	1.28	77.12	0.85	1.00	0.84	1.28	78.13	0.85	1.00	0.88	1.28
	3	83.07	0.827	1.003	0.828	1.346	83.57	0.826	1.003	0.846	1.344	84.62	0.825	1.003	0.891	1.341

Table C-22b: (Continued)

	β	Carbon Steel for T>200°F				
		f_O=2.5				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_O	γ'_{PO}
f_{Po}= 0.5	2	8.60	0.968	1.003	2.728	0.994
	2.5	12.86	0.97	1.00	4.38	0.99
	3	21.20	0.968	1.001	7.612	0.993
f_{PO}=1	2	9.11	0.966	1.003	2.721	0.997
	2.5	13.37	0.97	1.00	4.37	1.00
	3	21.71	0.968	1.001	7.606	0.994
f_{PO}=3	2	11.20	0.959	1.003	2.685	1.009
	2.5	15.44	0.96	1.00	4.34	1.00
	3	23.77	0.965	1.001	7.579	0.998
f_{PO}=5	2	13.32	0.952	1.003	2.630	1.022
	2.5	17.54	0.958	1.002	4.299	1.011
	3	25.85	0.963	1.001	7.546	1.033
f_{PO}= 10	2	18.84	0.932	1.004	2.379	1.060
	2.5	22.91	0.95	1.00	4.13	1.03
	3	31.11	0.956	1.001	7.433	1.015
f_{PO}= 50	2	72.63	0.878	1.002	0.882	1.211
	2.5	78.65	0.851	1.002	0.900	1.274
	3	85.17	0.825	1.003	0.919	1.339

Table C-23a: Adjusted Nominal Resistance Factor for and Carbon Steel and γ_A=1.1, γ_{PO}=1.2 and γ_O=1.5 for g_{12}

	β	Carbon Steel														
		f_O=0.5					f_O=1.0					f_O=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PO}=0.5	2	0.83(1)	0.76(1)	0.83(1)	0.78(1)	0.81	0.73(1)	0.66(1)	0.73(1)	0.68(1)	0.75	0.64(1)	0.58(1)	0.64(1)	0.60(1)	0.70
	2.5	0.65(1)	0.89	0.65(1)	0.61(1)	0.63	0.52(1)	0.65	0.52(1)	0.49(1)	0.54	0.43(1)	0.57	0.43(1)	0.41(1)	0.48
	3	0.58	0.53	0.58	0.55	0.44	0.46	0.42	0.46	0.44	0.35	0.39	0.35	0.39	0.37	0.29
f_{PO}=1	2	0.89(1)	0.81(1)	0.88(1)	083(1)	0.84	0.78(1)	0.71(1)	0.78(1)	0.73(1)	0.78	0.67(1)	0.62(1)	0.68(1)	0.64(1)	0.73
	2.5	0.70(1)	0.83	0.71(1)	0.67(1)	0.68	0.58(1)	0.70	0.58(1)	0.54(1)	0.58	0.47(1)	0.61	0.47(1)	0.44(1)	0.50
	3	0.65	0.60	0.65	0.62	0.49	0.51	0.47	0.51	0.48	0.39	0.42	0.38	0.42	0.39	0.31
f_{PO}=3	2	0.97(1)	0.89(1)	0.95(1)	0.89(1)	0.88	0.89(1)	0.82(1)	0.89(1)	0.83(1)	0.86	0.78(1)	0.71(1)	0.78(1)	0.74(1)	0.80
	2.5	0.86(1)	0.97	0.85(1)	0.80(1)	0.79	0.72(1)	0.79	0.72(1)	0.68(1)	0.70	0.58(1)	0.72	0.58(1)	0.55(1)	0.59
	3	0.85	0.77	0.85	0.80	0.64	0.67	0.61	0.67	0.63	0.50	0.52	0.48	0.52	0.49	0.39
f_{PO}=5	2	0.97(1)	0.88(1)	0.94(1)	0.88(1)	0.86	0.95(1)	0.86(1)	0.93(1)	0.88(1)	0.89	0.85(1)	0.78(1)	0.85(1)	0.80(1)	0.84
	2.5	0.91(1)	1.02	0.87(1)	0.82(1)	0.80	0.80(1)	0.93	1.01(1)	0.95(1)	0.62	0.66(1)	0.80	0.66(1)	0.62(1)	0.66
	3	0.96	0.87	0.99	0.93	0.74	0.78	0.71	0.78	0.73	0.59	0.61	0.55	0.61	0.57	0.46
f_{PO}=10	2	0.95(1)	0.86(1)	0.92(1)	0.86(1)	0.84	0.96(1)	0.88(1)	0.93(1)	0.88(1)	0.87	0.94(1)	0.85(1)	0.93(1)	0.87(1)	0.89
	3	0.89(1)	0.98	0.85(1)	0.80(1)	0.78	0.90(1)	1.01	0.86(1)	0.81(1)	0.80	0.79(1)	0.92	0.79(1)	0.74(1)	0.75
	4.5	1.01	0.92	0.96	0.90	0.72	0.94	0.86	0.99	0.93	0.74	0.76	0.70	0.76	0.72	0.57
f_{PO}=50	2	0.92(1)	0.84(1)	0.90(1)	0.84(1)	0.81	0.93(1)	0.85(1)	0.90(1)	0.85(1)	0.82	0.94(1)	0.85(1)	0.91(1)	0.85(1)	0.83
	2.5	0.86(1)	0.95	0.83(1)	0.78(1)	0.72	0.86(1)	0.95	0.83(1)	0.78(1)	0.76	0.87(1)	0.97	0.84(1)	0.79(1)	0.77
	3	0.97	0.88	0.92	0.86	0.69	0.97	0.89	0.93	0.87	0.70	0.99	0.91	0.94	0.89	0.71

(1) $\gamma_A=\gamma_{P0}$=1 and γ_O=0.9

Table C-23a: (Continued)

	β	Carbon Steel f_O=2.5 R.T.	200°F	400°F	600°F	800°F
f_{PO}=0.5	2	0.61[1]	0.56[1]	0.62[1]	0.58[1]	0.69
	2.5	0.41[1]	0.56	0.41[1]	0.39[1]	0.46
	3	0.37	0.34	0.37	0.35	0.28
f_{PO}=1	2	0.65[1]	0.59[1]	0.65[1]	0.61[1]	0.71
	2.5	0.44[1]	0.59	0.44[1]	0.42[1]	0.48
	3	0.39	0.36	0.40	0.37	0.30
f_{PO}=3	2	0.75[1]	0.68[1]	0.75[1]	0.70[1]	0.78
	2.5	0.54[1]	0.68	0.54[1]	0.51[1]	0.56
	3	0.48	0.44	0.49	0.46	0.37
f_{PO}=5	2	0.81[1]	0.74[1]	0.81[1]	0.76[1]	0.82
	2.5	0.62[1]	0.75	0.62[1]	0.58[1]	0.62
	3	0.56	0.51	0.56	0.53	0.42
f_{PO}=10	2	0.91[1]	0.83[1]	0.90[1]	0.85[1]	0.87
	3	0.74[1]	0.88	0.74[1]	0.70[1]	0.72
	4.5	0.70	0.64	0.70	0.66	0.53
f_{PO}=50	2	0.94[1]	0.86[1]	0.91[1]	0.86[1]	0.84
	2.5	0.88[1]	0.98	0.84[1]	0.79[1]	0.77
	3	1.00	0.91	0.95	0.89	0.72

(1) For these factors $\gamma_A=\gamma_{PO}=1$ and $\gamma_O=0.9$

Table C-23b: Adjusted Nominal Resistance Factor for g_{12} and Stainless Steel for γ_A=1.1, γ_{PO}=1.2 and γ_O=1.5

		Stainless Steel														
	β	f_O=0.5					f_O=1.0					f_O=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PO}= 0.5	2	0.82(1)	0.71(1)	0.82	0.82	0.79	0.71(1)	0.62(1)	0.76	0.76	0.74	0.62(1)	0.54(1)	0.71	0.71	0.69
	2.5	0.64(1)	0.71	0.64	0.64	0.62	0.51(1)	0.61	0.55	0.55	0.53	0.42(1)	0.54	0.48	0.48	0.47
	3	0.57	0.49	0.42	0.42	0.43	0.45	0.39	0.35	0.35	0.34	0.38	0.33	0.30	0.30	0.29
f_{PO}=1	2	0.87(1)	0.76(1)	0.86	0.86	0.83	0.76(1)	0.66(1)	0.80	0.80	0.77	0.66(1)	0.57(1)	0.74	0.74	0.71
	2.5	0.71(1)	0.77	0.69	0.69	0.77	0.57(1)	0.66	0.59	0.59	0.57	0.46(1)	0.57	0.51	0.51	0.49
	3	0.64	0.56	0.50	0.50	0.48	0.50	0.44	0.39	0.39	0.38	0.41	0.6	0.32	0.32	0.31
f_{PO}=3	2	0.95(1)	0.83(1)	0.92	0.92	0.89	0.88(1)	0.76(1)	0.88	0.88	0.85	0.77(1)	0.67(1)	0.81	0.81	0.78
	2.5	0.84(1)	0.90	0.81	0.81	0.78	0.71(1)	0.79	0.71	0.71	0.68	0.57(1)	0.67	0.60	0.60	0.60
	3	0.83	0.72	0.65	0.65	0.63	0.66	0.57	0.51	0.51	0.50	0.57	0.50	0.40	0.40	0.39
f_{PO}=5	2	0.95(1)	0.83(1)	0.91	0.91	0.88	0.93(1)	0.81(1)	0.91	0.91	0.88	0.84(1)	0.72(1)	0.86	0.86	0.83
	2.5	0.89(1)	0.95	0.85	0.85	0.82	0.79(1)	0.87	0.78	0.78	0.75	0.65(1)	0.74	0.67	0.67	0.64
	3	0.94	0.82	0.73	0.73	0.71	0.77	0.66	0.60	0.60	0.58	0.60	0.52	0.46	0.46	0.45
f_{PO}=10	2	0.93(1)	0.81(1)	0.88	0.88	0.85	0.94(1)	0.82(1)	0.91	0.91	0.88	0.92(1)	0.80(1)	0.91	0.91	0.88
	3	0.87(1)	0.92	0.82	0.82	0.80	0.88(1)	0.95	0.85	0.85	0.82	0.78(1)	0.86	0.77	0.77	0.74
	4.5	0.99	0.86	0.77	0.77	0.75	0.93	0.80	0.72	0.72	0.70	0.75	0.65	0.58	0.58	0.56
f_{PO}=50	2	0.91(1)	0.79(1)	0.85	0.85	0.82	0.91(1)	0.79(1)	0.86	0.86	0.83	0.92(1)	0.80(1)	0.87	0.87	0.84
	2.5	0.85(1)	0.88	0.79	0.79	0.77	0.85(1)	0.89	0.80	0.80	0.71	0.86(1)	0.91	0.81	0.81	0.79
	3	0.95	0.82	0.74	0.74	0.71	0.96	0.83	0.75	0.75	0.72	0.97	0.85	0.76	0.76	0.73

(1) For these factors γ_A=γ_{PO}=1 and γ_O=0.9

Table C-23b: (Continued)

	β	Stainless Steel				
		f_O =2.5				
		R.T.	200°F	400°F	600°F	800°F
f_{PO}= 0.5	2	0.60[1]	0.52[1]	0.70	0.70	0.67
	2.5	0.40[1]	0.52	0.47	0.47	0.45
	3	0.36	0.31	0.28	0.28	0.27
f_{PO}=1	2	0.63[1]	0.55[1]	0.72	0.72	0.70
	2.5	0.43[1]	0.55	0.49	0.49	0.47
	3	0.39	0.34	0.30	0.30	0.29
f_{PO}=3	2	0.73[1]	0.64[1]	0.79	0.79	0.76
	2.5	0.53[1]	0.64	0.57	0.57	0.55
	3	0.48	0.41	0.37	0.37	0.36
f_{PO}=5	2	0.80[1]	0.69[1]	0.83	0.83	0.81
	2.5	0.61[1]	0.70	0.63	0.63	0.61
	3	0.55	0.48	0.43	0.43	0.41
f_{PO}=10	2	0.89[1]	0.77[1]	0.90	0.90	0.87
	2.5	0.73[1]	0.82	0.73	0.73	0.71
	3	0.69	0.60	0.54	0.54	0.52
f_{PO}=50	2	0.92[1]	0.80[1]	0.88	0.88	0.85
	2.5	0.86[1]	0.91	0.82	0.82	0.79
	3	0.98	0.85	0.77	0.77	0.74

(1) For these factors $\gamma_A=\gamma_{PO}=1$ and $\gamma_O=0.9$

C.11. Performance Function g_{13}

Table C-24 gives the calculated mean load and resistance factors for performance function g_{13}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-25 shows the evaluated adjusted nominal resistance factors for load factors γ_A=1.1, γ_{PC}=1.2, and γ_M=1.2.

