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EXTERNAL REFERENCE

How To

Allowable values and limits in service level C and D for ITER mechanical components

This document provides guidelines for the definition of the allowable or limit values for load conditions and load combinations for which service level C and D are applied.

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Allowable values and limits in service level C and D for ITER mechanical components (3G3SYJ_v3_1)	v3.1	Approved	16 Nov 2012	Changes with respect to version 2.0: Specific limits for pipes have been defined. Chapters have been reorganised. Appendix B has been added with comparison of allowable values increases from level A to level C and D in the most used nuclear codes. Details changes in track change mode from last approved version 2.0 can be seen in the word version stored in attachment.
Allowable values and limits in service level C and D for ITER mechanical components (3G3SYJ_v3_0)	v3.0	Signed	16 Nov 2012	Specific limits for pipes have been defined. Chapters have been reorganised. Appendix B has been added with comparison of allowable values increases from level A to level C and D in the most used nuclear codes.
Allowable values and limits in service level C and D for ITER mechanical components (3G3SYJ_v2_0)	v2.0	Approved	02 Dec 2010	Records of Revision: Version No. Date Descriptions 1.0 2.0 Implemented comments from C&S Expert 3 Allowable values and limits in service level C and D for ITER components GB LV

				Table 1 modified to include definition of SIC1 and SIC2 following comments from safety division Table 3 included with list of analysis methods and failure modes Section 3: more specification on limits for membrane + bending primary equivalent stress Table 4 included with summary of limits Rules for protection against local failure have been added (section 4)

				Limit to prevent progressive deformation and fatigue failures included for level D Rules to prevent bolt failure for service level D have been included Section 9 for serviceability limits has been included Appendix A included with an example of application for ASME VIII Div. 2
Allowable values and limits in service level C and D for ITER mechanical components (3G3SYJ_v1_0)	v1.0	Disapproved	23 Jul 2010	

Table of Content

1 Introduction

The ITER loading conditions [1] are categorized, into four categories based on the expectation of occurrence:

Category I: Operational Loading Conditions
Category II: Likely Loading Conditions
Category III: Unlikely Loading Conditions
Category IV: Extremely Unlikely Loading Conditions

The acceptable damage limits are then established for each Loading Condition Category (e.g., Normal, Upset, Emergency, or Faulted) and for each system/component based on the safety importance and project investment protection.
This is summarised in the following table [1].

Table 1: Damage Limits for Loading Condition Categories

<table>
<tr><td colspan="2">Loading Category / Event</td><td>Category I: Operational/ Design Loading</td><td>Category II: Likely Loading</td><td>Category III: Unlikely Loading</td><td>Category IV: Extremely Unlikely Loading</td><td>Test Loading</td></tr>
<tr><td colspan="2">Plant Level</td><td>Normal</td><td>Normal</td><td>Emergency</td><td>Faulted</td><td>Normal/test</td></tr>
<tr><td rowspan="3">Component</td><td>SIC-1</td><td>Normal</td><td>Normal (4)</td><td>Emergency (3)</td><td>Faulted (1),(3)</td><td>Normal/test</td></tr>
<tr><td>SIC-2 (5)</td><td>Normal</td><td>Normal (4)</td><td>Emergency (3)</td><td>Faulted (3)</td><td>Normal/test</td></tr>
<tr><td>Not-SIC</td><td>Normal</td><td>Upset (3)</td><td>Emergency (2) (3)</td><td>Faulted (2) (3)</td><td>Normal/test</td></tr>
<tr><td colspan="7">Notes
(1) Faulted for passive components with no deformation limits. Emergency for active SIC-1 components and some passive components in which general deformations should be limited.
(2) Events don’t need to be considered from the safety point of view, but only for investment protection if required.
(3) Damage limits can be made more stringent either for investment protection reasons or to reduce delay/cost of post incident inspections. Design limit is Normal for some SIC-1 active and some passive components which are required to function following Category III and IV accident (e.g. fire dampers and detritiation system)
(4) Normal damage limits are assumed to have a robust design for SIC components not only for category I event, but also for category II.
(5) Case by case considerations (this system is not credited for bringing the plant into a safe status)</td></tr>
</table>

The structural service criteria (allowable or limit values) for each damage limit (e.g., ASME Levels A, B, C, and D, RCC-M Levels A, C, and D) are established and associated to each damage limit.
As specified in [1] Structural Service Criteria (or Criteria Levels) are aimed at preventing a specific degree of damage to the component in question. Four distinct Service Criteria levels are given: A, B, C, and D, with the general objectives defined below with the correspondence between the damage limit and the structural service criteria.

As a general strategy for loads associated to events in category I and II the criteria level A is applied. For loads associated to events in category III and IV the criteria levels C and D are applied respectively. This basic strategy can be modified for reasons related to special safety requirements or for ITER capital investment protections.

Table 2: Damage limit, Structural Service criteria and general objectives of criteria.

