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Comparison of tubular member strength provisions in codes and standards

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1. INTRODUCTION

The purpose of this Technical Note is to review and compare formulations for tubular member strength given in the NORSOK standard for the design of Steel Structures [1], the 4th Edition Guidance Notes [2] and the draft of the forthcoming ISO standard for fixed steel offshore structures [3].

A general comparison is made first in Section 2, followed by detailed comparisons between the provisions in the ISO and NORSOK standards, in terms of design resistances. These cover:

i. axial tension;
ii. bending;
iii. compression;
iv. hydrostatic pressure;
v. axial tension combined with bending;
vi. axial compression combined with bending;
vii. axial tension, bending and hydrostatic pressure;
viii. axial compression, bending and hydrostatic pressure.

The reasons for limiting the detailed comparison to the ISO and NORSOK standards are given in Section 2.

All the symbols and nomenclature used pertaining to the formulae set out in sections 3 to 10 are defined in Appendix A

2. GENERAL COMPARISONS

Both the ISO and NORSOK standards involve modern limit state approaches to steel design. This involves the use of partial safety factors applied as multiples to characteristic loads to give design action effects, and divisors applied to characteristic resistances to give design resistances.

In considering the resistance partial safety factors, a principal difference between ISO and NORSOK is that ISO uses factors that are constant in value for the type of resistance under consideration. NORSOK, on the other hand, in cases of loading that generates compressive stresses, uses partial safety factors that vary and depend on the severity of the loading and the slenderness of the component under design.

Both these codes have limits of applicability on the geometric slenderness - tubular diameter to thickness (D/t) - to be < 120, and tubular wall thickness to be > 6mm. ISO also limits the material yield strength and yield ratio (yield to ultimate strength) to 500 MPa and 0.85, respectively. NORSOK argues that the use of steel with yield strength in excess of 500 MPa must be justified.

The 4th Edition Guidance Notes (GNs) were not meant to be a code or a standard and were intended to deliver guidance. As such direct quantitative comparison with ISO and NORSOK is not possible.

Section 21 of the GNs gives information on steel in material terms, and in terms of steelwork design. Clauses deal with allowable stresses in steel that should be in accordance with the steel grade, and within the limits specified in an appropriate code. Tensile stress limits of 60% and 80% of yield are suggested for operating and extreme loading conditions, respectively.

In terms of compression, clauses indicate that bending of components must be considered including:

i. slender, tubular, chord and bracing elements of the structural framework
ii. flat stiffened panels
iii. ring-stiffened cylindrical shells
iv. end-closures to cylindrical shells
v. large diameter orthogonally stiffened cylinders.

Reference in the GNs is made to Appendix A21 for 'detailed guidance'. This, however, only relates to buckling. Each of the items i. to v., above, is dealt with textually. Reference is made to other contemporaneous technical information (OTC papers, journal papers, DNV guidelines, API/BSI Standards / Codes etc.), much of which would now be outdated, superseded or incorporated into more current codes and standards. The guidance notes give no technical formulations for detailed design, but the principles therein remain valid however.

For these reasons, therefore, the comparisons in the remainder of this Technical Note focus on the NORSOK and ISO provisions.

3. AXIAL TENSION

The design criteria for tubular members subjected to axial tensile loads, from the two standards are set out in Table 3.1.

Hence, in comparing design resistances alone (i.e. not allowing for any differences in partial safety factors applied to the actions) then the NORSOK design resistance is 1.05 / 1.15 = 91% of the ISO design resistance. This difference is entirely due to the differences between the partial safety factors on resistance.

ISO	**NORSOK**
$f_t \leq \frac{F_y}{g_{Rt}}$	$N_{Sd} \leq N_{t.Rd} = \frac{A \cdot f_y}{g_M}$
f_t = axial tensile stress due to forces from factored actions	N_{Sd} = design axial force
	A = cross-section area
F_y = characteristic yield strength in stress units	f_y = characteristic yield strength
g_{Rt} = partial resistance factor for axial tensile strength = 1.05	g_M = partial material factor [for axial tensile strength] = 1.15

Table 3.1 Design Criteria for Axial Tension

4. AXIAL COMPRESSION

4.1 DESIGN CRITERIA

The design criteria for tubular members subjected to axial compressive loads, without hydrostatic pressure, from the two standards are set out in Table 4.1.

Potential sources of difference between the two codes are discussed in the following subsections in respect of:

- partial safety factor
- effective length factor
- axial compressive strength and local buckling strength.