Table C-24a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F and Stainless Steel for g_{13}

	β	Carbon Steel $T \leq 200^{o}$F & Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M
f_{PC}=0.5	3	2.63	0.89	1.13	1.27	1.17	3.34	0.90	1.10	1.13	1.33	4.87	0.91	1.06	1.04	1.43
	4.5	3.07	0.86	1.16	1.74	1.22	3.89	0.85	1.13	1.27	1.56	5.83	0.87	1.07	1.07	1.74
	5.5	3.44	0.84	1.16	2.23	1.24	4.32	0.83	1.15	1.41	1.73	6.59	0.85	1.08	1.08	1.99
f_{PC}=1	3	3.41	0.92	1.08	1.51	1.08	4.04	0.91	1.07	1.40	1.20	5.48	0.91	1.05	1.16	1.38
	4.5	4.20	0.89	1.08	2.13	1.09	4.85	0.88	1.08	1.97	1.23	6.50	0.87	1.07	1.32	1.63
	5.5	4.89	0.88	1.08	2.67	1.09	5.56	0.87	1.08	2.49	1.24	7.31	0.85	1.07	1.50	1.80
f_{PC}=3	3	6.85	0.94	1.03	1.63	1.02	7.40	0.94	1.03	1.62	1.05	8.56	0.93	1.03	1.56	1.12
	4.5	9.12	0.92	1.03	2.28	1.02	9.69	0.92	1.03	2.26	1.05	10.88	0.91	1.03	2.19	1.13
	5.5	11.12	0.90	1.03	2.84	1.02	11.70	0.90	1.03	2.81	1.05	12.92	0.89	1.03	2.74	1.14
f_{PC}=5	3	10.33	0.95	1.02	1.65	1.01	10.87	0.94	1.02	1.64	1.02	11.98	0.94	1.02	1.62	1.06
	4.5	14.10	0.92	1.02	2.30	1.01	14.65	0.92	1.02	2.29	1.03	15.79	0.92	1.02	2.26	1.07
	5.5	17.42	0.91	1.02	2.86	1.01	17.98	0.91	1.02	2.85	1.03	19.14	0.90	1.02	2.82	1.07
f_{PC}=10	3	19.07	0.95	1.01	1.66	1.00	19.60	0.95	1.01	1.66	1.01	20.67	0.95	1.01	1.65	1.02
	4.5	26.56	0.93	1.01	2.32	1.00	27.10	0.93	1.01	2.31	1.01	28.20	0.92	1.01	2.30	1.03
	5.5	33.17	0.91	1.01	2.88	1.00	33.72	0.91	1.01	2.87	1.01	34.84	0.91	1.01	2.86	1.03
f_{PC}=50	3	89.02	0.95	1.00	1.67	0.99	89.54	0.95	1.00	1.66	0.99	90.59	0.95	1.00	1.66	1.00
	4.5	126.3	0.93	1.00	2.32	0.99	126.9	0.93	1.00	2.32	0.99	127.9	0.93	1.00	2.32	1.00
	5.5	159.3	0.92	1.00	2.89	0.99	159.8	0.92	1.00	2.88	0.99	160.9	0.91	1.00	2.88	1.00

Table C-24b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{13}

	β	Carbon Steel, T>200°F														
		f_M=0.5					f_M=1.0					f_M=2.0				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PC}	γ'_M
f_{PC}=0.5	3	2.88	0.78	1.11	1.15	1.13	3.64	0.79	1.08	1.09	1.24	5.27	0.80	1.05	1.03	1.33
	4.5	3.48	0.70	1.14	1.39	1.20	4.41	0.70	1.11	1.17	1.41	6.51	0.73	1.07	1.06	1.57
	5.5	3.96	0.66	1.16	1.71	1.22	5.02	0.65	1.13	1.25	1.53	7.52	0.68	1.07	1.07	1.76
f_{PC}=1	3	3.68	0.81	1.07	1.36	1.08	4.38	0.80	1.06	1.25	1.17	5.93	0.80	1.05	1.11	1.29
	4.5	4.62	0.76	1.08	1.87	1.09	5.40	0.73	1.08	1.66	1.22	7.29	0.72	1.06	1.22	1.49
	5.5	5.46	0.72	1.08	2.32	1.09	6.28	0.70	1.08	2.08	1.23	8.39	0.67	1.07	1.32	1.63
f_{PC}=3	3	7.23	0.85	1.03	1.54	1.02	7.84	0.84	1.03	1.51	1.05	9.13	0.83	1.02	1.43	1.12
	4.5	9.81	0.81	1.03	2.12	1.02	10.46	0.80	1.03	2.08	1.05	11.85	0.78	1.03	1.98	1.13
	5.5	12.15	0.77	1.03	2.61	1.02	12.82	0.76	1.03	2.56	1.05	14.27	0.75	1.03	2.45	1.14
f_{PC}=5	3	10.86	0.86	1.02	1.57	1.01	11.45	0.86	1.02	1.56	1.02	12.67	0.85	1.02	1.52	1.06
	4.5	15.10	0.82	1.02	2.16	1.01	15.72	0.81	1.02	2.14	1.03	17.02	0.80	1.02	2.09	1.07
	5.5	18.93	0.78	1.02	2.65	1.01	19.58	0.78	1.02	2.63	1.03	20.94	0.77	1.02	2.58	1.07
f_{PC}=10	3	19.98	0.87	1.01	1.59	1.00	20.55	0.87	1.01	1.58	1.01	21.73	0.86	1.01	1.57	1.02
	4.5	28.35	0.82	1.01	2.19	1.00	28.96	0.82	1.01	2.18	1.01	30.20	0.82	1.01	2.16	1.03
	5.5	35.93	0.79	1.01	2.68	1.00	36.57	0.79	1.01	2.67	1.01	37.86	0.78	1.01	2.65	1.03
f_{PC}=50	3	93.03	0.88	1.00	1.60	0.99	93.59	0.88	1.00	1.60	0.99	94.73	0.88	1.00	1.60	1.00
	4.5	134.5	0.83	1.00	2.20	0.99	135.1	0.83	1.00	2.20	0.99	136.3	0.83	1.00	2.20	1.00
	5.5	172.1	0.80	1.00	2.71	0.99	172.7	0.79	1.00	2.70	0.99	173.9	0.79	1.00	2.70	1.00

Table C-25a: Adjusted Nomianl Resistance Factors for Carbon Steel and γ_A=1.1, γ_M=γ_{PC}=1.2 for g_{13}

	β	Carbon Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PC}=0.5	3	1.00(1)	0.96	0.98	0.92	0.74	0.98(1)	0.94	0.97	0.91	0.73	0.93(1)	0.91	0.93	0.88	0.70
	4.5	0.90	0.82	0.81	0.76	0.61	0.89	0.81	0.80	0.75	0.60	0.83	0.76	0.76	0.71	0.57
	5.5	0.80	0.73	0.71	0.67	0.53	0.80	0.73	0.70	0.66	0.53	0.73	0.67	0.65	0.62	0.49
f_{PC}=1	3	0.99(1)	0.96	0.99	0.93	0.74	0.99(1)	0.96	0.99	0.93	0.75	0.96(1)	0.94	0.97	0.91	0.73
	4.5	0.85	0.78	0.79	0.74	0.59	0.88	0.80	0.80	0.76	0.60	0.87	0.79	0.79	0.74	0.59
	5.5	0.73	0.67	0.67	0.63	0.50	0.77	0.70	0.69	0.65	0.52	0.77	0.71	0.68	0.64	0.52
f_{PC}=3	3	0.93(1)	0.91	0.96	0.90	0.72	0.95(1)	0.93	0.98	0.92	0.73	0.96(1)	0.95	0.99	0.93	0.75
	4.5	0.75	0.68	0.71	0.67	0.53	0.78	0.71	0.73	0.69	0.55	0.82	0.75	0.76	0.72	0.57
	5.5	0.61	0.56	0.57	0.54	0.43	0.64	0.59	0.60	0.56	0.45	0.69	0.63	0.63	0.60	0.48
f_{PB}=5	3	0.90(1)	0.89	0.94	0.89	0.71	0.92(1)	0.90	0.96	0.90	0.72	0.94(1)	0.93	0.98	0.92	0.73
	4.5	0.71	0.65	0.68	0.64	0.51	0.73	0.67	0.70	0.65	0.52	0.77	0.70	0.73	0.68	0.55
	5.5	0.58	0.53	0.54	0.51	0.41	0.60	0.55	0.56	0.53	0.42	0.63	0.58	0.59	0.55	0.44
f_{PC}=10	3	0.88(1)	0.87	0.93	0.87	0.70	0.89(1)	0.88	0.93	0.88	0.70	0.90(1)	0.89	0.95	0.89	0.71
	4.5	0.68	0.63	0.65	0.61	0.49	0.70	0.64	0.66	0.62	0.50	0.72	0.66	0.68	0.64	0.51
	5.5	0.55	0.50	0.52	0.48	0.39	0.56	0.51	0.53	0.49	0.40	0.58	0.53	0.54	0.51	0.41
f_{PC}=50	3	0.86(1)	0.85	0.91	0.85	0.68	0.86(1)	0.85	0.91	0.86	0.69	0.86(1)	0.86	0.92	0.86	0.69
	4.5	0.66	0.60	0.63	0.59	0.47	0.66	0.60	0.63	0.59	0.47	0.67	0.61	0.64	0.60	0.48
	5.5	0.52	0.48	0.49	0.46	0.37	0.52	0.48	0.49	0.46	0.37	0.53	0.48	0.50	0.47	0.37

(1) For these factors γ_A=γ_M=γ_{PC}=1.1

Table C-25b: Adjusted Nomianl Resistance Factors for Stainless Steel and γ_A=1.1, γ_M=γ_{PC}=1.2 for g_{13}

	β	Stainless Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PC}=0 5	3	0.99[(1)]	0.90	0.81	0.81	0.78	0.96[(1)]	0.88	0.79	0.79	0.76	0.92[(1)]	0.85	0.76	0.76	0.73
	4.5	0.89	0.77	0.69	0.69	0.67	0.87	0.76	0.68	0.68	0.66	0.82	0.71	0.63	0.63	0.61
	5.5	0.79	0.69	0.62	0.62	0.59	0.79	0.68	0.61	0.61	0.59	0.72	0.63	0.56	0.56	0.54
f_{PC}=1	3	0.98[(1)]	0.89	0.80	0.80	0.78	0.98[(1)]	0.90	0.81	0.81	0.78	0.95[(1)]	0.88	0.79	0.79	0.76
	4.5	0.84	0.73	0.65	0.65	0.63	0.86	0.75	0.67	0.67	0.65	0.85	0.74	0.66	0.66	0.64
	5.5	0.72	0.62	0.56	0.56	0.54	0.75	0.65	0.59	0.59	0.57	0.76	0.66	0.59	0.59	0.57
f_{PC}=3	3	0.91[(1)]	0.85	0.76	0.76	0.74	0.93[(1)]	0.87	0.78	0.78	0.75	0.95[(1)]	0.89	0.80	0.80	0.77
	4.5	0.74	0.64	0.57	0.57	0.55	0.76	0.66	0.59	0.59	0.57	0.80	0.70	0.63	0.63	0.60
	5.5	0.60	0.52	0.47	0.47	0.45	0.63	0.55	0.49	0.49	0.47	0.68	0.59	0.53	0.53	0.51
f_{PC}=5	3	0.89[(1)]	0.83	0.75	0.75	0.72	0.90[(1)]	0.84	0.76	0.76	0.73	0.92[(1)]	0.86	0.78	0.78	0.75
	4.5	0.70	0.61	0.55	0.55	0.53	0.72	0.63	0.56	0.56	0.54	0.76	0.66	0.59	0.59	0..57
	5.5	0.57	0.49	0.44	0.44	0.43	0.59	0.51	0.46	0.46	0.44	0.62	0.54	0.49	0.49	0.47
f_{PC}= 10	3	0.86[(1)]	0.81	0.73	0.73	0.71	0.87[(1)]	0.82	0.74	0.74	0.71	0.89[(1)]	0.84	0.75	0.75	0.72
	4.5	0.67	0.58	0.52	0.52	0.51	0.68	0.59	0.53	0.53	0.51	0.71	0.61	0.55	0.55	0.53
	5.5	0.54	0.47	0.42	0.42	0.41	0.55	0.48	0.43	0.43	0.41	0.57	0.50	0.44	0.44	0.43
f_{PC}=5 0	3	0.84[(1)]	0.80	0.71	0.71	0.69	0.84[(1)]	0.80	0.72	0.72	0.69	0.85[(1)]	0.80	0.72	0.72	0.70
	4.5	0.65	0.56	0.50	0.50	0.49	0.65	0.56	0.51	0.51	0.49	0.65	0.57	0.51	0.51	0.49
	5.5	0.51	0.44	0.40	0.40	0.39	0.52	0.45	0.40	0.40	0.39	0.52	0.45	0.41	0.41	0.39

(1) For these factors γ_A=γ_M=γ_{PC}=1.1

C.12. Performance Function g_{14}

Table C-26 gives the calculated mean load and resistance factors for performance function g_{14}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-27 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PO}=1.2, γ_M=1.2, and γ_O=1.5.

Table C-26a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F for g_{14}

		β=2.5	Carbon Steel $T \leq 200^{o}$F & Stainless Steel																	
			f_M=0.5						f_M=1.0						f_M=2.0					
		fo	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o
f_{Po}	0.5	0.5	4.27	0.98	1.01	1.00	1.00	4.35	4.78	0.98	1.01	1.00	1.01	4.32	5.84	0.97	1.01	1.00	1.04	4.18
		1	6.59	0.96	1.01	1.00	1.00	4.33	7.00	0.98	1.01	1.00	1.00	4.39	8.03	0.98	1.01	1.00	1.01	4.36
		2	10.97	0.99	1.00	0.99	0.99	4.42	11.47	0.99	1.00	0.99	1.00	4.41	12.48	0.99	1.00	0.99	1.00	4.40
		2.5	13.21	0.99	1.00	0.99	0.99	4.42	13.71	0.99	1.00	0.99	0.99	4.42	14.72	0.99	1.00	0.99	1.00	4.41
	1	0.5	4.78	0.98	1.01	1.01	1.00	4.32	5.30	0.98	1.01	1.01	1.01	4.28	6.35	0.97	1.01	1.01	1.04	4.13
		1	7.00	0.98	1.01	1.00	1.00	4.39	7.51	0.98	1.01	1.00	1.08	4.38	8.54	0.98	1.01	1.00	1.01	4.34
		2	11.47	0.99	1.00	1.00	0.99	4.41	11.98	0.99	1.00	1.00	1.08	4.41	12.79	0.99	1.00	1.00	1.00	4.40
		2.5	13.71	0.99	1.00	1.00	0.99	4.42	14.21	0.99	1.00	1.00	0.99	4.41	15.22	0.99	1.00	1.00	1.00	4.41
	3	0.5	6.90	0.97	1.01	1.06	1.00	4.01	7.42	0.97	1.01	1.06	1.02	3.95	8.49	0.96	1.01	1.06	1.05	3.72
		1	9.06	0.98	1.01	1.02	1.00	4.32	9.57	0.98	1.01	1.02	1.00	4.30	10.60	0.98	1.01	1.02	1.01	4.26
		2	13.50	0.99	1.00	1.01	0.99	4.39	14.01	0.98	1.00	1.01	1.00	4.39	15.02	0.98	1.00	1.01	1.00	4.38
		2.5	15.73	0.99	1.00	1.00	0.99	4.40	16.24	0.99	1.00	1.00	0.99	4.40	17.25	0.98	1.00	1.00	1.00	4.39
	5	0.5	9.23	0.93	1.02	1.28	1.02	1.19	9.78	0.92	1.02	1.28	1.04	1.17	10.95	0.92	1.02	1.26	1.10	1.11
		1	11.17	0.98	1.01	1.04	1.00	4.18	11.68	0.97	1.01	1.04	1.00	4.16	12.72	0.97	1.01	1.04	1.02	4.11
		2	15.56	0.98	1.00	1.02	0.99	4.36	16.06	0.98	1.00	1.02	1.00	4.35	17.08	0.98	1.00	1.02	1.00	4.34
		2.5	17.78	0.98	1.00	1.01	0.99	4.38	18.28	0.98	1.00	1.01	0.99	4.38	19.30	0.98	1.00	1.01	1.00	4.37
	10	0.5	16.26	0.93	1.01	1.32	1.00	0.91	16.80	0.93	1.01	1.31	1.02	0.91	17.92	0.93	1.01	1.30	1.05	0.91
		1	16.81	0.93	1.01	1.29	1.00	1.23	17.35	0.93	1.01	1.29	1.02	1.22	18.46	0.93	1.01	1.28	1.05	1.19
		2	20.81	0.98	1.00	1.04	0.99	4.20	21.31	0.98	1.00	1.04	1.00	4.19	22.34	0.98	1.00	1.04	1.00	4.18
		2.5	22.97	0.98	1.00	1.03	0.99	4.28	23.48	0.98	1.00	1.03	0.99	4.28	24.50	0.98	1.00	1.03	1.00	4.26
	50	0.5	72.99	0.94	1.00	1.33	0.99	0.83	73.52	0.94	1.00	1.33	0.99	0.83	74.59	0.93	1.00	1.33	1.00	0.83
		1	73.44	0.94	1.00	1.33	0.99	0.85	73.99	0.94	1.00	1.33	0.99	0.85	75.04	0.93	1.00	1.33	1.00	0.85
		2	74.37	0.94	1.00	1.33	0.99	0.89	74.90	0.93	1.00	1.32	0.99	0.89	75.96	0.93	1.00	1.32	1.00	0.89
		2.5	74.85	0.93	1.00	1.32	0.99	0.91	75.38	0.93	1.00	1.32	0.99	0.92	76.45	0.93	1.00	1.32	1.00	0.91