Damage limit	Structural Service Criteria	**General objective**
Normal	A	Negligible damage. All structures, systems, and components are functional
Upset	A or B	Negligible damage. All structures, systems, and components are functional. Anticipated maintenance and minor adjustment might be required. Same service level as for Criteria Level A but with lower margin.
Emergency	C	May be significant local distortion. Inspections may be required. Call for repair or replacement of faulty components
Faulted	D	May be large general distortion and investment loss. Repair may not be considered economic. Minimum safety functions shall be maintained.

The structural service criteria are defined in the design code selected for the component.
Some codes (i.e. ASME VIII, EN13445, B31.3, etc.) which have been selected for ITER mechanical components do not define structural service criteria for emergency or faulted conditions. In general they define allowable values for normal, test and exceptional events.
ITER documents (System Load Specification documents of each single system or sub-system) shall define on a case by case basis the association of the of load category with the criteria level.

2 Aim and scope

This document provides guideline to define the allowable limits for structural service criteria level C and D in case the selected design code does not provide any indication.

In most of the codes rules are provided for the determination of the ultimate limit state. Ultimate limit state is a structural condition (of the component or vessel) associated with burst or collapse, or with other forms of structural failure. In the present case of service level C and D, these include failure by gross plastic deformation and plastic collapse local failure, collapse caused by instability, and leakage which affects safety, and any other state prior to collapse which, for simplicity, is considered in the place of the collapse itself.

Rules are not here provided for serviceability limit state. Serviceability limit state is a structural condition beyond which the service criteria specified for the component are no longer met. Serviceability limit states include deformation or deflection which adversely affects the use of the System, Structure or Component (SSC) (including the proper functioning of machines or services), or causes damage to structural or non-structural elements. These criteria, if they exist, for any Structural Service Level have to be specified by the user or owner of the component. These limits must also appear in the “Instructions for Use” or equivalent document provided by the Manufacturer.
Examples of components or component assemblies where serviceability limits may be required are:

- Flange assembly to limit leakage
- Piping connection
- Alignment of trays, platforms, and other internal or external appurtenances
- Interference between adjacent equipment

Rules of paragraph 2 apply to base metal and welded joints.

The rules in this document are applicable in case the SSC is not exposed to:

- Creep
- Corrosion/erosion

Chapter 3 provides general rules applied to all structures except for bolts and pipes. Bolts and pipe criteria are specified in chapters 4 and 5 respectively.

3 General limit criteria for structures other than pipes and bolts

Table 3 provides a summary of the types of failure modes, the types of analysis methods and the paragraphs where criteria are defined.

Table 3: Analysis methods applied for protection against different failure modes.

	LINEAR (ELASTIC) ANALYSIS METHOD	LIMIT ANALYSIS METHOD	ELASTIC PLASTIC ANALYSIS METHOD
Protection against excessive deformation or plastic collapse	Yes See § 3.1.1	Yes See § 3.1.2	Yes See § 3.1.2
Protection against local failure	Yes See § 3.2.1	No See § 3.2.2	Yes See § 3.2.2
Protection against collapse from buckling	Yes See § 3.3	Yes See § 3.3	See § 3.3
Serviceability limits provided by the User in the Design Specifications	No (*)	No	Yes See § 6
Yes means that the method can be used No means that the method cannot be used (*) Linear analysis results can be used if it is demonstrated that the structure response is always linear. In case of small non linearity, correction factors from linear analysis may be used to evaluate effective response.			

3.1 Limits to prevent excessive deformation or plastic collapse

For service level C rules for exceptional events may be used if the basic code defines them. In alternative the following rules for elastic and non-linear analyses shall be used.

3.1.1 Elastic analyses

The rules to prevent excessive deformations or plastic collapse applied to analysis results based on elastic analysis consist on limits on the General Primary Membrane Equivalent Stress (P_m), on the Local Primary Membrane Equivalent Stress (P_L), and on the Primary Membrane (General or Local) Plus Primary Bending Equivalent Stress (P_m+P_b).[1]

[1] Precautions have to be taken when using the elastic analysis method in cases where the stress classification is not easy or ambiguous, in particular for thick components. In these cases the use of non-linear analysis is recommended as alternative to the elastic analysis.

The definition of these types of stresses is included in the reference base code (i.e EN13445 Appendix C).
The limts for service level A are increased:

- for service level C by a factor 1.2.
- for service level D by a factor 2.

For service level D the allowable value for membrane cannot exceed 0.7 Su where Su is the minimum ultimate stress. The allowable value for membrane plus bending stress shall not exceed 0.7 k Su where k is the section factor that takes into account the bending stress redistribution as maximum stress reaches yield value. This factor is equal to 1.5 for shell or rectangular sections. If this stress redistribution is not allowed (i.e. non ductile material) the limit for membrane plus bending and for local primary membrane equivalent stress is equal to 0.9 Su.

NOTE: following PED Annex 1 Chapter 7 a material is defined ductile if elongation at rupture is larger than 14%.