4.2 PARTIAL SAFETY FACTOR

Differences in the partial safety factors between the ISO and NORSOK standards exist as follows:

ISO	NORSOK
$\gamma_{Rc} = 1.18$	$\gamma_M = 1.15$ for $\lambda_s < 0.5$ $\gamma_M = 0.85 + 0.60\,\lambda_s$ for $0.5 \leqslant \lambda_s \leqslant 1.0$ $\gamma_M = 1.45$ for $\lambda_s > 1.0$ For the case of axial compression **ONLY** $\lambda_s^2 = \frac{f_y}{f_{cle}}$ Hence, $\lambda_s = 1.291\sqrt{\left[\frac{f_y}{E}\cdot\frac{D}{t}\right]}$

It is clear from this that the difference in the partial safety factors depends on the product of the ratios f_y/E and D/t. The NORSOK partial safety factor ranges between 98% and 123% of the ISO one. The NORSOK standard becomes more conservative than ISO when:

$$\left[\left(\frac{F_y}{E}\cdot\frac{D}{t}\right)_{ISO},\left(\frac{f_y}{E}\cdot\frac{D}{t}\right)_{NORSOK}\right] > 0.181$$

ISO	**NORSOK**
$f_c \le \frac{F_c}{g_{Rc}}$	$N_{Sd} \le N_{c.Rd} = \frac{A \cdot f_c}{g_M}$
f_c = axial compressive stress due to forces from factored actions	N_{Sd} = design axial force
$F_c = \left(1.0 - 0.28 \cdot l^2\right) \cdot F_{yc} \cdot for \cdot l \le 1.34$	$f_c = \left(1.0 - 0.28 \cdot l^2\right) \cdot f_y \cdot for \cdot l \le 1.34$
$F_c = \frac{0.9}{l^2} \cdot F_{yc} \cdot for \cdot l > 1.34$	$f_c = \frac{0.9}{l^2} \cdot f_y \cdot for \cdot l > 1.34$
$l = \frac{K \cdot L}{p \cdot r} \cdot \left(\frac{F_{yc}}{E}\right)^{0.5}$	$l = \frac{k \cdot l}{p \cdot i} \cdot \left(\frac{f_{cl}}{E}\right)^{0.5}$
$F_{yc} = F_y \cdot for \cdot \frac{F_y}{F_{xe}} \le 0.170$	$f_{cl} = f_y \cdot for \cdot \frac{f_y}{f_{cle}} \le 0.170$
$F_{yc} = \left(1.047 - 0.274 \cdot \frac{F_y}{F_{xe}}\right) \cdot F_y \cdot for \cdot 0.170 < \frac{F_y}{F_{xe}} \le 1.911$	$f_{cl} = \left(1.047 - 0.274 \cdot \frac{f_y}{f_{cle}}\right) \cdot f_y \cdot for \cdot 0.170 < \frac{f_y}{f_{cle}}$
$F_{yc} = F_{xe} \cdot for \cdot \frac{F_y}{F_{xe}} > 1.911$	
$F_{xe} = 2 \cdot C_x \cdot E \cdot \left(\frac{t}{D}\right)$ $C_x = 0.6$ (theory); = 0.3 (recommended)	$f_{cle} = 2 \cdot C_e \cdot E \cdot \left(\frac{t}{D}\right)$ $C_e = 0.3$
K = effective length factor L = unbraced length of member in y- [in-plane] or z- [out-of-plane] direction	k = effective length factor l = unbraced length of member in y- [in-plane] or z- [out-of-plane] direction
r = radius of gyration [of cross-section]	i = radius of gyration [of cross-section]
E = Young's modulus of elasticity	E = Young's modulus of elasticity
D = outside diameter [of cross-section]	D = outside diameter [of cross-section]
t = wall thickness [of cross-section]	t = wall thickness [of cross-section]

Table 4.1 Design Criteria for Axial Compression

4.3 EFFECTIVE LENGTH FACTOR

The effective length factors of the ISO and NORSOK standards (K and k, respectively) are derived in an identical fashion, according to the table given below. No differences between the standards will be introduced into the design resistances through this mechanism.

Structural element	**K or k**
Superstructure legs	
- Braced	1.0
- Portal (unbraced)	see note below
Jacket legs and piling	
- Grouted composite section	1.0
- Ungrouted jacket legs	1.0
- Ungrouted piling between shim points	1.0
Jacket braces	
- Primary diagonals and horizontals	0.7
- K-braces (3)	0.7
- Longer segment length of X-braces (3)	0.8
Secondary horizontals	0.7

Note: for both standards the effective length factors for unbraced superstructure legs are derived from a commentary.

Table 4.2 Effective Length Factors

4.4 AXIAL COMPRESSIVE STRENGTH AND LOCAL BUCKLING STRENGTH

With study, it is clear from the equations given in Table 4.1 that the ISO and NORSOK codes will give identical values for characteristic axial compressive strengths if

$$\frac{F_y}{E} \cdot \frac{D}{t} = \frac{f_y}{E} \cdot \frac{D}{t} \leqslant 0.102.$$

This is because, for this range of the product of these ratios, $F_{yc} = F_y = f_y$ and hence $F_c = f_c$.