Table C-26a: (Continued)

		Carbon Steel $T \leq 200^{o}$F & Stainless Steel																	
	β=3.5	f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fy}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fy}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o
0.5	0.5	9.35	0.99	1.00	0.99	0.99	14.46	9.86	0.99	1.00	0.99	1.00	14.44	10.87	0.98	1.00	0.99	1.00	14.39
	1	16.69	0.99	1.00	0.99	0.99	14.49	17.19	0.99	1.00	0.99	0.99	14.48	18.20	0.99	1.00	0.99	1.00	14.46
	2	31.35	0.99	1.00	0.99	0.99	14.50	31.85	0.99	1.00	0.99	0.99	14.50	32.86	0.99	1.00	0.99	0.99	14.49
	2.5	38.69	0.99	1.00	0.99	0.99	14.50	39.19	0.99	1.00	0.99	0.99	14.50	4019	0.99	1.00	0.99	0.99	14.49
1	0.5	9.86	0.99	1.00	1.00	0.99	14.44	10.36	0.99	1.00	1.00	1.00	14.42	11.38	0.98	1.00	1.00	1.00	14.37
	1	17.19	0.99	1.00	0.99	0.99	14.48	17.69	0.99	1.00	0.99	0.99	14.47	18.70	0.99	1.00	0.99	1.00	14.46
	2	31.86	0.99	1.00	0.99	0.99	14.50	32.36	0.99	1.00	0.99	0.99	14.49	33.36	0.99	1.00	0.99	0.99	14.49
	2.5	39.19	0.99	1.00	0.99	0.99	14.50	39.69	0.99	1.00	0.99	0.99	14.50	40.69	0.99	1.00	0.99	0.99	14.49
3	0.5	11.90	0.98	1.00	1.01	0.99	14.34	12.40	0.98	1.00	1.01	1.00	14.31	13.42	0.98	1.00	1.01	1.01	14.25
	1	19.21	0.99	1.00	1.00	0.99	14.45	19.71	0.99	1.00	1.00	0.99	14.44	20.72	0.99	1.00	1.00	1.00	14.42
	2	33.87	0.99	1.00	1.00	0.99	14.48	34.37	0.99	1.00	1.00	0.99	14.48	35.38	0.99	1.00	1.00	0.99	14.47
	2.5	41.20	0.99	1.00	1.00	0.99	14.49	41.70	0.99	1.00	1.00	0.99	14.49	42.71	0.99	1.00	1.00	0.99	14.48
5	0.5	13.97	0.98	1.00	1.02	0.99	14.16	14.48	0.98	1.00	1.02	1.00	14.13	15.50	0.98	1.00	1.02	1.01	14.07
	1	21.25	0.98	1.00	1.01	0.99	14.39	21.75	0.98	1.00	1.01	0.99	14.39	22.76	0.98	1.00	1.01	1.00	14.37
	2	35.89	0.99	1.00	1.00	0.99	14.47	36.39	0.99	1.00	1.00	0.99	14.46	37.40	0.99	1.00	1.00	0.99	14.45
	2.5	43.22	0.99	1.00	1.00	0.99	14.48	43.72	0.99	1.00	1.00	0.99	14.47	44.73	0.99	1.00	1.00	0.99	14.47
10	0.5	18.50	0.91	1.02	1.48	1.01	0.95	19.07	0.90	1.02	1.47	1.03	0.95	20.22	0.90	1.02	1.46	1.07	0.95
	1	26.41	0.98	1.00	1.02	0.99	14.19	26.91	0.98	1.00	1.02	0.99	14.18	27.93	0.98	1.00	1.02	1.00	14.10
	2	40.98	0.99	1.00	1.01	0.99	14.41	41.48	0.99	1.00	1.01	0.99	14.40	42.49	0.98	1.00	1.01	0.99	14.39
	2.5	48.29	0.99	1.00	1.00	0.99	14.43	48.79	0.99	1.00	1.00	0.99	14.43	49.80	0.99	1.00	1.00	0.99	14.43
50	0.5	83.93	0.91	1.00	1.49	0.99	0.83	84.47	0.91	1.00	1.49	1.00	0.83	85.57	0.91	1.00	1.49	1.00	0.83
	1	84.39	0.91	1.00	1.49	0.99	0.85	84.94	0.91	1.00	1.49	1.00	0.85	86.03	0.91	1.00	1.49	1.00	0.85
	2	85.36	0.91	1.00	1.49	0.99	0.97	85.98	0.91	1.00	1.49	1.00	0.91	87.00	0.91	1.00	1.49	1.00	0.91
	2.5	85.87	0.91	1.00	1.49	0.99	0.96	86.42	0.91	1.00	1.49	1.00	0.96	87.52	0.91	1.00	1.48	1.00	0.96

Table C-26b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{14}

	β=2.5	Carbon Steel T>200°F																	
		f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o
0.5	0.5	4.35	0.95	1.01	1.00	1.00	4.23	4.88	0.94	1.01	1.00	1.02	4.15	5.98	0.93	1.01	1.00	1.05	3.90
	1	6.50	0.99	1.01	1.00	1.00	4.40	7.11	0.96	1.01	1.00	1.00	4.31	8.17	0.95	1.01	1.00	1.01	4.24
	2	11.11	0.97	1.00	0.99	0.99	4.37	11.62	0.96	1.00	0.99	1.00	4.36	12.66	0.96	1.00	0.99	1.00	4.34
	2.5	1.337	0.97	1.00	0.99	0.99	4.37	13.88	0.97	1.00	0.99	0.999	4.37	14.92	0.96	1.00	0.99	1.00	4.35
1	0.5	4.88	0.94	1.01	1.01	1.00	4.15	5.42	0.94	1.01	1.01	1.02	4.07	6.53	0.92	1.01	1.01	1.05	3.78
	1	7.11	0.96	1.01	1.00	1.00	4.31	7.63	0.95	1.01	1.00	1.00	4.28	8.69	0.95	1.01	1.00	1.02	4.21
	2	11.62	0.96	1.00	1.00	0.99	4.36	12.14	0.96	1.00	1.00	1.00	4.35	13.18	0.96	1.00	1.00	1.00	4.33
	2.5	13.88	0.97	1.00	1.00	0.99	4.37	14.40	0.96	1.00	1.00	0.99	4.36	15.43	0.96	1.00	1.00	1.00	4.34
3	0.5	7.11	0.91	1.01	1.07	1.00	3.54	7.67	0.90	1.01	1.07	1.02	3.35	8.87	0.83	1.02	1.14	1.12	1.33
	1	9.24	0.95	1.01	1.02	1.00	4.17	9.77	0.94	1.01	1.02	1.00	4.13	10.84	0.94	1.01	1.02	1.02	4.05
	2	13.71	0.96	1.00	1.01	0.99	4.31	14.22	0.96	1.00	1.01	1.00	4.30	15.27	0.95	1.00	1.01	1.00	4.28
	2.5	15.96	0.96	1.00	1.00	0.99	4.33	16.47	0.96	1.00	1.00	0.99	4.33	17.51	0.96	1.00	1.00	1.00	4.31
5	0.5	9.83	0.84	1.02	1.23	1.01	1.06	10.44	0.83	1.02	1.22	1.04	1.04	11.72	0.83	1.02	1.20	1.08	1.01
	1	11.44	0.93	1.01	1.05	1.00	3.92	11.98	0.93	1.01	1.05	1.00	3.88	13.07	0.92	1.01	1.05	1.02	3.75
	2	15.82	0.95	1.00	1.02	0.99	4.25	16.34	0.95	1.00	1.02	1.00	4.24	17.39	0.95	1.00	1.02	1.00	4.21
	2.5	18.06	0.96	1.00	1.01	0.99	4.29	18.58	0.96	1.00	1.01	0.99	4.28	19.62	0.95	1.00	1.01	1.00	4.26
10	0.5	17.27	0.84	1.01	1.26	1.00	0.90	17.87	0.84	1.01	1.26	1.01	0.90	19.09	0.84	1.01	1.24	1.04	0.89
	1	17.84	0.84	1.01	1.25	1.00	1.08	18.44	0.84	1.01	1.24	1.01	1.07	19.66	0.84	1.01	1.23	1.04	1.05
	2	21.27	0.94	1.00	1.05	0.99	3.99	21.80	0.94	1.00	1.05	1.00	3.97	22.87	0.93	1.00	1.05	1.00	3.92
	2.5	23.43	0.94	1.00	1.03	0.99	4.12	23.96	0.94	1.00	1.03	0.99	4.11	25.01	0.94	1.00	1.03	1.00	4.08
50	0.5	77.21	0.85	1.00	1.28	0.99	0.83	77.79	0.85	1.00	1.28	0.99	0.83	78.96	0.85	1.00	1.27	1.00	0.83
	1	77.70	0.85	1.00	1.28	0.99	0.84	78.28	0.85	1.00	1.28	0.99	0.84	79.46	0.85	1.00	1.27	1.00	0.84
	2	78.71	0.85	1.00	1.27	0.99	0.88	79.29	0.85	1.00	1.27	0.99	0.88	80.47	0.85	1.00	1.27	1.00	0.88
	2.5	79.23	0.85	1.00	1.27	0.99	0.90	79.82	0.85	1.00	1.27	0.99	0.90	80.99	0.85	1.00	1.27	1.00	0.90

Table C-26b: (Continued)

		Carbon Steel T>200°F																	
	β=3.5	f_M=0.5						f_M=1.0						f_M=2.0					
f_{Po}	fo	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	ϕ'_{fu}	γ'_A	γ'_{Po}	γ'_M	γ'_o	ϕ'_{fu}
0.5	0.5	9.48	0.96	1.00	0.99	0.99	14.27	10.00	0.96	1.00	0.99	1.00	14.22	11.04	0.96	1.00	0.99	1.01	14.12
	1	16.90	0.97	1.00	0.99	0.99	14.33	17.41	0.97	1.00	0.99	0.99	14.32	18.44	0.96	1.00	0.99	1.00	14.28
	2	31.73	0.97	1.00	0.99	0.99	14.36	32.34	0.97	1.00	0.99	0.99	14.36	33.27	0.97	1.00	0.99	0.99	14.34
	2.5	39.15	0.97	1.00	0.99	0.99	14.37	39.66	0.97	1.00	0.99	0.99	14.36	40.69	0.97	1.00	0.99	0.99	14.35
1	0.5	10.00	0.96	1.00	1.00	0.99	14.23	10.52	0.96	1.00	1.00	1.00	14.18	11.56	0.96	1.00	1.00	1.01	14.08
	1	17.41	0.97	1.00	0.99	0.99	14.32	17.92	0.96	1.00	0.99	0.99	14.30	18.96	0.96	1.00	0.99	1.00	14.26
	2	32.24	0.97	1.00	0.99	0.99	14.36	32.76	0.97	1.00	0.99	0.99	14.35	33.78	0.97	1.00	0.99	0.99	14.33
	2.5	39.66	0.97	1.00	0.99	0.99	14.36	40.17	0.97	1.00	0.99	0.99	14.36	41.20	0.97	1.00	0.99	0.99	14.34
3	0.5	12.10	0.95	1.00	1.01	0.99	14.01	12.62	0.95	1.00	1.01	1.00	13.96	13.67	0.95	1.00	1.01	1.01	13.84
	1	19.48	0.96	1.00	1.00	0.99	14.24	20.00	0.96	1.00	1.00	0.99	14.22	21.03	0.96	1.00	1.00	1.00	14.18
	2	34.30	0.97	1.00	1.00	0.99	14.32	34.81	0.97	1.00	1.00	0.99	14.32	35.84	0.96	1.00	1.00	0.99	14.30
	2.5	41.72	0.97	1.00	1.00	0.99	14.34	42.23	0.97	1.00	1.00	0.99	14.33	43.26	0.97	1.00	1.00	0.99	14.32
5	0.5	14.24	0.95	1.00	1.02	0.99	13.70	14.77	0.94	1.00	1.02	1.00	13.64	13.42	0.77	1.02	1.29	1.12	1.26
	1	21.57	0.96	1.00	1.01	0.99	14.14	22.09	0.96	1.00	1.01	0.99	14.12	23.13	0.96	1.00	1.01	1.00	14.07
	2	36.37	0.96	1.00	1.00	0.99	14.29	36.88	0.96	1.00	1.00	0.99	14.28	37.91	0.96	1.00	1.00	0.99	14.26
	2.5	43.78	0.97	1.00	1.00	0.99	14.31	44.29	0.96	1.00	1.00	0.99	14.30	45.32	0.96	1.00	1.00	0.99	14.29
10	0.5	20.09	0.79	1.01	1.39	1.01	0.93	20.73	0.79	1.01	1.38	1.02	0.93	22.05	0.78	1.01	1.37	1.06	0.93
	1	26.90	0.95	1.00	1.02	0.99	13.78	27.42	0.95	1.00	1.02	0.99	13.75	28.47	0.95	1.00	1.02	1.00	13.69
	2	41.58	0.96	1.00	1.01	0.99	14.17	42.10	0.96	1.00	1.01	0.99	14.16	43.13	0.96	1.00	1.01	0.99	14.14
	2.5	48.97	0.96	1.00	1.0	0.99	14.23	49.49	0.96	1.00	1.00	0.99	14.22	50.52	0.96	1.00	1.00	0.99	14.20
50	0.5	90.67	0.80	1.00	1.41	0.99	0.83	91.29	0.80	1.00	1.41	1.00	0.83	92.53	0.80	1.00	1.41	1.00	0.83
	1	91.19	0.80	1.00	1.41	0.99	0.85	91.81	0.80	1.00	1.41	1.00	0.85	93.06	0.80	1.00	1.41	1.00	0.85
	2	92.28	0.80	1.00	1.41	0.99	0.90	92.91	0.80	1.00	1.41	1.00	0.90	94.16	0.80	1.00	1.41	1.00	0.90
	2.5	92.86	0.80	1.00	1.41	0.99	0.94	93.48	0.80	1.00	1.41	1.00	0.94	94.73	0.80	1.00	1.40	1.00	0.94

Table C-27a: Adjusted Nominal Resistance Factors for Carbon Steel and γ_A=1.1, γ_{PO}=γ_M=1.2, γ_O=1.5 for g_{14}