Table 4: Acceptance criteria for service levels C and D using elastic analysis

Acceptance criteria	Service level C	Service level D
General primary membrane equivalent stress	$P_{\mathrm{m}} \leq 1{,}2 \cdot S$	$P_{\mathrm{m}} \leq 2 \cdot S$ Cannot exceed $0{,}7 \cdot S_{\mathrm{u}}$
Local primary membrane equivalent stress	$P_{\mathrm{L}} \leq 1{,}8 \cdot S$	$P_{\mathrm{L}} \leq 3 \cdot S$ If material is not ductile cannot exceed $0{,}9 \cdot S_{\mathrm{u}}$
Primary membrane (General or Local) plus bending equivalent stress	$(P_{\mathrm{m}} \text{ or } P_{\mathrm{L}}) + P_{\mathrm{b}} \leq 1{,}2 * k \cdot S$	$(P_{\mathrm{m}} \text{ or } P_{\mathrm{L}}) + P_{\mathrm{b}} \leq 2 * k \cdot S$ If material is not ductile cannot exceed $0{,}9 \cdot S_{\mathrm{u}}$

Where
S is the nominal design stress or stress allowable for service level A
S_{u} is the ultimate tensile strength

3.1.2 Non linear analyses

3.1.2.1 Limit and Elastic-plastic analyses

Limit analysis and elastic-plastic analysis methods can be used to verify that loads do not generate stresses that exceed the limits to primary membrane and primary membrane + bending stresses. This is particularly useful in geometries and type of loads when the stress linearization procedure to estimate the primary membrane and bending stresses used in elastic analysis methods is difficult, not applicable or not reliable.

Procedures for limit and elastic-plastic analyses are described in several codes. It is here assumed that the analysis has been performed following the procedures described in:

- ASME VIII Div 2 procedure described in par 5.2.3 and 5.2.4 in code version 2007 or
- RCC-MR RB 3228 and 3251 in code version 2007 or
- EN13445-3:2009 Annex B.

If a different procedure is used the increase factors for the allowable limits defined below have to be corrected to guarantee that the same structural safety margins are maintained.

These codes define the methods to calculate the collapse loads (limit or elastic-plastic).

The allowable limit or plastic collapse load of service level A is increased by the factors:

- 1.2 for service level C
- 2.0 for service level D.

For service level D the allowable collapse load cannot be larger than 0.7 times the calculated collapse load.

3.2 Protection against local failure

These rules apply if the selected base code (i.e. ASME VIII Div.2 - Part 5.3) includes requirements for protection again local failure in normal condition (service level A).
In addition to demonstrating protection against excessive deformation or plastic collapse, the applicable local failure criteria below shall be satisfied at each point of the structure.
These requirements apply to all components where the thickness and configuration of the component is established using Design-By-Analysis (DBA) rules.
The strain limit criterion does not need to be checked if the component is in accordance with the basic design rules of the construction code regarding thicknesses and welds.

3.2.1 Elastic analysis

The sum of the local primary membrane plus bending principal stresses shall verify:

$$(\sigma_1 + \sigma_2 + \sigma_3) \leq 4.8\ S \quad \text{for service level C and D}$$

Where σ_i is the local primary membrane plus bending principal stress in direction i.

3.2.2 Elastic Plastic analysis

For service level C, the strain determined by elastic plastic analysis shall be less than 1.2 times the strain limit for service level A.
For service level D the strain determined by elastic plastic analysis shall be less than 2 times the strain limit for service level A and shall not exceed 0.5 the minimum elongation at failure of the material.

3.3 Limit to prevent buckling

The allowable buckling load defined for normal operation condition (service level A) is increased by the factors:

- 1.2 for service level C

For service level D the most severe limit is applied among the following:

- The allowable buckling load defined for normal operation condition is increased by a factors 2.0
- Margin to failure is larger than 1/0.7

These factors are applied either to limits defined for elastic and non-linear analyses.

3.4 Limit to prevent progressive deformations

Loads in service level C and D do not need to be verified against progressive deformation (ratchetting).
Loads that are expected to be applied repetitively to a structure and generate cyclic stresses (or loads) that produce progressive deformations cannot be classified in the service level C or D.

3.5 Limit to prevent fatigue

Loads in service level C and D do not need to be verified against fatigue.
Loads that are expected to be applied repetitively to a structure and generate cyclic stresses (or loads) that produce non negligible fatigue damages cannot be classified in the service level C or D.

4 Rules to prevent bolts failure

For service level C the same allowable limit as for normal operation shall be applied to bolts and threads.
For service level D:

- the maximum primary membrane stress calculated by linear elastic analysis shall be limited by the minimum between Sy(T) and 0.7 Su (T) where Sy(T) and Su (T) are the minimum yield and ultimate stresses at the maximum temperature during the event under consideration.
- In case of preloaded bolted assemblies having the safety function of maintaining leak tightness the maximum primary plus secondary membrane stress shall not exceed Sy(T) in order to avoid leak.
- In case of preloaded bolted assemblies where the shear load are taken by friction the preload shall be enough to avoid sliding and the maximum primary plus secondary membrane stress shall not exceed Sy(T).
- the maximum primary plus secondary stress intensity at the periphery of the bolt cross section (neglecting stress concentration) calculated by linear elastic analysis due to all loads shall not exceed Su(T).
- the value of the average shear stress τ_{th} in the threads of the bolt or nut (part) and the average shear stress τ_h in the head of the bolt calculated by linear elastic analysis due to all loads shall not exceed the minimum between 0.6 Sy(T) and 0.42 Su(T).