A slightly different situation arises if the following obtains:

$$0.102 < \frac{F_y}{E} \cdot \frac{D}{t} = \frac{f_y}{E} \cdot \frac{D}{t} \leqslant 1.147$$

In this case the effective length factors are the same value for both codes, but because the ISO formula for characteristic axial compressive strength uses the characteristic local buckling strength (F_{yc}), whereas NORSOK uses the yield strength, then F_c (ISO)< f_c (NORSOK). The characteristic local buckling strength degrades linearly with the F_y/E, D/t product according to:

$$\frac{F_{yc}}{F_y} = \left(1.047 - 0.457 \frac{F_y}{E} \cdot \frac{D}{t}\right).$$

Given the limitations on F_y and D/t set by both the ISO and NORSOK standards of 500 MPa and 120, respectively, this sets an upperbound of:

$$\frac{F_y}{E} \cdot \frac{D}{t} = \frac{f_y}{E} \cdot \frac{D}{t} \leqslant 0.286$$

At this upperbound, therefore, the NORSOK characteristic axial compressive strength will be about 109% of that calculated via the ISO standard.

The NORSOK standard is not clear, however, about the procedure to adopt when $F_y/E \times D/t > 0.102$. It may be that it is necessary to bring the calculations closer into alignment with those of ISO in this situation.

4.5 DIFFERENCES ISO VERSUS NORSOK

Within the practical ranges of materials and slenderness parameters discussed in the proceeding subsection, and with reference to Table 4.1 (after some simplifying algebra), it can be shown that differences in the design resistance are caused by two effects:

a. partial safety factor computation; i.e. differences between γ_{Rc} - ISO, and γ_M - NORSOK

b. use of the characteristic local buckling strength in the computation of the characteristic axial compressive strength; i.e. differences between F_c - ISO, and f_c - NORSOK.

The individual differences depend on the value of F_y/E.D/t and contribute to the overall differences in the way set out in Table 4.3. This gives, for a range and specific values of F_y/E x D/t (or f_y/E x D/t), the ratios of partial safety factors, characteristic axial compressive strengths and factored axial resistances.

	Ratio of NORSOK:ISO		
	Partial Safety Factors a (see above)	Characteristic Axial Compressive Strengths b (see above)	Factored Axial Resistances b/a (NORSOK/ISO)
$\frac{F_y}{E} \cdot \frac{D}{t}$ or $\frac{f_y}{E} \cdot \frac{D}{t}$	$\frac{\gamma_M}{\gamma_{Rc}}$	$\frac{f_c}{F_c}$	$\frac{f_c}{\gamma_M} \cdot \frac{\gamma_{Rc}}{F_c}$
$\leqslant$ 0.102	0.975	1.000	1.026
0.150	0.975	0.979	1.004
0.286	1.071	0.916	0.855

Table 4.3 Design Resistance Ratios

It is worth noting that, whilst at the upper limits corresponding to F_y = 500 MPa and D/t = 120 the NORSOK design resistance is 15% less than the ISO value, in practice D/t ratios are likely to be less than 60. This gives F_y/E.D/t for 350 MPa steel and 500 MPa steel as 0.100 and 0.143, respectively. Therefore, under these practical circumstances, the difference between ISO and NORSOK regarding design resistance is negligible.

5. BENDING

5.1 DESIGN CRITERIA

The design criteria for tubular members subjected to bending alone are set out in Table 5.1. The difference between the two codes lies with the partial safety factors, as discussed below.

5.2 PARTIAL SAFETY FACTORS

Differences in the partial safety factors for bending between the ISO and NORSOK standards exist as follows:

ISO	**NORSOK**
$\gamma_{Rb} = 1.05$	The same expressions as for axial compression are used for γ_M (see Subsection 4.2). These become, upon simplification for bending only: $\gamma_M = 1.15$ for $\frac{f_y}{E} \cdot \frac{D}{t} < 0.15$ $\gamma_M = 0.85 + 0.775 \sqrt{\left[\frac{f_y}{E} \cdot \frac{D}{t}\right]}$ for $0.150 \leqslant \frac{f_y}{E} \cdot \frac{D}{t} \leqslant 0.600$ $\gamma_M = 1.45$ for $\frac{f_y}{E} \cdot \frac{D}{t} > 0.600$

The limitations on F_y (f_y) and D/t set by both the ISO and NORSOK standards give an upper limit to F_y/E x D/t of 0.286. Noting that the only contribution to the difference between the two standards regarding bending is via the partial safety factors, then these differences can be quantified as set out in Table 5.2.