	β=2.5	Carbon Steel														
		f_M=0.5					f_M=1.0					f_M=2.0				
f_{Po}	*fo*	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
0.5	0.5	0.73[1]	0.72	0.76[1]	0.84	0.67	0.77[1]	0.86	0.77[1]	0.89	0.71	0.83[1]	0.92	0.82[1]	0.94	0.75
	1	0.58[1]	0.60	0.65[1]	0.72	0.58	0.62[1]	0.74	0.63[1]	0.76	0.61	0.70[1]	0.80	0.70[1]	0.83	0.66
	2	0.49[1]	0.49	0.57[1]	0.63	0.50	0.52[1]	0.63	0.57[1]	0.66	0.52	0.57[1]	0.68	0.57[1]	0.71	0.57
	2.5	0.47[1]	0.47	0.54[1]	0.60	0.48	0.49[1]	0.61	0.49[1]	0.63	0.50	0.54[1]	0.65	0.54[1]	0.67	0.54
1	0.5	0.77[1]	0.77	0.81[1]	0.89	0.71	0.81[1]	0.90	0.80[1]	0.93	0.74	0.85[1]	0.95	0.85[1]	0.97	0.78
	1	0.64[1]	0.64	0.69[1]	0.77	0.61	0.67[1]	0.78	0.67[1]	0.80	0.64	0.73[1]	0.83	0.72[1]	0.86	0.68
	2	0.52[1]	0.53	0.59[1]	0.66	0.53	0.55[1]	0.66	0.55[1]	0.69	0.55	0.58[1]	0.71	0.60[1]	0.73	0.59
	2.5	0.49[1]	0.50	0.57[1]	0.63	0.50	0.51[1]	0.63	0.52[1]	0.65	0.52	0.56[1]	0.67	0.56[1]	0.70	0.56
3	0.5	0.89[1]	0.88	0.92[1]	1.00	0.80	0.90[1]	1.00	0.89[1]	1.02	0.81	0.92[1]	1.02	0.90[1]	1.03	0.82
	1	0.76[1]	0.76	0.81[1]	0.89	0.71	0.78[1]	0.89	0.78[1]	0.91	0.73	0.81[1]	0.92	0.81[1]	0.94	0.75
	2	0.62[1]	0.63	0.69[1]	0.76	0.61	0.64[1]	0.76	0.64[1]	0.78	0.62	0.68[1]	0.79	0.68[1]	0.81	0.65
	2.5	0.58[1]	0.59	0.65[1]	0.72	0.58	0.60[1]	0.72	0.60[1]	0.74	0.59	0.63[1]	0.75	0.63[1]	0.77	0.62
5	0.5	0.93[1]	0.88	0.96[1]	1.01	0.81	0.93[1]	1.03	0.89[1]	1.01	0.81	0.94[1]	1.04	0.89[1]	1.02	0.81
	1	0.83[1]	0.83	0.86[1]	0.96	0.77	0.85[1]	0.95	0.84[1]	0..98	0.78	0.87[1]	0.98	0.86[1]	0.99	0.80
	2	0.70[1]	0.70	0.76[1]	0.84	0.67	0.71[1]	0.82	0.71[1]	0.85	0.68	0.74[1]	0.81	0.74[1]	0.87	0.70
	2.5	0.65[1]	0.65	0.72[1]	0.79	0.63	0.67[1]	0.78	0.67[1]	0.81	0.64	0.69[1]	0.85	0.69[1]	0.83	0.66
10	0.5	0.90[1]	0.86	0.92[1]	0.98	0.78	0.90[1]	1.00	0.86[1]	0.98	0.78	0.91[1]	1.00	0.87[1]	0.99	0.79
	1	0.91[1]	0.88	0.95[1]	1.01	0.81	0.92[1]	1.02	0.88[1]	1.01	0.81	0.93[1]	1.03	0.88[1]	1.01	0.81
	2	0.81[1]	0.81	0.86[1]	0.95	0.76	0.82[1]	0.93	0.82[1]	0.96	0.76	0.83[1]	0.95	0.83[1]	0.97	0.77
	2.5	0.77[1]	0.77	0.82[1]	0.91	0.73	0.78[1]	0.89	0.77[1]	0.92	0.73	0.79[1]	0.91	0.79[1]	0.93	0.74
50	0.5	0.86[1]	0.83	0.88[1]	0.94	0.75	0.86[1]	0.95	0.83[1]	0.94	0.75	0.87[1]	0.95	0.83[1]	0.94	0.75
	1	0.87[1]	0.84	0.89[1]	0.95	0.76	0.87[1]	0.96	0.84[1]	0.95	0.76	0.87[1]	0.96	0.84[1]	0.95	0.76
	2	0.88[1]	0.84	0.91[1]	0.96	0.77	0.88[1]	0.97	0.85[1]	0.96	0.77	0.88[1]	0.98	0.85[1]	0.97	0.77
	2.5	0.88[1]	0.85	0.91[1]	0.97	0.78	0.87[1]	0.98	0.85[1]	0.97	0.78	0.89[1]	0.98	0.85[1]	0.97	0.78

(1) γ_A=γ_M=γ_{PO}= γ_O=1.00

Table C-27a: (Continued)

		Carbon Steel														
	β=3.5	f_M=0.5					f_M=1.0					f_M=2.0				
	fo	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
f_{Po} = 0.5	0.5	0.41	0.37	0.41	0.39	0.31	0.46	0.42	0.46	0.43	0.35	0.54	0.50	0.54	0.51	0.41
	1	0.30	0.27	0.30	0.28	0.23	0.33	0.30	0.33	0.31	0.25	0.39	0.35	0.39	0.37	0.29
	2	0.23	0.21	0.23	0.22	0.18	0.25	0.23	0.25	0.24	0.19	0.28	0.26	0.29	0.27	0.22
	2.5	0.22	0.20	0.22	0.21	0.10	0.23	0.21	0.23	0.22	0.18	0.26	0.24	0.26	0.25	0.20
1	0.5	0.46	0.42	0.46	0.44	0.35	0.51	0.46	0.51	0.48	0.38	0.58	0.53	0.58	0.55	0.44
	1	0.3	0.30	0.33	0.31	0.25	0.36	0.33	0.36	0.34	0.27	0.42	0.38	0.42	0.39	0.31
	2	0.25	0.23	0.25	0.24	0.19	0.27	0.25	0.27	0.25	0.20	0.30	0.28	0.30	0.29	0.23
	2.5	0.23	0.21	0.23	0.22	0.18	0.25	0.23	0.25	0.23	0.19	0.28	0.25	0.28	0.26	0.21
3	0.5	0.63	0.57	0.63	0.59	0.47	0.66	0.60	0.66	0.62	0.49	0.71	0.71	0.71	0.67	0.53
	1	0.45	0.41	0.45	0.42	0.34	0.47	0.43	0.47	0.44	0.36	0.52	0.52	0.52	0.49	0.39
	2	0.32	0.29	0.32	0.30	0.24	0.34	0.31	0.34	0.32	0.26	0.37	0.37	0.37	0.35	0.28
	2.5	0.29	0.27	0.29	0.28	0.22	0.31	0.28	0.31	0.29	0.23	0.33	0.33	0.33	0.31	0.25
5	0.5	0.74	0.68	0.74	0.70	0.56	0.76	0.70	0.76	0.72	0.57	0.80	0.94	0.94	0.89	0.71
	1	0.54	0.49	0.54	0.51	0.41	0.56	0.51	0.56	0.58	0.42	0.60	0.60	0.60	0.56	0.45
	2	0.39	0.35	0.39	0.36	0.29	0.40	0.36	0.40	0.38	0.30	0.42	0.43	0.43	0.40	0.32
	2.5	0.35	0.32	0.35	0.33	0.26	0.36	0.33	0.36	0.34	0.27	0.38	0.38	0.38	0.36	0.29
10	0.5	0.95	0.87	0.89	0.84	0.67	0.96	0.88	0.90	0.85	0.68	0.97	0.91	0.91	0.85	0.68
	1	0.71	0.65	0.7	0.67	0.53	0.72	0.66	0.72	0.68	0.54	0.75	0.75	0.75	0.70	0.56
	2	0.51	0.47	0.52	0.48	0.39	0.52	0.48	0.53	0.49	0.40	0.54	0.55	0.55	0.51	0.41
	2.5	0.46	0.42	0.46	0.43	0.35	0.47	0.43	0.47	0.44	0.35	0.49	0.49	0.49	0.46	0.37
50	0.5	0.90	0.82	0.85	0.80	0.64	0.90	0.83	0.85	0.80	0.64	0.91	0.86	0.86	0.81	0.65
	1	0.91	0.83	0.86	0.81	0.65	0.91	0.83	0.86	0.81	0.65	0.92	0.86	0.86	0.81	0.65
	2	0.93	0.85	0.87	0.82	0.66	0.93	0.85	0.87	0.82	0.66	0.93	0.88	0.88	0.83	0.66
	2.5	0.94	0.85	0.88	0.83	0.66	0.94	0.86	0.88	0.83	0.66	0.94	0.89	0.89	0.83	0.67

Table C-27b: Adjusted Nominal Resistance Factors for Stainless Steel and γ_A=1.1, γ_{PO}=γ_M=1.2, γ_O=1.5 for g_{14}

		Stainless Steel														
	β=2.5	f_M=0.5					f_M=1.0					f_M=2.0				
	fo	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{Po} = 0.5	0.5	0.71(1)	0.76	0.69	0.69	0.66	0.75(1)	0.81	0.72	0.72	0.70	0.81(1)	0.86	0.77	0.77	0.75
	1	0.59(1)	0.65	0.59	0.59	0.57	0.63(1)	0.69	0.62	0.62	0.60	0.68(1)	0.75	0.67	0.67	0.65
	2	0.48(1)	0.57	0.51	0.51	0.49	0.51(1)	0.59	0.53	0.53	0.51	0.56(1)	0.64	0.57	0.57	0.55
	2.5	0.46(1)	0.54	0.49	0.49	0.47	0.48(1)	0.57	0.51	0.51	0.49	0.53(1)	0.61	0.55	0.55	0.53
1	0.5	0.76(1)	0.81	0.73	0.73	0.70	0.79(1)	0.84	0.76	0.76	0.73	0.84(1)	0.89	0.80	0.80	0.77
	1	0.63(1)	0.69	0.62	0.62	0.60	0.66(1)	0.75	0.65	0.65	0.63	0.71(1)	0.78	0.70	0.70	0.67
	2	0.51(1)	0.59	0.53	0.53	0.52	0.54(1)	0.62	0.56	0.56	0.54	0.59(1)	0.66	0.59	0.59	0.57
	2.5	0.49(1)	0.57	0.51	0.51	0.49	0.52(1)	0.59	0.53	0.53	0.51	0.55(1)	0.63	0.56	0.56	0.55
3	0.5	0.87(1)	0.92	0.83	0.83	0.80	0.89(1)	0.94	0.84	0.84	0.81	0.91(1)	0.96	0.86	0.86	0.83
	1	0.75(1)	0.81	0.73	0.73	0.70	0.77(1)	0.83	0.74	0.74	0.72	0.80(1)	0.86	0.77	0.77	0.94
	2	0.61(1)	0.69	0.62	0.62	0.60	0.63(1)	0.71	0.63	0.63	0.61	0.66(1)	0.74	0.66	0.66	0.64
	2.5	0.57(1)	0.65	0.59	0.59	0.57	0.59(1)	0.67	0.60	0.60	0.58	0.62(1)	0.70	0.63	0.63	0.61
5	0.5	0.91(1)	0.96	0.86	0.86	0.83	0.92(1)	0.96	0.87	0.87	0.84	0.92(1)	0.97	0.87	0.87	0.84
	1	0.82(1)	0.88	0.79	0.79	0.76	0.83(1)	0.89	0.80	0.80	0.77	0.85(1)	0.91	0.82	0.82	0.79
	2	0.68(1)	0.76	0.68	0.68	0.66	0.70(1)	0.77	0.69	0.69	0.67	0.72(1)	0.79	0.71	0.71	0.69
	2.5	0.64(1)	0.72	0.64	0.64	0.62	0.65(1)	0.73	0.66	0.66	0.63	0.68(1)	0.75	0.68	0.68	0.65
10	0.5	0.88(1)	0.92	0.83	0.83	0.80	0.89(1)	0.93	0.83	0.83	0.81	0.90(1)	0.94	0.84	0.84	0.81
	1	0.90(1)	0.95	0.85	0.85	0.83	0.90(1)	0.96	0.86	0.86	0.83	0.91(1)	0.96	0.86	0.86	0.83
	2	0.80(1)	0.86	0.78	0.78	0.75	0.81(1)	0.87	0.78	0.78	0.75	0.82(1)	0.88	0.79	0.79	0.77
	2.5	0.76(1)	0.82	0.74	0.74	0.72	0.76(1)	0.83	0.75	0.75	0.72	0.78(1)	0.85	0.76	0.76	0.73
50	0.5	0.85(1)	0.88	0.79	0.79	0.77	0.85(1)	0.89	0.80	0.80	0.77	0.85(1)	0.89	0.80	0.80	0.77
	1	0.85(1)	0.89	0.80	0.80	0.77	0.85(1)	0.89	0.80	0.80	0.78	0.86(1)	0.90	0.81	0.81	0.78
	2	0.86(1)	0.91	0.81	0.81	0.79	0.86(1)	0.91	0.82	0.82	0.79	0.87(1)	0.91	0.82	0.82	0.79
	2.5	0.87(1)	0.91	0.82	0.82	0.79	0.88(1)	0.92	0.82	0.82	0.79	0.87(1)	0.92	0.82	0.82	0.80

(1) γ_A=γ_M=γ_{PO}=γ_O=1

Table C-27a: (Continued)