For service level C and D fatigue and progressive deformation verifications are not needed.

5 Rules to prevent pipes failure

5.1 Limits to prevent excessive deformation or plastic collapse

5.1.1 Elastic analysis

The rules to prevent excessive deformations or plastic collapse applied to analysis results based on elastic analysis consist on limits on the maximum allowed pressure and the maximum stress due to primary loads (pressure and bending moments).
In the load conditions for which the service level C is applied, the maximum stress in a pipe caused by all primary actions on the pipe shall not exceed the allowable defined for normal condition as specified by the basic code multiplied by a factor 1.5. This limit stress value shall not exceed 1.8 S_y. S_y value corresponds to the minimum yield stress value at temperature consistent with the loading under consideration.
In the load conditions for which the service level D is applied, the maximum stress in a pipe caused by all primary actions on the pipe shall not exceed the allowable defined for normal condition as specified by the basic code multiplied by a factor 2.0. This limit stress value shall not exceed 2.0 S_y. S_y value corresponds to the minimum yield stress value at temperature consistent with the loading under consideration.
Appendix B reports a summary of the factors to be applied to the limit values for normal condition to get the limit values associated to service level C and D and the comparison with specifications in some nuclear codes.

Limits associated to anchor motions and thermal expansions in conditions for which service level C and D are applied, shall be limited following the general practise applied in nuclear field. Anchor motion and thermal expansions in service level C and D can generate large displacements but are compensated by the use of material with adequate ductility. If this is the case, in service level D the amplitude of the membrane stress from the axial force and the range of the membrane plus bending stresses are limited by S_{all} and $6*S_{all}$ respectively, where S_{all} is the allowable value specified for normal condition or service level A (corresponding to S_h for B31.3). In service level C these limits correspond to 70% of the allowable for level D.
It must be verified that elastic follow up does not cause excessive strain concentrated at specific locations.
This occurs in unbalanced systems where only a small portion of the piping undergoes plastic strain. In these cases, the weaker or higher stressed portions will be subjected to strain concentrations due to elastic follow-up of the stiffer or lower stressed portions. Unbalance can be produced

(a) by the use of small pipe runs in series with larger or stiffer pipe, with the small lines relatively highly stressed;
(b) by local reduction in size or cross section, or local use of a weaker material.

In the case of unbalanced systems, the design shall be modified to eliminate the unbalance or the piping secondary membrane plus bending stress range shall be limited by a stress value equal to 3 S_{all} instead of 6 S_{all}.

5.1.2 Plastic analyis

If plastic analysis is allowed by the basic code, for service level C and D the allowable values are increased by the same factors as specified for elastic analysis.

5.2 Limit to prevent buckling

Limit to prevent buckling in pipe for conditions in service level C and D shall follow the same principle defined in chapter 3.3. Alternative approach can be proposed if justified by use in other nuclear codes.

5.3 Limit to prevent fatigue and progressive deformation

For service level C and D fatigue and progressive deformation verifications are not needed.
Loads that are expected to be applied repetitively to a structure and generate cyclic stresses (or loads) that produce non negligible fatigue damages or generate progressive deformations cannot be classified in the service level C or D.

6 Serviceability limits

Serviceability limits (typically maximum deflections or relative displacements) are defined by the Design Specification.
Serviceability limits for service level C and D, mentioned in paragraph 2, shall be checked by elastic-plastic analyses.
Strains and displacements obtained by limit analysis have no physical meaning,
Linear analysis results can be used if it is demonstrated that the structure response is always linear

7 References

[1] Load Specifications (LS) *(ITER_D_222QGL)*

Appendix A: Example of application for ASME VIII Div 2 – Design by analysis.

A.1 Introduction.

ASME VIII Div.2 defines the following types of loads

- pressure testing
- normal operation loads (dead weight, pressure, live loads, thermal loads, applied displacement etc.)
- occasional loads (typically wind, earthquake, snow)
- abnormal or start-up loads (typically include pressure increase due to abnormal conditions or transients)

ASME VIII Div. 2 in the part related to design by analysis (chapter 5) defines different approaches for linear elastic, limit and elasto-plastic analyses.

ASME VIII Div.2 uses the definition of factored load in load case combinations. It means that each single load is multiplied by specific factors. These factors account for deviations of actual load from the nominal load, for uncertainties in the analysis, and for the probability that more than one load will occur simultaneously. By doing this allowable stress is not increased for occasional loads or for load combinations with low probability.
These factors and load combinations are defined in table 5.3, 5.4, and 5.5 of ASME VIII Div. 2 part 5 for elastic, limit load, and elasto-plastic analyses (see table A.2 of this appendix).
When using these tables the following two major problems are encountered:

1) the seismic event considered by ASME (typically defined considering a return period of ~500 years) does not corresponds to either SL-1(return period of ~100 years), SMHV or SL-2 (return period of more than 1000 years).
2) Electromagnetic loads on conductors in the foreseen plasma equilibrium scenario are not mentioned.
3) Electromagnetic loads in plasma and magnet transient events inducing currents in conductive structure are not mentioned.