$\frac{F_y}{E} \cdot \frac{D}{t}$ or $\frac{f_y}{E} \cdot \frac{D}{t}$	$\frac{\gamma_M}{\gamma_{Rb}}$
$\leqslant 0.150$	1.095
0.286	1.204

Table 5.2 Bending Partial Safety Factor Ratios

ISO	**NORSOK**
$f_b \le \frac{F_b}{g_{Rb}}$ f_b = bending stress due to forces from factored actions $F_b = \left(\frac{Z}{S}\right)\cdot F_y \cdot \text{for} \cdot \frac{F_y}{E}\cdot\frac{D}{t} \le 0.0517$ $F_b = \left(1.13 - 2.58\cdot\frac{F_y}{E}\cdot\frac{D}{t}\right)\cdot\left(\frac{Z}{S}\right)\cdot F_y \cdot \text{for} \cdot 0.0517 < \frac{F_y}{E}\cdot\frac{D}{t} \le 0.1034$ $F_b = \left(0.94 - 0.76\cdot\frac{F_y}{E}\cdot\frac{D}{t}\right)\cdot\left(\frac{Z}{S}\right)\cdot F_y \cdot \text{for} \cdot 0.1034 < \frac{F_y}{E}\cdot\frac{D}{t} \le 120\cdot\frac{F_y}{E}$	$M_{Sd} \le M_{Rd} = \frac{W \cdot f_m}{g_M}$ M_{Sd} = design bending moment $f_m = \left(\frac{Z}{W}\right)\cdot f_y \cdot \text{for} \cdot \frac{f_y}{E}\cdot\frac{D}{t} \le 0.0517$ $f_m = \left(1.13 - 2.58\cdot\frac{f_y}{E}\cdot\frac{D}{t}\right)\cdot\left(\frac{Z}{W}\right)\cdot f_y \cdot \text{for} \cdot 0.0517 < \frac{f_y}{E}\cdot\frac{D}{t} \le 0.1034$ $f_m = \left(0.94 - 0.76\cdot\frac{f_y}{E}\cdot\frac{D}{t}\right)\cdot\left(\frac{Z}{W}\right)\cdot f_y \cdot \text{for} \cdot 0.1034 < \frac{f_y}{E}\cdot\frac{D}{t} \le 120\cdot\frac{f_y}{E}$
Z = [cross-section] plastic section modulus S = [cross-section] elastic section modulus	Z = [cross-section] plastic section modulus W = [cross-section] elastic section modulus

Table 5.1 Design Criteria for Bending

6. HYDROSTATIC PRESSURE

6.1 DESIGN CRITERIA

The design criteria for tubular members subjected to hydrostatic pressure alone are set out in Table 6.1.

Thus, by observation, the differences between the ISO and NORSOK formulations for the design resistances are due to the partial safety factors. These are dealt with in the next subsection.

6.2 PARTIAL SAFETY FACTORS

Differences in the partial safety factors for hydrostatic pressure between the ISO and NORSOK standards are as follows.

ISO	NORSOK
$\gamma_{Rh} = 1.25$	$\gamma_M = 1.15$ for $\lambda_s < 0.5$ $\gamma_M = 0.85 + 0.60\,\lambda_s$ for $0.5 \leqslant \lambda_s \leqslant 1.0$ $\gamma_M = 1.45$ for $\lambda_s > 1.0$ For the case of hydrostatic pressure **ONLY** $\lambda_s^2 = \frac{f_y}{f_{he}}$

Hence, the NORSOK partial safety factor follows the complex expression for f_{he} (elastic hoop buckling strength) given in Table 6.1. The difference between the ISO and NORSOK safety factors is set out indicatively in Table 6.2.

$\frac{F_y}{E} \cdot \frac{D}{t}$ or $\frac{f_y}{E} \cdot \frac{D}{t}$	$\frac{\gamma_M}{\gamma_{Rh}}$
$\leqslant 0.5\ C_h$	0.920
$\geqslant 2\ C_h$	1.160