		β=3.5	Carbon Steel														
			f_M=0.5					f_M=1.0					f_M=2.0				
		fo	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{Po}	0.5	0.5	0.41	0.37	0.41	0.39	0.31	0.46	0.42	0.46	0.43	0.35	0.54	0.50	0.54	0.51	0.41
		1	0.30	0.27	0.30	0.28	0.23	0.33	0.30	0.33	0.31	0.25	0.39	0.35	0.39	0.37	0.29
		2	0.23	0.21	0.23	0.22	0.18	0.25	0.23	0.25	0.24	0.19	0.28	0.26	0.29	0.27	0.22
		2.5	0.22	0.20	0.22	0.21	0.10	0.23	0.21	0.23	0.22	0.18	0.26	0.24	0.26	0.25	0.20
	1	0.5	0.46	0.42	0.46	0.44	0.35	0.51	0.46	0.51	0.48	0.38	0.58	0.53	0.58	0.55	0.44
		1	0.3	0.30	0.33	0.31	0.25	0.36	0.33	0.36	0.34	0.27	0.42	0.38	0.42	0.39	0.31
		2	0.25	0.23	0.25	0.24	0.19	0.27	0.25	0.27	0.25	0.20	0.30	0.28	0.30	0.29	0.23
		2.5	0.23	0.21	0.23	0.22	0.18	0.25	0.23	0.25	0.23	0.19	0.28	0.25	0.28	0.26	0.21
	3	0.5	0.63	0.57	0.63	0.59	0.47	0.66	0.60	0.66	0.62	0.49	0.71	0.71	0.71	0.67	0.53
		1	0.45	0.41	0.45	0.42	0.34	0.47	0.43	0.47	0.44	0.36	0.52	0.52	0.52	0.49	0.39
		2	0.32	0.29	0.32	0.30	0.24	0.34	0.31	0.34	0.32	0.26	0.37	0.37	0.37	0.35	0.28
		2.5	0.29	0.27	0.29	0.28	0.22	0.31	0.28	0.31	0.29	0.23	0.33	0.33	0.33	0.31	0.25
	5	0.5	0.74	0.68	0.74	0.70	0.56	0.76	0.70	0.76	0.72	0.57	0.80	0.94	0.94	0.89	0.71
		1	0.54	0.49	0.54	0.51	0.41	0.56	0.51	0.56	0.58	0.42	0.60	0.60	0.60	0.56	0.45
		2	0.39	0.35	0.39	0.36	0.29	0.40	0.36	0.40	0.38	0.30	0.42	0.43	0.43	0.40	0.32
		2.5	0.35	0.32	0.35	0.33	0.26	0.36	0.33	0.36	0.34	0.27	0.38	0.38	0.38	0.36	0.29
	10	0.5	0.95	0.87	0.89	0.84	0.67	0.96	0.88	0.90	0.85	0.68	0.97	0.91	0.91	0.85	0.68
		1	0.71	0.65	0.7	0.67	0.53	0.72	0.66	0.72	0.68	0.54	0.75	0.75	0.75	0.70	0.56
		2	0.51	0.47	0.52	0.48	0.39	0.52	0.48	0.53	0.49	0.40	0.54	0.55	0.55	0.51	0.41
		2.5	0.46	0.42	0.46	0.43	0.35	0.47	0.43	0.47	0.44	0.35	0.49	0.49	0.49	0.46	0.37
	50	0.5	0.90	0.82	0.85	0.80	0.64	0.90	0.83	0.85	0.80	0.64	0.91	0.86	0.86	0.81	0.65
		1	0.91	0.83	0.86	0.81	0.65	0.91	0.83	0.86	0.81	0.65	0.92	0.86	0.86	0.81	0.65
		2	0.93	0.85	0.87	0.82	0.66	0.93	0.85	0.87	0.82	0.66	0.93	0.88	0.88	0.83	0.66
		2.5	0.94	0.85	0.88	0.83	0.66	0.94	0.86	0.88	0.83	0.66	0.94	0.89	0.89	0.83	0.67

C.13. Performance Function g_{16}

Table C-28 gives the calculated mean load and resistance factors for performance function g_{16}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-29 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1 and γ_S=1.5.

Table C-28: Computed Mean Partial Safety Factors for g_{16}

	β	Carbon Steel (T≤200°F) & Stainless Steel				Carbon Steel (T>200°F)			
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S
f_S=2	1.5	4.77	0.989	1.006	1.853	4.82	0.969	1.006	1.834
	2	6.60	0.988	1.004	2.758	6.68	0.968	1.004	2.730
	3	16.56	0.989	1.002	7.684	16.75	0.969	1.002	7.614
f_S=3	1.5	6.64	0.989	1.004	1.855	6.71	0.971	1.004	1.839
	2	9.39	0.989	1.003	2.761	9.50	0.970	1.003	2.735
	3	24.33	0.989	1.001	7.686	24.62	0.969	1.001	7.619
f_S=4	1.5	8.52	0.990	1.003	1.856	8.61	0.972	1.003	1.841
	2	12.18	0.989	1.002	2.761	12.32	0.970	1.002	2.738
	3	32.11	0.989	1.001	7.687	32.48	0.970	1.001	7.621

Table C-29a: Adjusted Nominal Resistance Factor for γ_A=1.1 and γ_S=1.5 and Carbon Steel for g_{16}

f_S	β	Carbon Steel				
		R.T.	200°F	400°F	600°F	800°F
2	1.5	0.97(1)	0.89(1)	0.98(1)	0.92(1)	0.93
	2	0.89	0.81	0.89	0.84	0.67
	3	0.35	0.32	0.36	0.33	0.27
3	1.5	0.95(1)	0.87(1)	0.96(1)	0.90(1)	0.93
	2	0.87	0.79	0.87	0.82	0.66
	3	0.34	0.31	0.34	0.32	0.25
4	1.5	0.94(1)	0.86(1)	0.95(1)	0.89(1)	0.93
	2	0.86	0.78	0.86	0.81	0.65
	3	0.33	0.30	0.33	0.31	0.25

(1) γ_A=1.1 and γ_S=1.1, R.T.=Room Temperature

Table C-29b: Adjusted Nominal Resistance Factors for γ_A=1.1 and γ_S=1.5 and Stainless Steel for g_{16}

f_S	β	Stainless Steel				
		R.T.	200°F	400°F	600°F	800°F
2	1.5	0.96[(1)]	0.83[(1)]	0.94	0.94	0.91
	2	0.87	0.76	0.68	0.68	0.66
	3	0.35	0.30	0.27	0.27	0.26
3	1.5	0.94[(1)]	0.81[(1)]	0.94	0.94	0.91
	2	0.85	0.74	0.67	0.67	0.64
	3	0.33	0.29	0.26	0.26	0.25
4	1.5	0.92[(1)]	0.80[(1)]	0.94	0.94	0.91
	2	0.84	0.73	0.66	0.66	0.64
	3	0.32	0.28	0.25	0.25	0.24

[(1)] γ_A=1.1 and γ_S=1.1, R.T.=Room Temperature

C.14. Performance Function g_{17}

Table C-30 gives the calculated mean load and resistance factors for performance function g_{17}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-31 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PS}=1.2, and γ_S=1.5.

Table C-30a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^oF$ and Stainless Steel for g_{17}

	β	Carbon Steel for $T \leq 200^oF$ and Stainless Steel														
		f_S=2					f_S=3					f_S=4				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}
f_{PS}= 0.5	2	7.10	0.988	1.004	2.755	0.995	9.89	0.99	1.00	2.76	0.99	12.68	0.99	1.00	2.76	0.99
	2.5	10.47	0.99	1.00	4.42	0.99	14.94	0.99	1.00	4.42	0.99	19.42	0.99	1.00	4.43	0.99
	3	17.06	0.988	1.002	7.682	0.993	24.83	0.99	1.00	7.68	0.99	32.61	0.99	1.00	7.69	0.99
f_{PS}=1	2	7.60	0.987	1.004	2.756	0.999	10.39	0.99	1.00	2.76	1.00	13.18	0.99	1.00	2.76	1.00
	2.5	10.97	0.99	1.00	4.42	1.00	15.45	0.99	1.00	4.42	0.99	19.92	0.99	1.00	4.42	0.99
	3	17.56	0.988	1.002	7.679	0.994	25.34	0.99	1.00	7.68	0.99	33.11	0.99	1.00	7.68	0.99
f_{PS}=3	2	9.65	0.984	1.004	2.723	1.013	12.42	0.99	1.00	274	1.01	15.21	0.99	1.00	2.75	1.00
	2.5	13.00	0.99	1.00	4.40	1.01	17.47	0.99	1.00	4.41	1.00	21.94	0.99	1.00	4.42	1.00
	3	19.58	0.987	1.002	7.662	1.000	27.35	0.99	1.00	7.67	1.00	35.12	0.99	1.00	7.68	1.00
f_{PS}=5	2	11.72	0.981	1.004	2.674	1.029	14.47	0.98	1.00	2.72	1.02	17.25	0.99	1.00	2.74	1.01
	2.5	15.05	0.98	1.00	4.36	1.02	19.50	0.99	1.00	4.39	1.01	23.97	0.99	1.00	4.41	1.00
	3	21.62	0.986	1.002	7.638	1.006	29.37	0.99	1.00	7.66	1.00	37.14	0.99	1.00	7.67	1.00
f_{PS}= 10	2	17.11	0.971	1.005	2.413	1.079	19.72	0.98	1.00	2.62	1.04	22.43	0.98	1.00	2.63	1.03
	2.5	20.30	0.98	1.00	4.21	1.04	24.66	0.98	1.00	4.33	1.02	29.09	0.98	1.00	4.37	1.02
	3	26.76	0.983	1.002	7.545	1.020	34.48	0.98	1.00	7.62	1.01	42.22	0.99	1.00	7.64	1.01
f_{PS}= 50	2	68.90	0.948	1.002	0.873	1.251	69.85	0.95	1.00	0.92	1.25	70.84	0.95	1.00	0.97	1.24
	2.5	73.84	0.94	1.00	0.89	1.33	74.82	0.94	1.00	0.95	1.32	75.87	0.94	1.00	1.04	1.32
	3	79.13	0.924	1.003	0.902	1.405	80.15	0.92	1.00	0.98	1.40	81.28	0.92	1.00	1.14	1.39

Table C-30b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{17}

	β	Carbon Steel for T>200°F														
		f_S=2					f_S=3					f_S=4				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_S	γ'_{PS}
f_{PS}= 0.5	2	7.19	0.966	1.004	2.723	0.995	10.01	0.97	1.00	2.73	0.99	12.83	0.97	1.00	2.73	0.99
	2.5	10.60	0.97	1.00	4.37	0.99	15.12	0.97	1.00	4.38	0.99	19.64	0.97	1.00	4.39	0.99
	3	17.27	0.968	1.002	7.607	0.993	25.13	0.97	1.00	7.61	0.99	32.99	0.97	1.00	7.62	0.99
f_{PS}=1	2	7.71	0.964	1.004	2.714	0.999	10.52	0.97	1.00	2.73	1.00	13.34	0.97	1.00	2.73	1.00
	2.5	11.11	0.97	1.00	4.37	1.00	15.63	0.97	1.00	4.38	0.99	20.16	0.97	1.00	4.38	0.99
	3	17.78	0.967	1.002	7.600	0.994	25.64	0.97	1.00	7.61	0.99	33.50	0.97	1.00	7.61	0.99
f_{PS}=3	2	9.80	0.956	1.004	2.662	1.014	12.60	0.96	1.00	2.70	1.01	15.41	0.96	1.00	2.71	1.00
	2.5	13.19	0.96	1.00	4.32	1.01	7.70	0.96	1.00	4.35	1.00	22.22	0.97	1.00	4.36	1.00
	3	19.85	0.964	1.002	7.564	1.000	24.70	0.97	1.00	7.59	1.00	35.55	0.97	1.00	7.60	1.00
f_{PS}=5	2	11.95	0.947	1.004	2.579	1.030	14.71	0.96	1.00	2.66	1.02	17.50	0.96	1.00	2.69	1.01
	2.5	15.30	0.95	1.00	4.26	1.02	19.79	0.96	1.00	4.32	1.01	24.29	0.96	1.00	4.34	1.00
	3	21.93	0.961	1.002	7.518	1.006	29.77	0.96	1.00	7.56	1.00	37.62	0.97	1.00	7.58	1.00
f_{PS}= 10	2	17.61	0.917	1.005	2.128	1.088	20.14	0.94	1.00	2.49	1.05	22.84	0.95	1.00	2.59	1.03
	2.5	20.74	0.94	1.00	4.00	1.05	25.11	0.95	1.00	4.20	1.03	29.55	0.96	1.00	4.27	1.02
	3	27.23	0.952	1.002	7.354	1.021	35.00	0.96	1.00	7.48	1.01	42.82	0.96	1.00	7.53	1.01
f_{PS}= 50	2	72.14	0.878	1.002	0.866	1.213	73.14	0.88	1.00	0.90	1.21	74.19	0.88	1.00	0.95	1.21
	2.5	78.13	0.85	1.00	0.88	1.28	79.19	0.85	1.00	0.93	1.27	80.31	0.85	1.00	0.99	1.27
	3	84.62	0.825	1.003	0.891	1.341	85.74	0.82	1.00	0.95	1.34	86.95	0.82	1.00	1.05	1.33

Table C-31a: Adjusted Nominal Resistance Factor for g_{17} and Carbon Steel for γ_A=1.1, γ_{PS}=1.2 and γ_S=1.5

	β	Carbon Steel														
		f_S=2					f_S=3					f_S=4				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PS}=0.5	2	0.64[1]	0.58[1]	0.64[1]	0.60[1]	0.70	0.60[1]	0.54[1]	0.60[1]	0.56[1]	0.68	0.57[1]	0.52[1]	0.58[1]	0.54[1]	0.67
	2.5	0.63	0.57	0.63	0.59	0.48	0.60	0.54	0.60	0.56	0.45	0.58	0.53	0.58	0.54	0.44
	3	0.39	0.35	0.39	0.37	0.29	0.36	0.33	0.36	0.34	0.27	0.34	0.31	0.35	0.32	0.26
f_{PS}=1	2	0.67[1]	0.62[1]	0.68[1]	0.64[1]	0.73	0.63[1]	0.57[1]	0.63[1]	0.59[1]	0.70	0.60[1]	0.55[1]	0.60[1]	0.57[1]	0.68
	2.5	0.67	0.61	0.67	0.63	0.50	0.62	0.57	0.63	0.59	0.47	0.60	0.55	0.60	0.57	0.45
	3	0.42	0.38	0.42	0.39	0.31	0.38	0.35	0.38	0.36	0.29	0.36	0.33	0.36	0.34	0.27
f_{PS}=3	2	0.78[1]	0.71[1]	0.78[1]	0.74[1]	0.80	0.72[1]	0.66[1]	0.72[1]	0.68[1]	0.76	0.68[1]	0.62[1]	0.68[1]	0.64[1]	0.74
	2.5	0.79	0.72	0.79	0.74	0.59	0.72	0.65	0.72	0.68	0.54	0.68	0.62	0.68	0.64	0.51
	3	0.52	0.48	0.52	0.49	0.39	0.46	0.42	0.46	0.43	0.35	0.42	0.39	0.42	0.40	0.32
f_{PS}=5	2	0.85[1]	0.78[1]	0.85[1]	0.80[1]	0.84	0.78[1]	0.72[1]	0.78[1]	0.74[1]	0.80	0.74[1]	0.67[1]	0.74[1]	0.70[1]	0.78
	2.5	0.87	0.80	0.87	0.82	0.66	0.79	0.72	0.79	0.75	0.60	0.74	0.68	0.74	0.70	0.56
	3	0.61	0.55	0.61	0.57	0.46	0.53	0.48	0.53	0.50	0.40	0.48	0.44	0.48	0.45	0.36
f_{PS}=10	2	0.94[1]	0.85[1]	0.93[1]	0.87[1]	0.89	0.88[1]	0.81[1]	0.88[1]	0.83[1]	0.86	0.84[1]	0.76[1]	0.84[1]	0.79[1]	0.84
	2.5	1.00	0.92	1.00	0.94	0.75	0.92	0.84	0.92	0.86	0.69	0.86	0.78	0.86	0.81	0.65
	3	0.76	0.70	0.76	0.72	0.57	0.66	0.60	0.66	0.62	0.50	0.59	0.54	0.59	0.56	0.45
f_{PS}=50	2	0.94[1]	0.85[1]	0.91[1]	0.85[1]	0.83	0.94[1]	0.86[1]	0.92[1]	0.86[1]	0.85	0.95[1]	0.87[1]	0.92[1]	0.87[1]	0.86
	2.5	1.06	0.97	1.02	0.96	0.77	1.08	0.99	1.04	0.98	0.78	1.10	1.00	1.05	0.99	0.79
	3	0.99	0.91	0.94	0.89	0.71	1.01	0.92	0.96	0.90	0.72	1.02	0.93	0.97	0.91	0.73