For the definition of load factors in the load combinations, for their dynamic nature and considering that are not permanently applied, SL-1 and electromagnetic loads due to plasma and magnet transient events in category 1 and II (MDI, MDII, VDE II, MFD I, MFD II) [1] are treated in the same way as live loads, while electromagnetic loads on conductors in plasma equilibrium scenarios that are permanently applied during operation are treated in the same way as operating pressure loads.

Wind load (*W*) is normally not a major design condition for ITER SSCs and for this reason it is not listed here in the load combinations. In case wind load is a relevant load condition it will be considered following ASME VIII Div.2 guidelines.

A.2 Definitions

In this appendix the following definitions are used as shown in the next table.

Table A.1 Definitions (*)

Symbol	Description
P	Internal and external maximum allowable pressure (including static head pressure

	from liquid or other bulk materials). Following ASME VIII Div.2 definition this value is defined based on the maximum gage pressure permissible at the top of a completed vessel in its normal operating position at the designated coincident temperature for that pressure. The maximum gage pressure is defined based on pressure values occurring in events classified in categories I and II.
D	Dead weight
P_{op}	Operating pressure (used in load case combinations).
SL-1	Seismic load level 1
SL-2	Seismic load level 2
EM_I	Includes all electromagnetic loads that are in categories I as MD I and MFD I
EM_{II}	Includes all electromagnetic loads that are in categories II as MD II, VDE_{TM}, and MFD II
EM_{III}	Includes all electromagnetic loads that are in categories III as MD III and VDE_{WC}
EM_{IV}	Includes all electromagnetic loads that are in categories IV as MD IV and VDE_{IV}
P_{III}	Maximum internal or external pressure defined for events in category III.
P_{IV}	Maximum internal or external pressure defined for events in category IV.

(*) for definition of seismic loads SL-1, SL-2 and for Electromagnetic loads MDs, VDEs and MFD see [1])

A.3 Protection against plastic collapse

A.3.1 Elastic analysis method

For elastic analysis method the allowable stress is not modified in any load case combination, but load factors are applied as mentioned in previous paragraph.

To evaluate protection against plastic collapse using the elastic analysis methods, calculated stresses are classified into categories and linearised following the procedures and guidelines defined in ASME VIII Div.2. These stresses are than compared to the following allowable values below:

$$P_m \leq S$$
$$P_l \leq 1.5\,S$$
$$P_m + P_b \leq 1.5S$$

Load-cases required to be considered (based on ASME VIII, Div. 2, Part 5, Table 5.3):

Service level A (Typically used for Category I and II events):

1) P + D
2) P_{op} + D + EM_I (or EM_{II})
3) P_{op} + D + SL-1 + MD I
4) P_{op} +D + SL-1 + MFD I (or II)

Service level C (Typically used for Category III events):

5) $\alpha_{III} \cdot (P_{III} + D)$
6) $\alpha_{III} \cdot (P_{op}$ + D + SL-1 + $EM_{II})$
7) $\alpha_{III} \cdot (P_{op}$ + D + $EM_{III})$
8) $\alpha_{III} \cdot (P_{op}$ + D + SMHV + MFD I (or II))

Service level D (typically used for Category IV events):

9) $\alpha_{IV} \cdot (P_{IV} + D)$
10) $\alpha_{IV} \cdot (P_{op} + D + EM_{IV})$
11) $\alpha_{IV} \cdot (P_{op} + D + SL\text{-}2)$
12) $\alpha_{IV} \cdot (P_{op} + D + SL\text{-}1 + MD\ III)$

In case dead weight (D) is beneficial it shall be multiplied by a factor 0.9 in all category combinations.

No thermal loads need to be considered in the verification against plastic collapse.

As ASME VIII Div. 2 does not define a clear strategy on the increase of the allowable value for exceptional loads as those in ITER category III, an increase of the allowable value by a factor 1.2 is assumed. This is equivalent to assume a reduction factor α_{III} on load equal to 0.83.

The definition of the α_{IV} factor is more complicated as the following conditions have to be respected:

- allowable limits are increased by a factor 2.
- the allowable value for membrane cannot exceed the 0.7 Su.
- the allowable value for membrane plus bending stress shall not exceed 0.7 k Su (0.9 Su for non ductile material)

Following these specifications the α_{IV} value is the largest between

- 0.5
- Sm/(Su*0.7)
- 1.5 Sm/(Su*0.9) (this applies if material has low ductility and if membrane+bending stress is the limiting stress).