Table 6.2 Hydrostatic Pressure Partial Safety Factors

ISO	**NORSOK**
$f_h \le \frac{F_h}{g_{Rh}}$	$s_{p.Sd} \le f_{h.Rd} = \frac{f_h}{g_M}$
f_h = hoop stress due to forces from factored hydrostatic pressure	$s_{p.Sd}$ = design hoop stress due to hydrostatic pressure
$F_h = F_y \cdot for \cdot 2.44 \cdot F_y < F_{he}$	$f_h = f_y \cdot for \cdot 2.44 \cdot f_y < f_{he}$
$F_h = 0.7 \cdot F_y \cdot \left(\frac{F_{he}}{F_y}\right)^{0.4} \cdot for \cdot 0.55 \cdot F_y < F_{he} \le 2.44 \cdot F_y$	$f_h = 0.7 \cdot f_y \cdot \left(\frac{f_{he}}{f_y}\right)^{0.4} \cdot for \cdot 0.55 \cdot f_y < f_{he} \le 2.44 \cdot f_y$
$F_h = F_{he} \cdot for \cdot F_{he} \le 0.55 \cdot F_y$	$f_h = f_{he} \cdot for \cdot f_{he} \le 0.55 \cdot f_y$
$F_{he} = 2 \cdot C_h \cdot E \cdot \frac{t}{D}$	$f_{he} = 2 \cdot C_h \cdot E \cdot \frac{t}{D}$
$C_h = 0.44 \cdot \frac{t}{D} \cdot for \cdot 1.6 \cdot \frac{D}{t} \le m$	$C_h = 0.44 \cdot \frac{t}{D} \cdot for \cdot 1.6 \cdot \frac{D}{t} \le m$
$C_h = 0.44 \cdot \frac{t}{D} + \frac{0.21}{m^4} \cdot \left(\frac{D}{t}\right)^3 \cdot for \cdot 0.825 \cdot \frac{D}{t} \le m < 1.6 \cdot \frac{D}{t}$	$C_h = 0.44 \cdot \frac{t}{D} + \frac{0.21}{m^4} \cdot \left(\frac{D}{t}\right)^3 \cdot for \cdot 0.825 \cdot \frac{D}{t} \le m < 1.6 \cdot \frac{D}{t}$
$C_h = \frac{0.737}{m - 0.579} \cdot for \cdot 1.5 \le m < 0.825 \cdot \frac{D}{t}$	$C_h = \frac{0.737}{m - 0.579} \cdot for \cdot 1.5 \le m < 0.825 \cdot \frac{D}{t}$
$C_h = 0.80 \cdot for \cdot m < 1.5$	$C_h = 0.80 \cdot for \cdot m < 1.5$
$m = \frac{L}{D} \cdot \sqrt{\frac{2 \cdot D}{t}}$	$m = \frac{L}{D} \cdot \sqrt{\frac{2 \cdot D}{t}}$
L = length between stiffening rings, diaphragms or end connections	L = length between stiffening rings, diaphragms or end connections

Table 6.1 Design Criteria for Hydrostatic Pressure

7. AXIAL TENSION AND BENDING

7.1 INTERACTION FORMULAE

The two standards use formulae to compute interaction ratios in the case of combined axial tension and bending. The formulae from the two standards are given in Table 7.1.

It is clear from these formulations and their contents that there are three sources of difference between the requirements of the two codes:

i. partial safety factors on actions
ii. partial safety factors on resistances
iii. formulation differences in the interaction formulae.

The effects of item i cannot be dealt with here. Items ii and iii are combined and addressed in the next subsection.

7.2 DIFFERENCES ISO VERSUS NORSOK

The differences between ISO and NORSOK are best illustrated by expressing the interaction formulae in a common stress basis, in the manner described below.

ISO	NORSOK
$\frac{\gamma_{Rt}\, f_t}{F_y} + \frac{\gamma_{Rb}\, f_{bres}}{F_b} \leqslant 1.0$ f_{bres} = resulting bending stress due to forces from factored actions	$\left(\frac{\gamma_{Mt}\, f_t}{f_y}\right)^{1.75} + \frac{\gamma_{Mb}\, f_{bres}}{f_m} \leqslant 1.0$ f_{bres} = as left γ_{Mt} = resulting material factor for tension alone γ_{Mb} = resulting material factor for bending alone

The other terms have been defined in previous subsections and it should be noted that $F_y = f_y$ and $F_b = f_m$. As set out in previous subsections, γ_{Rt} and γ_{Rb} are constants (both 1.05), and γ_{Mt} is constant and equal to 1.15. γ_{Mb} is not constant, however, and varies between 1.15 and 1.264 according to the values of f_y/E x D/t (see Subsection 5.2).

The comparison between the interaction formulae is given in Figure 7.1, plotted as tensile stress ratio (f_t/F_y or f_t/f_y) versus bending stress ratio (f_{bres}/F_b or f_{bres}/f_m). Two curves for the NORSOK formulation are given, corresponding to γ_{Mb} (denoted as psf in the figure) of 1.15 and 1.264.

As can be seen from this figure, NORSOK is more conservative than ISO only for cases of mainly tension or mainly bending. Otherwise the opposite is true, although for γ_{Mb} (psf) = 1.264 the differences between ISO and NORSOK are small.