(1) γ_A=γ_{PS}=1 and γ_{PS}=0.9

Table C-31b: Adjusted Nominal Resistance Factor for g_{17} and Stainless Steel for γ_A=1.1, γ_{PS}=1.2 and γ_S=1.5

	β	Stainless Steel														
		f_S=2					f_S=3					f_S=4				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PS}= 0.5	2	0.62[(1)]	0.54[(1)]	0.71	0.71	0.69	0.59[(1]	0.51[(1]	0.69	0.69	0.66	0.56	0.52	0.68	0.68	0.65
	2.5	0.62	0.54	0.48	0.48	0.47	0.58	0.51	0.46	0.46	0.44	0.57	0.49	0.44	0.44	0.43
	3	0.38	0.33	0.30	0.30	0.29	0.35	0.31	0.27	0.27	0.26	0.34	0.29	0.26	0.26	0.25
f_{PS}=1	2	0.66[(1)]	0.57[(1)]	0.74	0.74	0.71	0.61[(1]	0.53[(1]	0.71	0.71	0.69	0.59	0.51	0.69	0.69	0.67
	2.5	0.66	0.57	0.51	0.51	0.49	0.61	0.53	0.48	0.48	0.46	0.59	0.51	0.46	0.46	0.44
	3	0.41	0.6	0.32	0.32	0.31	0.37	0.32	0.29	0.29	0.28	0.35	0.31	0.28	0.28	0.27
f_{PS}=3	2	0.77[(1)]	0.67[(1)]	0.81	0.81	0.78	0.71[(1]	0.61[(1]	0.77	0.77	0.75	0.67	0.58	0.75	0.75	0.72
	2.5	0.77	0.67	0.60	0.60	0.50	0.70	0.61	0.55	0.55	0.53	0.66	0.58	0.52	0.52	0.50
	3	0.57	0.50	0.40	0.40	0.39	0.45	0.39	0.35	0.35	0.34	0.41	0.36	0.32	0.32	0.31
f_{PS}=5	2	0.84[(1)]	0.72[(1)]	0.86	0.86	0.83	0.77[(1]	0.67[(1]	0.82	0.82	0.79	0.72	0.63	0.79	0.79	0.76
	2.5	0.86	0.74	0.67	0.67	0.64	0.78	0.67	0.61	0.61	0.58	0.73	0.63	0.57	0.57	0.55
	3	0.60	0.52	0.46	0.46	0.45	0.52	0.45	0.40	0.40	0.39	0.47	0.41	0.37	0.37	0.35
f_{PS}= 10	2	0.92[(1)]	0.80[(1)]	0.91	0.91	0.88	0.88[(1]	0.81[(1]	0.88	0.88	0.85	0.82	0.71	0.85	0.85	0.81
	2.5	0.99	0.86	0.77	0.77	0.74	0.90	0.78	0.70	0.70	0.70	0.84	0.73	0.66	0.66	0.64
	3	0.75	0.65	0.58	0.58	0.56	0.65	0.56	0.50	0.50	0.49	0.58	0.50	0.45	0.45	0.44
f_{PS}= 50	2	0.92[(1)]	0.80[(1)]	0.87	0.87	0.84	0.93[(1]	0.80[(1]	0.89	0.89	0.86	0.93	0.81	0.90	0.90	0.87
	2.5	1.04	0.91	0.81	0.81	0.79	1.06	0.92	0.83	0.83	0.80	1.08	0.93	0.84	0.84	0.81
	3	0.97	0.85	0.76	0.76	0.73	0.99	0.86	0.77	0.77	0.75	1.00	0.87	0.78	0.78	0.76

(1) For these factors γ_A=γ_{PS}=1 and γ_S=0.9

C.15. Performance Function g_{18}

Table C-32 gives the calculated mean load and resistance factors for performance function g_{18}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-33 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PD}=1.2, and γ_L=1.3.

Table C-32a: Mean Load and Resistance Factors for Carbon Steel and $T \leq 200^{o}$F and Stainless Steel for g_{18}

	β	Carbon Steel $T \leq 200^{o}$F & Stainless Steel														
		f_L=0.5					f_L=1.0					f_L=2.0				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L
f_{PD}=0.5	3	2.73	0.91	1.10	1.39	1.39	3.61	0.93	1.06	1.10	1.76	5.55	0.95	1.03	1.02	1.85
	4	3.09	0.89	1.11	1.65	1.65	4.26	0.92	1.06	1.11	2.29	6.81	0.93	1.03	1.02	2.40
	5	3.79	0.87	1.12	2.16	2.16	5.54	0.89	1.06	1.12	3.34	9.33	0.91	1.03	1.03	3.47
f_{PD}=1	3	3.61	0.93	1.06	1.10	1.10	4.29	0.93	1.05	1.46	1.46	6.12	0.94	1.03	1.10	1.81
	4	4.26	0.92	1.06	1.11	1.11	4.98	0.91	1.06	1.74	1.74	7.38	0.93	1.03	1.11	2.35
	5	5.54	0.89	1.06	1.12	1.12	6.33	0.88	1.06	2.27	2.27	9.92	0.90	1.03	1.12	3.41
f_{PD}=3	3	7.52	0.95	1.02	1.00	1.00	8.06	0.95	1.02	1.86	1.04	9.23	0.94	1.02	1.77	1.18
	4	9.40	0.94	1.02	1.00	1.00	9.94	0.93	1.02	2.40	2.40	11.14	0.93	1.02	2.30	1.20
	5	13.16	0.91	1.02	1.00	1.00	13.72	0.91	1.02	3.47	1.05	14.96	0.90	1.02	3.35	1.22
f_{PD}=5	3	11.48	0.95	1.01	0.99	0.99	12.00	0.95	1.01	1.88	1.01	13.09	0.95	1.01	1.85	1.07
	4	14.58	0.94	1.01	0.99	0.99	15.11	0.94	1.01	2.43	1.01	16.22	0.93	1.01	2.40	1.07
	5	20.83	0.92	1.01	0.99	0.99	21.38	0.91	1.01	3.51	1.01	22.52	0.91	1.01	3.47	1.07
f_{PD}=10	3	21.39	0.96	1.01	0.98	0.98	21.90	0.96	1.01	1.89	0.99	22.95	0.95	1.01	1.89	1.61
	4	27.57	0.94	1.01	0.98	0.98	28.09	0.94	1.01	2.45	0.99	29.16	0.94	1.01	2.44	1.01
	5	40.03	0.92	1.01	0.98	0.98	40.56	0.92	1.01	3.53	0.99	41.65	0.92	1.01	3.52	1.01
f_{PD}=50	3	100.7	0.96	1.00	0.97	0.97	101.2	0.96	1.00	1.90	0.99	102.2	0.96	1.00	1.90	0.97
	4	131.5	0.95	1.00	0.97	0.97	132.1	0.95	1.00	2.46	0.97	133.1	0.95	1.00	2.46	0.98
	5	193.6	0.92	1.00	0.97	0.97	144.2	0.92	1.00	3.54	0.97	195.2	0.92	1.00	3.54	0.98

Table C-32b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{18}

	β	Carbon Steel T>200°F														
		f_L=0.5					f_L=1.0					f_L=2.0				
		μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PD}	γ'_L
f_{PD}=0.5	3	2.95	0.80	1.09	1.28	1.28	3.85	0.83	1.06	1.09	1.61	5.84	0.86	1.03	1.02	1.75
	4	3.40	0.76	1.11	1.47	1.47	4.59	0.80	1.06	1.11	2.06	7.25	0.83	1.03	1.02	2.24
	5	4.27	0.70	1.12	1.89	1.89	6.11	0.75	1.06	1.11	2.97	10.15	0.78	1.03	1.03	3.19
f_{PD}=1	3	3.85	0.83	1.06	1.61	1.09	4.58	0.83	1.05	1.37	1.37	6.46	0.85	1.03	1.10	1.69
	4	4.59	0.80	1.06	2.06	1.11	5.40	0.79	1.06	1.60	1.60	7.89	0.82	1.03	1.11	2.17
	5	6.11	0.75	1.06	2.97	1.11	7.03	0.73	1.06	2.05	2.05	10.84	0.77	1.03	1.11	3.10
f_{PD}=3	3	7.88	0.87	1.02	1.79	1.00	8.47	0.87	1.02	1.76	1.04	9.75	0.85	1.02	1.65	1.17
	4	9.96	0.84	1.02	2.29	1.00	10.57	0.83	1.02	2.25	1.05	11.91	0.82	1.02	2.12	1.20
	5	14.25	0.79	1.02	3.24	1.00	14.90	0.78	1.02	3.20	1.05	16.34	0.77	1.02	3.04	1.21
f_{PD}=5	3	11.98	0.88	1.01	1.81	0.99	12.55	0.88	1.01	1.80	1.01	13.73	0.87	1.01	1.76	1.06
	4	15.40	0.85	1.01	2.32	0.99	15.99	0.85	1.01	2.30	1.01	17.22	0.84	1.01	2.26	1.07
	5	22.47	0.80	1.01	3.29	0.99	23.10	0.79	1.01	3.26	1.01	24.42	0.79	1.01	3.21	1.07
f_{PD}=10	3	22.27	0.89	1.01	1.83	0.98	22.82	0.89	1.01	1.82	0.99	23.95	0.88	1.01	1.81	1.01
	4	29.04	0.86	1.01	2.34	0.98	29.62	0.85	1.01	2.33	0.99	30.79	0.85	1.01	2.32	1.01
	5	43.08	0.80	1.01	3.31	0.98	43.69	0.80	1.01	3.30	0.99	44.94	0.80	1.01	3.28	1.01
f_{PD}=50	3	104.7	0.89	1.00	1.84	0.97	105.2	0.89	1.00	1.84	0.97	106.3	0.89	1.00	1.84	0.97
	4	138.3	0.86	1.00	2.36	0.97	138.9	0.86	1.00	2.35	0.97	140	0.86	1.00	2.35	0.98
	5	208	0.81	1.00	3.33	0.97	208.6	0.81	1.00	3.33	0.97	202.7	0.81	1.00	3.33	0.98

Table C-33a: Adjusted Nomianl Resistance Factors for Carbon Steel and γ_A=1.1, γ_L=1.3, γ_{PD}=1.2 for g_{18}

	β	Carbon Steel														
		f_L=0.5					f_L=1.0					f_L=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PD}=0.5	3	1.03(1)	0.94(1)	0.97(1)	0.91(1)	0.73(1)	0.98(1)	0.90(1)	0.94(1)	0.88(1)	0.71(1)	0.91(1)	0.83(1)	0.88(1)	0.82(1)	0.66(1)
	4	0.97	0.89	0.90	0.85	0.68	0.97	0.83	0.86	0.81	0.65	0.83	0.76	0.79	0.75	0.60
	5	0.79	0.72	0.72	0.67	0.54	0.70	0.64	0.65	0.61	0.49	0.60	0.55	0.57	0.53	0.43
f_{PD}=1	3	0.81(1)	0.85(1)	0.95(1)	0.89(1)	0.71(1)	1.01(1)	0.92(1)	0.96(1)	0.91(1)	0.72(1)	0.95(1)	0.87(1)	0.92(1)	0.86(1)	0.69(1)
	4	0.91	0.83	0.86	0.81	0.65	0.95	0.87	0.89	0.84	0.67	0.87	0.75	0.84	0.79	0.63
	5	0.70	0.64	0.64	0.61	0.48	0.75	0.68	0.69	0.65	0.52	0.66	0.60	0.61	0.57	0.46
f_{PD}=3	3	0.90(1)	0.82(1)	0.87(1)	0.82(1)	0.66(1)	0.93(1)	0.85(1)	0.90(1)	0.85(1)	0.68(1)	0.97(1)	0.89(1)	0.94(1)	0.88(1)	0.71(1)
	4	0.78	0.71	0.75	0.70	0.56	0.82	0.75	0.79	0.74	0.59	0.89	0.82	0.85	0.80	0.64
	5	0.56	0.51	0.52	0.49	0.39	0.60	0.55	0.56	0.53	0.42	0.65	0.57	0.62	0.58	0.47
f_{PD}=5	3	0.86(1)	0.79(1)	0.84(1)	0.79(1)	0.63(1)	0.89(1)	0.81(1)	0.86(1)	0.81(1	0.65(1)	0.93(1)	0.85(1)	0.90(1)	0.85(1)	0.68(1)
	4	0.74	0.67	0.71	0.67	0.54	0.77	0.70	0.74	0.70	0.56	0.82	0.75	0.79	0.74	0.60
	5	0.52	0.47	0.49	0.46	0.37	0.54	0.50	0.51	0.48	0.39	0.60	0.54	0.56	0.53	0.42
f_{PD}=10	3	0.83(1)	0.76(1)	0.81(1)	0.77(1)	0.61(1)	0.85(1)	0.77(1)	0.83(1)	0.78(1)	0.62(1)	0.87(1)	0.80(1)	0.85(1)	0.80(1)	0.64(1)
	4	0.70	0.64	0.68	0.64	0.51	0.72	0.66	0.70	0.65	0.52	0.76	0.69	0.73	0.68	0.55
	5	0.48	0.44	0.46	0.43	0.34	0.50	0.46	0.47	0.44	0.36	0.53	0.48	0.50	0.47	0.38
f_{PD}=50	3	0.80(1)	0.73(1)	0.79(1)	0.74(1)	0.59(1)	0.81(1)	0.74(1)	0.79(1)	0.74(1)	0.60(1)	0.81(1)	0.74(1)	0.80(1)	0.75(1)	0.60(1)
	4	0.67	0.61	0.65	0.61	0.49	0.68	0.62	0.65	0.61	0.49	0.68	0.62	0.66	0.62	0.50
	5	0.46	0.42	0.43	0.41	0.33	0.44	0.42	0.44	0.41	0.33	0.47	0.43	0.44	0.42	0.33

(1) For these factors γ_A=γ_L=γ_{PD}=1.1

Table C-33b: Adjusted Nomianl Resistance Factors for Stainless Steel and γ_A=1.1, γ_L=1.3, γ_{PD}=1.2 for g_{18}