A.3.2 Limit load analysis

To evaluate protection against plastic collapse using the limit load analysis methods, material stress –strain curve an elastic perfectly plastic material property has to be defined following rules defined in ASME VIII Div.2. The concept of Load and Resistance Factor Design (LRFD) is used as an alternative to the rigorous computation of a plastic collapse load to design a component. In this procedure, factored loads that include a design factor to account for uncertainty, and the resistance of the component to these factored loads is determined using a limit load analysis. The load case combinations as shown next shall be used in the analysis. Each of the indicated load cases shall be evaluated unless an equivalent elastic analysis or a plastic analysis is performed.

If convergence is achieved, the component is stable under the applied loads for this load case.

Load-cases required to be considered (based on ASME VIII, Div. 2, Part 5, Table 5.4):

<u>Service level A (Typically used for Category I and II events):</u>

1) $1.5\cdot(P+D)$
2) $1.5\cdot(P_{op}+D+EM_I \text{ (or } EM_{II}))$ or[2] $1.3\cdot(P_{op}+D)+1.7\cdot EM_I \text{ (or } EM_{II})$

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[2] Selection of load factors in the load combinations depends if EM or seismic loads are treated as operational loads (combination on the left) or live loads (combination on the right). In case of missing of a clear definition, the worst factored load combination shall be considered or all factored load combination.

3) $1.5\cdot(P_{op}+D+SL\text{-}1+MD\ I)$ or[2] $1.3\cdot(P_{op}+D)+1.7\cdot(SL\text{-}1+MD\ I)$
4) $1.5\cdot(P_{op}+D+SL\text{-}1+MFD\ I\ (or\ II))$ or[2] $1.3\cdot (P_{op}+D)+1.7\cdot(SL\text{-}1+MFD\ I\ (or\ II))$

Service level C (Typically used for Category III events):

5) $1.25\cdot(P_{III}+D)$
6) $1.25\cdot(P_{op}+D+SL\text{-}1+EM_{II})$ or[2] $1.08\cdot(P_{op}+D)+1.42\cdot(SL\text{-}1+EM_{II})$
7) $1.25\cdot(P_{op}+D+EM_{III})$ or[2] $1.08\cdot(P_{op}+D)+1.42\cdot EM_{III}$
8) $1.25\cdot(P_{op}+D+SMHV+MFD\ I\ (or\ II))$ or[2] $1.08\cdot(P_{op}+D)+1.42\cdot (SMHV+ MFD\ I\ (or\ II))$

Service level D (Typically used for Category IV events):

9) $\beta_{IV}\cdot(P_{IV}+D)$
10) $\beta_{IV}\cdot(P_{op}+D+ EM_{IV})$
11) $\beta_{IV}\cdot(P_{op}+D+SL\text{-}2)$
12) $\beta_{IV}\cdot(P_{op}+D+SL\text{-}1+MD\ III)$

In case dead weight (D) is beneficial it shall be multiplied by a factor 0.9 in all category combinations.

No thermal loads need to be considered in the verification against plastic collapse.

For service level C, an increase by a factor 1.2 of the allowable values of the service level A is assumed. This is equivalent to assume a load factor of 1.25 instead of 1.5 for service level C.

The definition of the $\beta\alpha_{IV}$ factor is more complicated as the following conditions have to be respected:

- allowable limits are increased by a factor 2.
- the allowable value for membrane cannot exceed the 0.7 Su.
- the allowable value for membrane plus bending stress shall not exceed 0.7 k Su (0.9 Su for non ductile material)

Following these specifications the β_{IV} value is the largest between

- 0.75
- 1.5 Sm/(Su*0.7)
- 1.5 Sm/(Su*0.9) (this applies if material has low ductility and if membrane+bending stress is the limiting stress).

A.3.3 Elasto-plastic analysis

To evaluate protection against plastic collapse using the elasto-plastic analysis methods, material stress –strain curve has to be defined following rules defined in ASME VIII Div.2. The concept of Load and Resistance Factor Design (LRFD) is used as an alternative to the rigorous computation of a plastic collapse load to design a component. In this procedure, factored loads that include a design factor to account for uncertainty, and the resistance of the component to these factored loads is determined using a elasto-plastic analysis. The load case combinations as shown next shall be used in the analyses. Each of the indicated load cases shall be evaluated unless an equivalent elastic analysis or a limit analysis is performed.

If convergence is achieved, the component is stable under the applied loads for this load case.