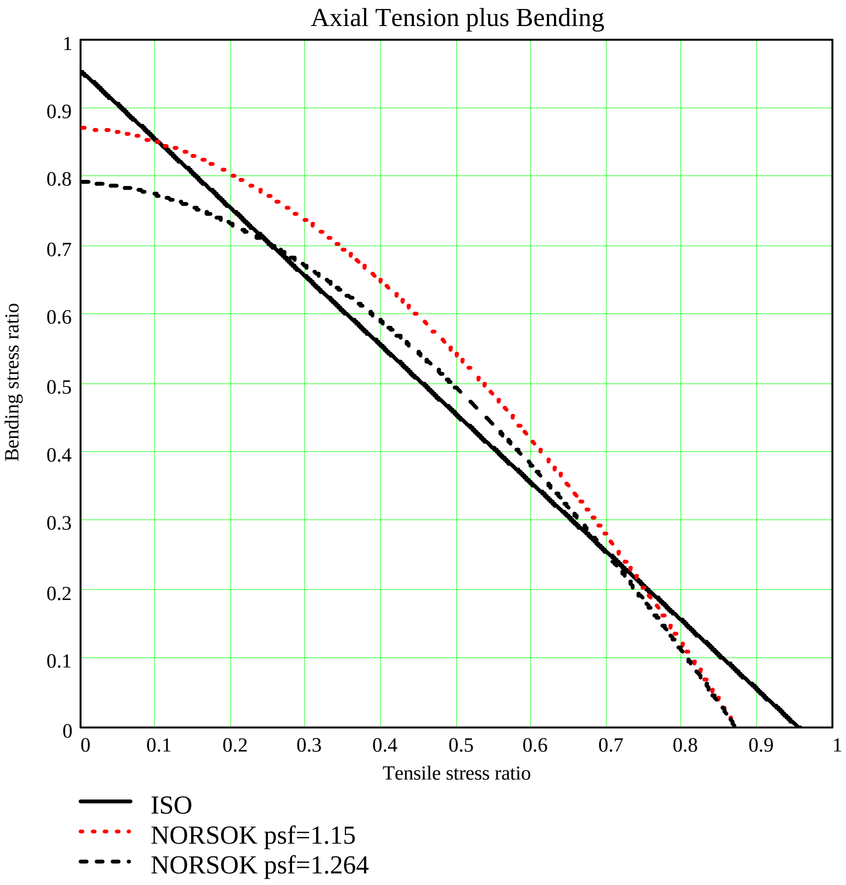

Figure 7.1 ISO Versus NORSOK Interaction Diagrams for Combined Axial Tension and Bending

ISO	NORSOK
$\frac{g_{Rt} \cdot f_t}{F_y} + \frac{g_{Rb} \cdot \sqrt{f_{by}^2 + f_{bz}^2}}{F_b} \le 1.0$	$\left(\frac{N_{Sd}}{N_{t.Rd}}\right)^{1.75} + \frac{\sqrt{M_{y.Sd}^2 + M_{z.Sd}^2}}{M_{Rd}} \le 1.0$
f_{by} = bending stress about member y-axis (in-plane) due to forces from factored actions f_{bz} = bending stress about member z-axis (out-of-plane) due to forces from factored actions	N_{Sd} = design tensile axial force [including partial safety factor on actions] $M_{y.Sd}$ = design bending moment about member y-axis (in-plane) [including partial safety factor on actions] $M_{z.Sd}$ = design bending moment about member z-axis (out-of-plane) [including partial safety factor on actions]

Table 7.1 Interaction Formulae for Combined Axial Tension and Bending

8. AXIAL COMPRESSION AND BENDING

8.1 INTERACTION FORMULAE

The two standards use formulae to compute interaction ratios in the case of combined axial compression and bending. Each standard employs two formulae: one involving overall compressive strength and P-δ amplified bending stress; and a second involving local buckling strength and unamplified bending stress (see Table 8.1).

When expressed in stress terms, the corresponding formulae from each standard are identical, except for the values of partial safety factors and expressions used for various characteristic strengths. The relevant formulae are as follows:

ISO	**NORSOK**
$\frac{\gamma_{Rc}\, f_{cd}}{F_c} + \frac{\gamma_{Rb}\, f^*_{bres}}{F_b} \leqslant 1.0$	$\frac{\gamma_{Mc}\, f_{cd}}{f_c} + \frac{\gamma_{Mb}\, f^*_{bres}}{f_m} \leqslant 1.0$
$\frac{\gamma_{Rc}\, f_{cd}}{F_{yc}} + \frac{\gamma_{Rb}\, f_{bres}}{F_b} \leqslant 1.0$	$\frac{\gamma_{Mc}\, f_{cd}}{f_{cl}} + \frac{\gamma_{Mb}\, f_{bres}}{f_m} \leqslant 1.0$
f_{cd} = compressive stress due to forces from factored actions	f_{cd} = as left
f_{bres}* resulting amplified bending stress due to forces from factored actions	f_{bres}* = as left
f_{bres} = resulting unamplified bending stress due to forces from factored actions	f_{bres} = as left