	β	Stainless Steel														
		f_L=0.5					f_L=1.0					f_L=2.0				
		R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PD}=0.5	3	1.01(1)	0.87(1)	0.78(1)	0.78(1)	0.76(1)	0.96(1)	0.84(1)	0.75(1)	0.75(1)	0.72(1)	0.89(1)	0.77(1)	0.69(1)	0.69(1)	0.67(1)
	4	0.96	0.63	0.74	0.74	0.72	0.90	0.78	0.70	0.70	0.67	0.81	0.71	0.63	0.63	0.61
	5	0.78	0.68	0.61	0.61	0.59	0.69	0.60	0.54	0.54	0.52	0.59	0.52	0.46	0.46	0.45
f_{PD}=1	3	0.98(1)	0.85(1)	0.76(1)	0.76(1)	0.73(1)	0.99(1)	0.86(1)	0.77(1)	0.77(1)	0.75(1)	0.94(1)	0.81(1)	0.73(1)	0.73(1)	0.70(1)
	4	0.89	0.77	0.70	0.70	0.67	0.94	0.81	0.73	0.73	0.70	0.87	0.75	0.67	0.67	0.65
	5	0.69	0.59	0.53	0.53	0.52	0.74	0.64	0.57	0.57	0.55	0.64	0.56	0.50	0.50	0.48
f_{PD}=3	3	0.88(1)	0.76(1)	0.69(1)	0.69(1)	0.66(1)	0.91(1)	0.79(1)	0.71(1)	0.71(1)	0.69(1)	0.96(1)	0.83(1)	0.74(1)	0.74(1)	0.72(1)
	4	0.77	0.66	0.60	0.60	0.58	0.81	0.70	0.63	0.63	0.61	0.88	0.76	0.68	0.68	0.66
	5	0.55	0.47	0.43	0.43	0.41	0.59	0.51	0.46	0.46	0.44	0.65	0.57	0.51	0.51	0.49
f_{PD}=5	3	0.85(1)	0.74(1)	0.66(1)	0.66(1)	0.64(1)	0.87(1)	0.76(1)	0.68(1)	0.68(1)	0.66(1)	0.91(1)	0.79(1)	0.71(1)	0.71(1)	0.69(1)
	4	0.73	0.63	0.57	0.57	0.55	0.76	0.66	0.59	0.59	0.57	0.81	0.70	0.63	0.63	0.61
	5	0.51	0.44	0.40	0.40	0.38	0.54	0.46	0.42	0.42	0.40	0.59	0.51	0.46	0.46	0.44
f_{PD}=10	3	0.82(1)	0.77(1)	0.64(1)	0.64(1)	0.62(1)	0.83(1)	0.72(1)	0.65(1)	0.65(1)	0.63(1)	0.86(1)	0.74(1)	0.67(1)	0.67(1)	0.65(1)
	4	0.61	0.60	0.54	0.54	0.52	0.71	0.61	0.55	0.55	0.53	0.74	0.64	0.58	0.58	0.56
	5	0.48	0.41	0.37	0.37	0.36	0.49	0.43	0.38	0.38	0.37	0.52	0.45	0.40	0.40	0.39
f_{PD}=50	3	0.79(1)	0.69(1)	0.62(1)	0.62(1)	0.65(1)	0.79(1)	0.69(1)	0.62(1)	0.62(1)	0.60(1)	0.89(1)	0.69(1)	0.62(1)	0.62(1)	0.60(1)
	4	0.66	0.57	0.51	0.51	0.50	0.66	0.58	0.52	0.52	0.50	0.67	0.58	0.52	0.52	0.51
	5	0.45	0.39	0.35	0.35	0.34	0.45	0.39	0.35	0.35	0.34	0.46	0.40	0.36	0.36	0.34

(1) For these factors $\gamma_A=\gamma_L=\gamma_{PD}$=1.1

C.16. Performance Function g_{19}

Table C-34 gives the calculated mean load and resistance factors for performance function g_{19}. In this table, μ_{fu} is the converged mean value of the ultimate strength of steel. Table C-35 shows the evaluated adjusted nominal resistance factors for nominal load factors γ_A=1.1, γ_{PS}=1.2, γ_L=1.3, and γ_S=1.5.

Table C-34a: Mean Load and Resistance Factors for Stainless Steel and Carbon Steel for $T \leq 200^oF$ for g_{19}

		β=2.5	Carbon Steel $T \leq 200^oF$ & Stainless Steel																	
			f_L=0.5						f_L=1.0						f_L=2.0					
		f_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S
f_{PS}	0.5	1	6.49	0.99	1.01	1.00	0.98	4.40	6.98	0.98	1.01	1.00	0.99	4.39	8.00	0.98	1.01	1.00	1.01	4.34
		2	10.96	0.99	1.00	0.99	0.97	4.42	11.45	0.99	1.00	0.99	0.98	441	12.45	0.99	1.00	0.99	0.99	4.40
		3	15.43	0.99	1.00	0.99	0.97	4.42	15.92	0.99	1.00	0.99	0.97	4.42	16.91	0.99	1.00	0.99	0.98	4.41
	1	1	6.99	0.98	1.01	1.00	0.98	4.39	7.49	0.98	1.01	1.00	0.99	4.38	8.51	0.98	1.01	1.00	1.01	4.33
		2	11.46	0.99	1.00	1.00	0.97	4.41	11.96	0.99	1.00	1.00	0.98	4.41	12.95	0.99	1.00	1.00	0.99	4.40
		3	15.94	0.99	1.00	0.99	0.97	4.42	16.43	0.99	1.00	0.99	0.97	4.42	17.42	0.99	1.00	0.99	0.98	4.41
	3	1	9.05	0.98	1.01	1.02	0.98	4.32	9.55	0.98	1.01	1.02	0.99	4.30	10.57	0.98	1.01	1.02	1.01	4.24
		2	13.49	0.99	1.00	1.01	0.97	4.39	13.99	0.98	1.00	1.01	0.98	4.39	14.98	0.98	1.00	1.01	0.99	4.37
		3	17.96	0.99	1.00	1.00	0.97	4.41	18.45	0.99	1.00	1.00	0.97	4.41	19.44	0.99	1.00	1.00	0.98	4.40
	5	1	11.16	0.98	1.01	1.04	0.98	4.18	11.66	0.97	1.01	1.04	0.99	4.16	12.69	0.97	1.01	1.04	1.01	4.09
		2	15.55	0.98	1.00	1.02	0.97	4.36	16.04	0.98	1.00	1.02	0.98	4.35	17.04	0.98	1.00	1.02	0.99	4.34
		3	19.99	0.99	1.00	1.01	0.97	4.39	20.49	0.98	1.00	1.01	0.97	4.39	21.48	0.98	1.00	1.01	0.98	4.38
	10	1	16.80	0.93	1.01	1.29	0.99	1.23	17.34	0.93	1.01	1.29	1.01	1.22	18.46	0.93	1.01	1.28	1.07	1.17
		2	20.79	0.98	1.00	1.04	0.97	4.20	21.29	0.98	1.00	1.04	0.98	4.19	22.30	0.98	1.00	1.04	0.99	4.17
		3	25.16	0.98	1.00	1.02	0.97	4.32	25.65	0.98	1.00	1.02	0.97	4.32	26.65	0.98	1.00	1.02	0.98	4.31
	50	1	73.43	0.94	1.00	1.33	0.97	0.85	73.95	0.94	1.00	1.33	0.98	0.85	75.00	0.93	1.00	1.33	0.98	0.85
		2	74.35	0.94	1.00	1.33	0.97	0.89	74.88	0.93	1.00	1.32	0.98	0.89	75.92	0.93	1.00	1.32	0.98	0.89
		3	75.33	0.93	1.00	1.32	0.97	0.95	75.85	0.93	1.00	1.32	0.98	0.95	76.90	0.93	1.00	1.32	0.98	0.95

Table C-34a: (Continued)

	β=3.0	Carbon Steel $T \leq 200^{o}$F & Stainless Steel																	
		f_L=0.5						f_L=1.0						f_L=2.0					
f_{PS}	f_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S
0.5	1	9.91	0.96	1.00	0.99	0.97	7.57	10.42	0.96	1.00	0.99	0.98	7.55	11.44	0.96	1.00	0.99	0.99	7.49
	2	17.77	0.97	1.00	0.99	0.97	7.60	18.27	0.97	1.00	0.99	0.97	7.59	19.28	0.96	1.00	0.99	0.98	7.57
	3	25.63	0.97	1.00	0.99	0.97	7.61	26.13	0.97	1.00	0.99	0.97	7.61	27.13	0.97	1.00	0.99	0.97	7.59
1	1	10.43	0.96	1.00	1.00	0.97	7.55	10.94	0.96	1.00	1.00	0.98	7.53	11.96	0.96	1.00	1.00	0.99	7.47
	2	18.28	0.97	1.00	0.99	0.97	7.59	18.78	0.97	1.00	0.99	0.97	7.58	19.80	0.96	1.00	0.99	0.98	7.56
	3	26.14	0.97	1.00	0.99	0.97	7.61	26.64	0.97	1.00	0.99	0.97	7.60	27.65	0.97	1.00	0.99	0.97	7.59
3	1	12.52	0.96	1.00	1.01	0.97	7.45	13.03	0.95	1.00	1.01	0.98	7.42	14.06	0.95	1.00	1.01	0.99	7.36
	2	20.35	0.96	1.00	1.00	0.97	7.56	20.85	0.96	1.00	1.00	0.97	7.55	21.87	0.96	1.00	1.00	0.98	7.53
	3	28.20	0.97	1.00	1.00	0.97	7.58	28.70	0.97	1.00	1.00	0.97	7.58	29.71	0.96	1.00	1.00	0.97	7.57
5	1	14.65	0.95	1.00	1.02	0.97	7.30	15.17	0.95	1.00	1.02	0.98	7.27	16.21	0.94	1.00	1.02	0.99	7.20
	2	22.44	0.96	1.00	1.01	0.97	7.51	22.94	0.96	1.00	1.01	0.97	7.50	23.96	0.96	1.00	1.01	0.98	7.48
	3	30.27	0.96	1.00	1.00	0.97	7.56	30.77	0.96	1.00	1.00	0.97	7.55	31.79	0.96	1.00	1.00	0.97	7.54
10	1	19.24	0.82	1.01	1.30	0.99	1.29	19.86	0.82	1.01	1.29	1.01	1.25	21.13	0.81	1.01	1.28	1.07	1.18
	2	27.74	0.95	1.00	1.02	0.97	7.34	28.25	0.95	1.00	1.02	0.97	7.33	29.28/	0.95	1.00	1.02	0.98	7.30
	3	35.51	0.96	1.00	1.01	0.97	7.47	36.01	0.96	1.00	1.01	0.97	7.46	37.03	0.96	1.00	1.01	0.97	7.45
50	1	84.16	0.83	1.00	1.34	0.97	0.85	84..75	0.83	1.00	1.34	0.98	0.85	85.94	0.82	1.00	1.34	0.99	0.85
	2	85.21	0.82	1.00	1.34	0.97	0.89	85.80	0.82	1.00	1.34	0.98	0.89	86.99	0.82	1.00	1.34	0.99	0.89
	3	86.33	0.82	1.00	1.34	0.97	0.95	86.92	0.82	1.00	1.34	0.98	0.95	88.11	0.82	1.00	1.34	0.99	0.95

Table C-34b: Mean Load and Resistance Factors for Carbon Steel and T>200°F for g_{19}

		Carbon Steel, T>200°F																	
	β=2.5	f_L=0.5						f_L=1.0						f_L=2.0					
	f_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S
f_{PS} = 0.5	1	6.58	0.96	1.01	1.00	0.98	4.33	10.42	0.96	1.00	0.99	0.98	7.55	11.44	0.96	1.00	0.99	0.99	7.49
	2	11.10	0.97	1.00	0.99	0.97	.37	18.27	0.97	1.00	0.99	0.97	7.59	19.28	0.96	1.00	0.99	0.98	7.57
	3	15.62	0.97	1.00	0.99	0.97	4.38	26.13	0.97	1.00	0.99	0.97	7.61	27.13	0.97	1.00	0.99	0.97	7.59
1	1	7.10	0.96	1.01	1.00	0.98	4.31	10.94	0.96	1.00	1.00	0.98	7.53	11.96	0.96	1.00	1.00	0.99	7.47
	2	11.61	0.96	1.00	1.00	0.97	4.36	18.78	0.97	1.00	0.99	0.97	7.58	19.80	0.96	1.00	0.99	0.98	7.56
	3	16.13	0.97	1.00	0.99	0.97	4.37	26.64	0.97	1.00	0.99	0.97	7.60	27.65	0.97	1.00	0.99	0.97	7.59
3	1	9.23	0.95	1.01	1.02	0.98	4.17	13.03	0.95	1.00	1.01	0.98	7.42	14.06	0.95	1.00	1.01	0.99	7.36
	2	13.70	0.96	1.00	1.01	0.97	4.31	20.85	0.96	1.00	1.00	0.97	7.55	21.87	0.96	1.00	1.00	0.98	7.53
	3	18.20	0.96	1.00	1.00	0.97	4.35	28.70	0.97	1.00	1.00	0.97	7.58	29.71	0.96	1.00	1.00	0.97	7.57
5	1	11.43	0.93	1.01	1.05	0.98	3.92	15.17	0.95	1.00	1.02	0.98	7.27	16.21	0.94	1.00	1.02	0.99	7.20
	2	15.81	0.95	1.00	1.02	0.97	4.25	22.94	0.96	1.00	1.01	0.97	7.50	23.96	0.96	1.00	1.01	0.98	7.48
	3	20.29	0.96	1.00	1.01	0.97	4.31	30.77	0.96	1.00	1.00	0.97	7.55	31.79	0.96	1.00	1.00	0.97	7.54
10	1	17.83	0.84	1.01	1.25	0.99	1.08	19.86	0.82	1.01	1.29	1.01	1.25	21.13	0.81	1.01	1.28	1.07	1.18
	2	21.26	0.94	1.00	1.05	0.97	3.99	28.25	0.95	1.00	1.02	0.97	7.33	29.28/	0.95	1.00	1.02	0.98	7.30
	3	25.62	0.95	1.00	1.03	0.97	4.19	36.01	0.96	1.00	1.01	0.97	7.46	37.03	0.96	1.00	1.01	0.97	7.45
50	1	77.69	0.85	1.00	1.28	0.97	0.84	84..75	0.83	1.00	1.34	0.98	0.85	85.94	0.82	1.00	1.34	0.99	0.85
	2	78.70	0.85	1.00	1.27	0.97	0.88	85.80	0.82	1.00	1.34	0.98	0.89	86.99	0.82	1.00	1.34	0.99	0.89
	3	79.76	0.85	1.00	1.27	0.97	0.93	86.92	0.82	1.00	1.34	0.98	0.95	88.11	0.82	1.00	1.34	0.99	0.95

Table C-34b: (Continued)