Load-cases required to be considered (based on ASME VIII, Div. 2, Part 5, Table 5.4):
Service level A (Typically used for Category I and II events):

1) $2.4\cdot(P + D)$
2) $2.4\cdot(P_{op} + D) + 1.7\cdot EM_{I}$ (or EM_{II}) or[3] $2.1\cdot(P_{op} + D) + 2.6\cdot EM_{I}$ (or EM_{II})
3) $2.4\cdot(P_{op} + D) + 1.7\cdot$ (SL-1 + MD I) or[3] $2.1\cdot(P_{op} + D) + 2.6\cdot$ (SL-1 + MD I)
4) $2.4\cdot(P_{op} + D) + 1.7\cdot$ (SL-1+MFD I (or II)) or[3] $2.1\cdot(P_{op} + D) + 2.6\cdot$ (MFD I (or II))

Service level C (Typically used for Category III events):

5) $2\cdot(P_{III}+D)$
6) $2\cdot(P_{op}+D+SL\text{-}1+EM_{I\&II})$ or[3] $1.75\cdot(P_{op}+D) + 2.17\cdot(SL\text{-}1+EM_{I\&II})$
7) $2\cdot(P_{op}+D+EM_{III})$ or[3] $1.75\cdot(P_{op}+D) + 2.17\cdot EM_{III}$
8) $2\cdot(P_{op}$+D+SMHV+MFD I (or II)) or[3] $1.75\cdot(P_{op}+D) + 2.17\cdot$(SMHV+MFD I (or II))

Service Level D (Typically used for Category IV events):

9) $\gamma_{IV} \cdot (P_{IV}+D)$
10) $\gamma_{IV} \cdot (P_{op}+D+ EM_{IV})$
11) $\gamma_{IV} \cdot (P_{op}+D+SL\text{-}2)$
12) $\gamma_{IV} \cdot (P_{op}$ + D + SL-1 + MD III)

In case dead weight (D) is beneficial it shall be multiplied by a factor 0.9 in all category combinations.

No thermal loads need to be considered in the verification against plastic collapse.

For service level C, an increase by a factor 1.2 of the allowable values of the service level A is assumed. This is equivalent to assume a load factor of 2 instead of 2.4 or 1.75 and 2.17 instead of 2.1 and 2.6 respectively for service level C.

The definition of the γ_{IV} factor is more complicated as the following conditions have to be respected:

- allowable limits are increased by a factor 2.
- the allowable value for membrane cannot exceed the 0.7 Su.
- the allowable value for membrane plus bending stress shall not exceed 0.7 k Su (0.9 Su for non ductile material)

Following these specifications the β_{IV} value is the largest between

- 1.2

[3] Selection of load factors in the load combinations depends if EM or seismic loads are treated as operational loads (combination on the left) or live loads (combination on the right). In case of missing of a clear definition, the worst factored load combination shall be considered.

- 2.4 Sm/(Su*0.7)
- 2.4 Sm/(Su*0.9) (this applies if material has low ductility and if membrane+bending stress is the limiting stress).

Table A.2a: Load combination tables extracted from ASME VIII Div.2 part 5 for elastic analysis.

Table 5.3 – Load Case Combinations and Allowable Membrane Stresses for an Elastic Analysis

Design Load Combination	Allowable General Primary Membrane Stress (1),(2),(3)
1) $P+P_s+D$	S
2) $P+P_s+D+L$	S
3) $P+P_s+D+S_s$	S
4) $0.6D+(W \ or \ 0.7E)$ (4)	S
5) $0.9P+P_s+D+(W \ or \ 0.7E)$	S
6) $0.9P+P_s+D+0.75L+0.75S_s$	S
7) $0.9P+P_s+D+0.75(W \ or \ 0.7E)+0.75L+0.75S_s$	S

Notes

1) The parameters used in the Design Load Combination column are defined in Table 5.2.
2) The term $0.9P$ is considered an operating pressure.
3) S is the allowable stress for the load case combination. This value represents the general primary membrane stress limit for "load-controlled" loads. Stress limits for local membrane and bending stresses from "load-controlled" or "strain-controlled" loads are provided in paragraph 5.2.2.4.
4) This load combination addresses an overturning condition. If anchorage is included in the design, consideration of this load combination is not required.

Table A.2b: Load combination tables extracted from ASME VIII Div.2 part 5 for limit analysis.

Table 5.4 – Load Case Combinations and Load Factors for a Limit Load Analysis

Design Conditions	
Criteria	Required Factored Load Combinations
Global Criteria	1) $1.5(P+P_s+D)$ 2) $1.3(P+P_s+D+T)+1.7L+0.54S_s$ 3) $1.3(P+D)+1.7S_s+\max[1.1L,\ 0.86W]$ 4) $1.3(P+D)+1.7W+1.1L+0.54S_s$ 5) $1.3(P+D)+1.1E+1.1L+0.21S_s$
Local Criteria	Per Table 5.5
Serviceability Criteria	Per User's Design Specification, if applicable, see Table 5.5
Hydrostatic Test Conditions	
Global Criteria	$\max\left[1.43,\ 1.25\left(\frac{S_T}{S}\right)\right]\cdot(P+P_s+D)+2.6W_{pt}$
Serviceability Criteria	Per User's Design Specification, if applicable.
Pneumatic Test Conditions	
Global Criteria	$1.15\left(\frac{S_T}{S}\right)\cdot(P+P_s+D)+2.6W_{pt}$
Serviceability Criteria	Per User's Design Specification, if applicable.

Notes:

1) The parameters used in the Design Load Combination column are defined in Table 5.2.
2) See paragraph 5.2.3.4 for descriptions of global and serviceability criteria.
3) S is the allowable membrane stress at the design temperature.
4) S_T is the allowable membrane stress at the pressure test temperature.