The other terms in the formulae have been defined in previous subsections, where it should be noted that $F_b = f_m$. As set out in previous subsections, γ_{Rc} and γ_{Rb} are constants (1.18 and 1.05, respectively). In addition to this, over the practical range $f_y/E \times D/t \leqslant 0.286$, $F_{yc} = f_{cl}$. Immediate comparisons between the formulae are rendered difficult by the fact that, generally, $F_c \neq f_c$.

ISO	**NORSOK**
$\frac{g_{Rc}\cdot f_c}{F_c}+\frac{g_{Rb}}{F_b}\cdot\left[\left(\frac{C_{my}\cdot f_{by}}{1-\frac{f_c}{F_{ey}}}\right)^2+\left(\frac{C_{mz}\cdot f_{bz}}{1-\frac{f_c}{F_{ez}}}\right)\right]^{0.5}\le 1.0$	$\frac{N_{Sd}}{N_{c.Rd}}+\frac{1}{M_{Rd}}\cdot\left[\left(\frac{C_{my}\cdot M_{y.Sd}}{1-\frac{N_{Sd}}{N_{Ey}}}\right)^2+\left(\frac{C_{mz}\cdot M_{z.Sd}}{1-\frac{N_{Sd}}{N_{Ez}}}\right)^2\right]^{0.5}\le 1.0$
$\frac{g_{Rc}\cdot f_c}{F_{yc}}+\frac{g_{Rb}\cdot\sqrt{f_{by}^2+f_{bz}^2}}{F_b}\le 1.0$	$\frac{N_{Sd}}{N_{cl.Rd}}+\frac{\sqrt{M_{y.Sd}^2+M_{z.Sd}^2}}{M_{Rd}}\le 1.0$
$F_{ey}=\frac{p^2\cdot E}{\left(\frac{K_y\cdot L_y}{r_y}\right)^2}$	$N_{Ey}=\frac{p^2\cdot E\cdot A}{\left[\left(\frac{k\cdot l}{i}\right)_y\right]^2}$
$F_{ez}=\frac{p^2\cdot E}{\left(\frac{K_z\cdot L_z}{r_z}\right)^2}$ f_c = axial compressive stress due to forces from factored actions	$N_{Ez}=\frac{p^2\cdot E\cdot A}{\left[\left(\frac{k\cdot l}{i}\right)_z\right]^2}$

Table 8.1 Interaction Formulae for Combined Axial Compression and Bending

8.2 DIFFERENCES ISO VERSUS NORSOK

The differences between the two sets of formulations are illustrated in Figure 8.1 (for the formulae involving the amplified bending stresses) and Figure 8.2 (for the formulae involving the unamplified bending stresses and the characteristic local buckling strength).

As in Subsection 7.2, it has been assumed that the stresses due to forces from factored actions are the same in each case. Owing to the differences between F_c and f_c (see Subsection 4.5), the ISO characteristic compressive strength has been used for the compressive stress ratio for both the ISO and NORSOK interaction lines in Figure 8.1.

In the case of Figure 8.1, which includes overall buckling effects, there are three NORSOK interaction lines corresponding with the different values of $F_y/E \times D/t$ from Subsection 4.5 (Table 4.3). As can be seen NORSOK is more conservative than ISO, except for the cases of low $F_y/E \times D/t$ ($\leqslant 0.150$) and mainly compression.

For Figure 8.2, which includes local buckling, there are two NORSOK interaction lines corresponding with $f_y/E \times D/t$ from Subsection 5.2 (Table 5.2). Similar comments regarding the relative conservatisms from Figure 8.1 apply here also.