		β=3.0	Carbon Steel, T>200°F																	
			f_L=0.5						f_L=1.0						f_L=2.0					
		f_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S	μ_{fu}	ϕ'_{fu}	γ'_A	γ'_{PS}	γ'_L	γ'_S
f_{PS}	0.5	1	9.91	0.96	1.00	0.99	0.97	7.57	10.42	0.96	1.00	0.99	0.98	7.55	11.44	0.96	1.00	0.99	0.99	7.49
		2	17.77	0.97	1.00	0.99	0.97	7.60	18.27	0.97	1.00	0.99	0.97	7.59	19.28	0.96	1.00	0.99	0.98	7.57
		3	25.63	0.97	1.00	0.99	0.97	7.61	26.13	0.97	1.00	0.99	0.97	7.61	27.13	0.97	1.00	0.99	0.97	7.59
	1	1	10.43	0.96	1.00	1.00	0.97	7.55	10.94	0.96	1.00	1.00	0.98	7.53	11.96	0.96	1.00	1.00	0.99	7.47
		2	18.28	0.97	1.00	0.99	0.97	7.59	18.78	0.97	1.00	0.99	0.97	7.58	19.80	0.96	1.00	0.99	0.98	7.56
		3	26.14	0.97	1.00	0.99	0.97	7.61	26.64	0.97	1.00	0.99	0.97	7.60	27.65	0.97	1.00	0.99	0.97	7.59
	3	1	12.52	0.96	1.00	1.01	0.97	7.45	13.03	0.95	1.00	1.01	0.98	7.42	14.06	0.95	1.00	1.01	0.99	7.36
		2	20.35	0.96	1.00	1.00	0.97	7.56	20.85	0.96	1.00	1.00	0.97	7.55	21.87	0.96	1.00	1.00	0.98	7.53
		3	28.20	0.97	1.00	1.00	0.97	7.58	28.70	0.97	1.00	1.00	0.97	7.58	29.71	0.96	1.00	1.00	0.97	7.57
	5	1	14.65	0.95	1.00	1.02	0.97	7.30	15.17	0.95	1.00	1.02	0.98	7.27	16.21	0.94	1.00	1.02	0.99	7.20
		2	22.44	0.96	1.00	1.01	0.97	7.51	22.94	0.96	1.00	1.01	0.97	7.50	23.96	0.96	1.00	1.01	0.98	7.48
		3	30.27	0.96	1.00	1.00	0.97	7.56	30.77	0.96	1.00	1.00	0.97	7.55	31.79	0.96	1.00	1.00	0.97	7.54
	10	1	19.24	0.82	1.00	1.30	0.97	1.29	19.86	0.82	1.00	1.29	1.01	1.25	21.13	0.81	1.00	1.28	1.07	1.18
		2	27.74	0.95	1.00	1.02	0.97	7.34	28.25	0.95	1.00	1.02	0.97	7.33	29.28	0.95	1.00	1.02	0.98	7.30
		3	35.51	0.96	1.00	1.01	0.97	7.47	36.01	0.96	1.00	1.01	0.97	7.46	37.03	0.96	1.00	1.01	0.97	7.45
	50	1	84.16	0.83	1.00	1.34	0.97	0.85	84.75	0.83	1.00	1.34	0.98	0.85	85.94	0.82	1.00	1.34	0.99	0.85
		2	85.21	0.82	1.00	1.34	0.97	0.89	85.80	0.82	1.00	1.34	0.98	0.89	86.99	0.82	1.00	1.34	0.99	0.89
		3	86.33	0.82	1.00	1.34	0.97	0.95	86.92	0.82	1.00	1.33	0.98	0.95	88.11	0.82	1.00	1.33	0.99	0.95

Table C-35a: Adjusted Nominal Resistance Factors for Carbon Steel and γ_A=1.1, γ_{PS}=1.0, γ_L=1.3, γ_S=1.5 for g_{19}

		β=2.5	Carbon Steel														
			f_L=0.5					f_L=1.0					f_L=2.0				
		f_S	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F	R.T.	200°F	400°F	600°F	800°F
f_{PS}	0.5	1	0.78	0.71	0.78	0.73	0.59	0.85	0.78	0.85	0.80	0.64	0.96	0.88	0.96	0.90	0.72
		2	0.67	0.61	0.67	0.63	0.51	0.72	0.66	0.72	0.68	0.54	0.80	0.73	0.81	0.76	0.61
		3	0.63	0.57	0.63	0.59	0.47	0.66	0.60	0.66	0.62	0.50	0.73	0.66	0.73	0.69	0.55
	1	1	0.81	0.74	0.81	0.76	0.61	0.87	0.80	0.87	0.82	0.66	0.97	0.89	0.97	0.92	0.73
		2	0.69	0.63	0.70	0.66	0.52	0.74	0.67	0.74	0.70	0.56	0.82	0.75	0.82	0.77	0.62
		3	0.64	0.59	0.65	0.61	0.49	0.68	0.62	0.68	0.64	0.51	0.74	0.68	0.74	0.70	0.56
	3	1	0.89	0.81	0.89	0.84	0.67	0.94	0.86	0.93	0.88	0.70	1.01	0.93	1.01	0.95	0.76
		2	0.77	0.70	0.77	0.72	0.58	0.80	0.73	0.81	0.76	0.61	0.87	0.79	0.87	0.82	0.65
		3	0.71	0.64	0.71	0.67	0.53	0.73	0.67	0.74	0.69	0.55	0.79	0.72	0.79	0.74	0.59
	5	1	0.94	0.86	0.93	0.88	0.70	0.98	0.89	0.97	0.91	0.73	1.04	0.95	1.02	0.96	0.77
		2	0.82	0.75	0.82	0.77	0.62	0.85	0.78	0.85	0.80	0.64	0.91	0.83	0.90	0.85	0.68
		3	0.76	0.69	0.76	0.71	0.57	0.78	0.71	0.78	0.73	0.59	0.83	0.75	0.83	0.78	0.62
	10	1	0.98	0.90	0.94	0.89	0.71	1.01	0.92	0.96	0.90	0.72	1.04	0.95	0.99	0.93	0.75
		2	0.91	0.83	0.90	0.85	0.68	0.93	0.85	0.92	0.87	0.69	0.96	0.88	0.96	0.90	0.72
		3	0.84	0.77	0.84	0.79	0.63	0.86	0.78	0.86	0.81	0.65	0.89	0.82	0.89	0.84	0.67
	50	1	0.88	0.81	0.85	0.80	0.64	0.89	0.81	0.86	0.80	0.64	0.90	0.82	0.87	0.81	0.65
		2	0.90	0.83	0.87	0.82	0.65	0.91	0.83	0.87	0.82	0.66	0.92	0.84	0.88	0.83	0.67
		3	0.92	0.84	0.89	0.83	0.67	0.93	0.85	0.89	0.84	0.67	0.94	0.86	0.90	0.85	0.68

Table C-35a: (Continued) Considered Load Factors γ_A=1.1, γ_{PS}=1.2, γ_L=1.3, γ_S=1.5

			Carbon Steel														
		β=3.0	f_L=0.5					f_L=1.0					f_L=2.0				
		f_S	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
f_{PS}	0.5	1	0.53	0.48	0.53	0.50	0.40	0.59	0.54	0.59	0.56	.44	0.69	0.63	0.69	0.65	0.52
		2	0.43	0.39	0.43	0.40	0.32	0.46	0.42	0.46	0.44	0.35	0.53	0.49	0.53	0.50	0.40
		3	0.39	0.35	0.39	0.36	0.29	0.41	0.38	0.41	0.39	0.31	0.46	0.42	0.47	0.44	0.35
	1	1	0.57	0.52	0.58	0.54	0.43	0.63	0.59	0.63	0.59	0.47	0.72	0.66	0.73	0.68	0.55
		2	0.45	0.41	0.46	0.43	0.34	0.49	0.45	0.49	0.46	0.37	0.55	0.51	0.56	0.53	0.42
		3	0.41	0.37	0.41	0.38	0.31	0.43	0.39	0.43	0.41	0.33	0.48	0.44	0.48	0.45	0.36
	3	1	0.71	0.65	0.72	0.67	0.54	0.76	0.69	0.76	0.71	0.57	0.83	0.76	0.83	0.78	0.62
		2	0.55	0.50	0.56	0.52	0.42	0.58	0.53	0.58	0.55	0.44	0.64	0.58	0.64	0.60	0.48
		3	0.48	0.44	0.48	0.45	0.36	0.50	0.46	0.51	0.48	0..38	0.55	0.50	0.55	0.52	0.41
	5	1	0.81	0.74	0.81	0.76	0.61	0.85	0.77	0.84	0.79	0.64	0.90	0.82	0.90	0.85	0.68
		2	0.63	0.58	0.64	0.60	0.48	0.66	0.60	0.66	0.62	0.50	0.71	0.64	0.71	0.66	0.53
		3	0.55	0.50	0.55	0.52	0.41	0.57	0.52	0.57	0.53	0.43	0.66	0.55	0.61	0.57	0.46
	10	1	0.96	0.88	1.00	0.94	0.75	0.98	0.90	1.02	0.96	0.76	1.02	0.93	1.04	0.98	0.78
		2	0.78	0.71	0.78	0.73	0.59	0.80	0.73	0.80	0.75	0.60	0.83	0.76	0.83	0.78	0.62
		3	0.67	0.62	0.68	0.63	0.51	0.69	0.63	0.69	0.65	0.52	0.72	0.66	0.72	0.68	0.54
	50	1	0.98	0.81	0.93	0.88	0.70	0.98	0.90	0.94	0.88	0.70	0.99	0.91	0.94	0.89	0.71
		2	1.00	0.91	0.95	0.89	0.71	1.0	0.91	0.95	0.89	0.72	1.01	0.92	0.96	0.90	0.72
		3	1.01	0.92	0.96	0.91	0.72	1.02	0.93	0.97	0.91	0.73	1.02	0.94	0.97	0.92	0.73

Table C-35a: Adjusted Nominal Resistance Factors for Stainless Steel and γ_A=1.1, γ_{PS}=1.0, γ_L=1.3, γ_S=1.5 for g_{19}

		β=2.5	Stainless Steel														
			f_L=0.5					f_L=1.0					f_L=2.0				
		f_S	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
f_{PS}	0.5	1	0.76	0.66	0.60	0.60	0.58	0.83	0.72	0.65	0.65	0.63	0.94	0.82	0.74	0.74	0.71
		2	0.6	0.57	0.51	0.51	0.50	0.71	0.61	0.55	0.55	0.53	0.79	0.68	0.61	0.61	0.59
		3	0.61	0.53	0.48	0.48	0.46	0.65	0.56	0.51	0.51	0.49	0.71	0.62	0.56	0.56	0.54
	1	1	0.79	0.69	0.62	0.62	0.60	0.86	0.74	0.67	0.67	0.64	0.96	0.83	0.75	0.75	0.72
		2	0.68	0.59	0.53	0.53	0.51	0.73	0.63	0.57	0.57	0.55	0.80	0.70	0.63	0.63	0.60
		3	0.63	0.55	0.49	0.49	0.48	0.67	0.58	0.52	0.52	0.50	0.73	0.63	0.57	0.57	0.55
	3	1	0.88	0.76	0.68	0.68	0.66	0.92	0.80	0.72	0.72	0.69	1.00	0.86	0.78	0.78	0.74
		2	0.76	0.66	0.59	0.59	0.57	0.79	0.69	0.62	0.62	0.59	0.85	0.74	0.66	0.66	0.64
		3	0.69	0.60	0.54	0.54	0.52	0.72	0.63	0.56	0.56	0.54	0.77	0.67	0.60	0.60	0.58
	5	1	0.92	0.80	0.72	0.72	0.70	0.96		0.75	0.75	0.72	1.02	0.88	0.79	0.79	0.77
		2	0.81	0.70	0.63	0.63	0.61	0.84	0.83	0.65	0.65	0.63	0.89	0.77	0.69	0.69	0.67
		3	0.74	0.64	0.58	0.58	0.56	0.77	0.73	0.60	0.60	0.58	0.81	0.70	0.63	0.63	0.61
	10	1	0.97	0.84	0.75	0.75	0.73	0.99	0.66	0.77	0.77	0.74	1.02	0.89	0.80	0.80	0.77
		2	0.89	0.77	0.69	0.69	0.67	0.91	0.86	0.71	0.71	0.68	0.95	0.82	0.74	0.74	0.71
		3	0.83	0.72	0.64	0.64	0.62	0.84	0.79	0.66	0.66	0.63	0.88	0.76	0.68	0.68	0.66
	50	1	0.87	0.75	0.68	0.68	0.65	0.87	0.73	0.68	0.68	0.66	0.89	0.77	0.69	0.69	0.67
		2	0.89	0.77	0.69	0.69	0.67	0.89	0.76	0.70	0.70	0.67	0.90	0.78	0.70	0.70	0.68
		3	0.91	0.79	0.71	0.71	0.68	0.91	0.78	0.71	0.71	0.69	0.92	0.80	0.72	0.72	0.69

Table C-35b: (Continued) Considered Load Factors γ_A=1.1, γ_{PS}=1.2, γ_L=1.3, γ_S=1.5

		β=3.0	Stainless Steel														
			f_L=0.5					f_L=1.0					f_L=2.0				
		f_S	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F	R.T.	200°F	400 °F	600 °F	800 °F
f_{PS}	0.5	1	0.52	0.45	0.40	0.40	0.39	0.58	0.50	0.45	0.45	0.44	0.68	0.59	0.53	0.53	0.51
		2	0.42	0.36	0.33	0.33	0.31	0.45	0.39	0.35	0.35	0.34	0.52	0.45	0.41	0.41	0..39
		3	0.38	0.33	0.30	0.30	0.29	0.41	0.35	0.32	0.32	0.30	0.45	0.39	0.35	0.35	0.34
	1	1	0.56	0.49	0.44	0.44	0.42	0.62	0.54	0.48	0.48	0.46	0.71	0.62	0.55	0.55	0.54
		2	0.45	0.39	0.35	0.35	0.34	0.48	0.42	0.37	0.37	0.36	0.55	0.47	0.42	0.42	0.41
		3	0.40	0.35	0.31	0.31	0.30	0.42	0.37	0.33	0.33	0.32	0.47	0.41	0.37	0.37	0.36
	3	1	0.70	0.61	0.55	0.55	0.53	0.74	0.64	0.58	0.58	0.56	0.81	0.71	0.63	0.63	0.61
		2	0.54	0.47	0.42	0.42	0.41	0.57	0.50	0.45	0.45	0.43	0.63	0.54	0.49	0.49	0.47
		3	0.47	0.41	0.37	0.37	0.36	0.50	0.43	0.39	0.39	0.37	0.54	0.47	0.42	0.42	0.40
	5	1	0.80	0.69	0.62	0.62	0.60	0.83	0.72	0.65	0.65	0.63	0.89	0.77	0.69	0.69	0.67
		2	0.62	0.54	0.48	0.48	0.47	0.65	0.56	0.50	0.50	0.49	0.69	0.60	0.54	0.54	0.52
		3	0.54	0.47	0.42	0.42	0.40	0.56	0.48	0.43	0.43	0.42	0.59	0.52	0.46	0.46	0.45
	10	1	0.95	0.82	0.74	0.74	0.71	0.97	0.84	0.75	0.75	0.73	1.00	0.87	0.78	0.78	0.75
		2	0.77	0.67	0.60	0.60	0.58	0.78	0.68	0.61	0.61	0.59	0.82	0.71	0.64	0.64	0.61
		3	0.66	0.57	0.52	0.52	0.50	0.68	0.59	0.53	0.53	0.51	0.71	0.61	0.55	0.55	0.53
	50	1	0.96	0.83	0.75	0.75	0.72	0.97	0.84	0.75	0.75	0.73	0.98	0.85	0.76	0.76	0.73
		2	0.98	0.85	0.76	0.76	0.74	0.98	0.85	0.77	0.77	0.74	0.99	0.86	0.77	0.77	0.75
		3	0.99	0.86	0.77	0.77	0.75	1.00	0.87	0.78	0.78	0.75	1.01	0.87	0.78	0.78	0.76

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