Table A.2c: Load combination tables extracted from ASME VIII Div.2 part 5 for Elastic-Plastic analysis.

Table 5.5 – Load Case Combinations and Load Factors for an Elastic-Plastic Analysis

Design Conditions	
Criteria	Required Factored Load Combinations
Global Criteria	1) $2.4(P+P_s+D)$ 2) $2.1(P+P_s+D+T)+2.6L+0.86S_s$ 3) $2.1(P+P_s+D)+2.6S_s+\max[1.7L,\ 1.4W]$ 4) $2.4(P+P_s+D)+2.6W+1.7L+0.86S_s$ 5) $2.4(P+P_s+D)+1.7E+1.7L+0.34S_s$
Local Criteria	$1.7(P+P_s+D)$
Serviceability Criteria	Per User's Design Specification, if applicable, see paragraph 5.2.4.3.b.
Hydrostatic Test Conditions	
Global and Local Criteria	$\max\left[2.3,\ 2.0\left(\frac{S_T}{S}\right)\right]\cdot(P+P_s+D)+W_{pt}$
Serviceability Criteria	Per User's Design Specification, if applicable.
Pneumatic Test Conditions	
Global and Local Criteria	$1.8\left(\frac{S_T}{S}\right)\cdot(P+P_s+D)+W_{pt}$
Serviceability Criteria	Per User's Design Specification, if applicable.

Notes:

1) The parameters used in the Design Load Combination column are defined in Table 5.2.
2) See paragraph 5.2.4.3 for descriptions of global and serviceability criteria.
3) S is the allowable membrane stress at the design temperature.
4) S_T is the allowable membrane stress at the pressure test temperature.

Appendix B: Comparison table for allowable stress for pipe in nuclear codes.

Table B-1: Comparison table for allowable stress for pipe in nuclear codes for pressure and sustained loads (6)

Event Category	Typical ITER Design Loading Combinations (1)	Level Service (ITER)	k factor (2)					
			ASME B31.3	ASME III NC3200	ASME III NC3600 and	RCC-M C3600	RCC-MR	ITER design
I	P + Dw + T	A	1.0 (9)	1.0 (10)	1.0 (11)	1.0 (13)	1.0 (8)	1.0
II	P + Dw + SL-1 + T	A (SIC) or B (non-SIC)		1.1 (10)	1.2 (12)	1.2 (14)	1.0 (8)	1.0 (for SIC) (7)
III	P + Dw + T + SMHV	C		1.2 (10)	1.5 (4)	1.8 (15)	1.25-1.46 (8)	1.5
IV	P + Dw + SL-2 + T	D		2.0 (10)	2.0 (5)	2.4 (16)	1.9-2.3 (8)	2.0
	P + Dw + SL non-nuclear + T		1.33 (3)					

Explanation notes.

1. The symbols in the second column have the following meaning:
    a. P = pressure load,
    b. Dw = dead Weight and live loads,
    c. T = secondary loads,
    d. SL-1 = ITER seismic level 1 [1]
    e. SMHV = ITER seismic level SMHV [1]
    f. SL-2 = ITER seismic level 2 [1]
    g. SL non-nuclear = ITER seismic level for building and equipment that are classified as NSC (non seismic classified). These systems have to follow the seismic level defined by Eurocode 8.
2. k factor is used to calculate allowable limits to primary stress in service level B, C and D, from the allowable limits of service level A. Limits in service level B, C, and D are calculated by increasing the allowable value in service level A by the k factor.
3. ASME B31.3 defines limits for occasional loads (Chapter 302.3.6). Occasional loads include seismic loads. For occasional loads the allowable value defined for normal condition is increased by a factor 1.33. B31E (Standard for Seismic Design and retrofit of Above-Ground piping systems) provides a method for the seismic design of piping systems in the scope of B31 codes. It defines a k factor of 2.4 for stress due to pressure and seismic loads. Stress shall not exceed 1.5 Sy and 408 MPa.
4. According to ASME III NC-3654.2, limit to primary membrane and bending stress should not be greater than 1.8Sy.
5. According to ASME III NC-3655, limit to primary membrane and bending stress should not be greater than 2.0Sy

6. All numbers in the table have to be used for piping only because of different values for vessel or pump & valve.
7. SIC components are required to have a robust design (normal damage limits) not only for category I event, but also for category II. For non-SIC components and category II event combinations, a larger k factor can be used. Limitation imposed by ITER investment protection requirements must be considered in selecting the k factor.
8. In RCC-MR different factors are applied depending on the type of stress (RCC-MR RC3600 RCC-MR RB3651).
9. ASME B31.3-2008 302.3.5 (c)
10. ASME III DIVISION 1- NC table NC-3217-1
11. ASME III DIVISION 1- NC-3652
12. ASME III DIVISION 1- NC-3653.1
13. RCC-M Edition 2007 C3652
14. RCC-M Edition 2007 C3654
15. RCC-M Edition 2007 C3655
16. RCC-M Edition 2007 C3656