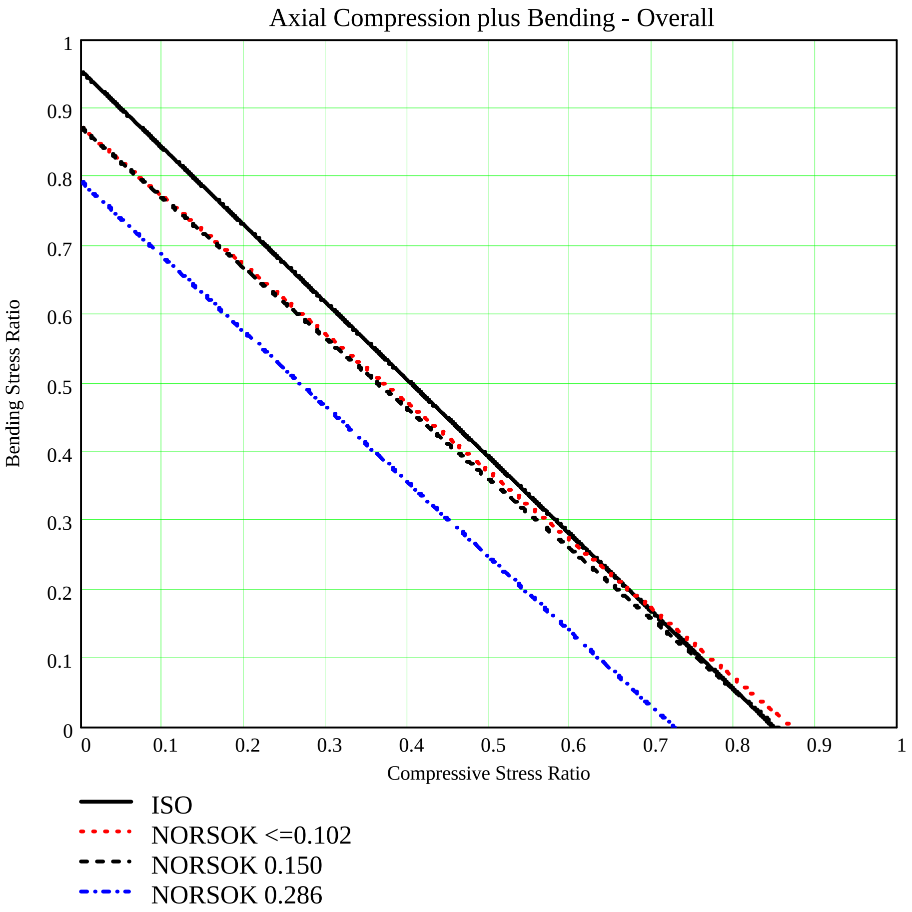

Figure 8.1 ISO Versus NORSOK Interaction Diagrams for Combined Compression and Bending - Including Overall Buckling

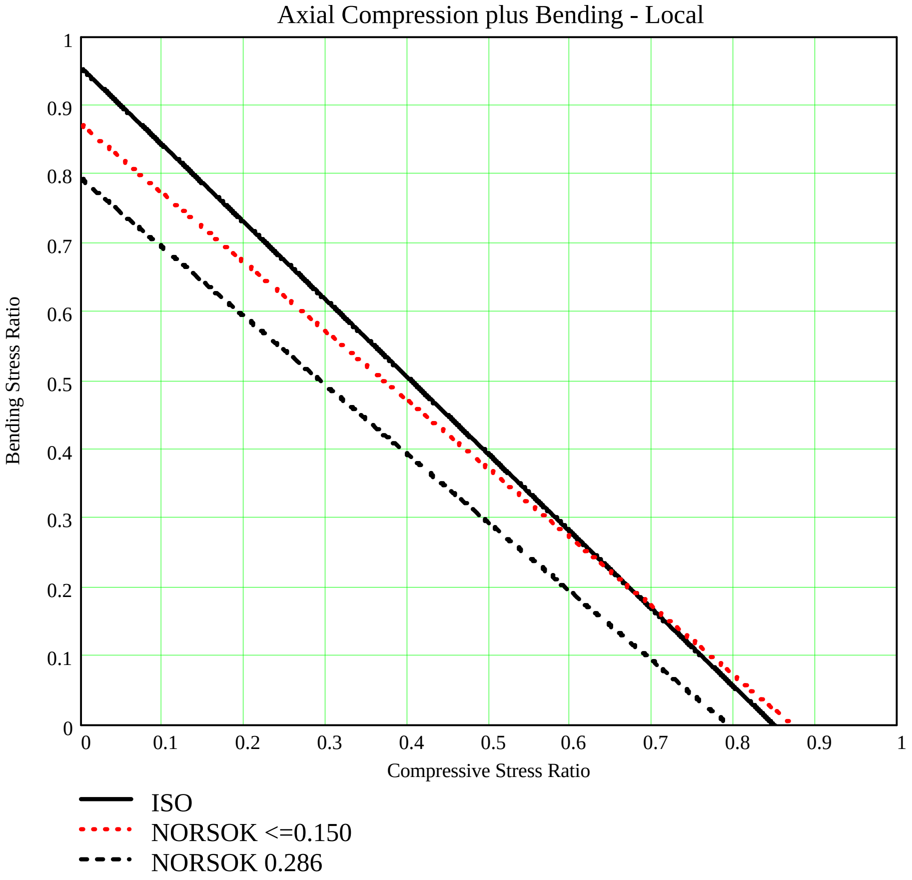

Figure 8.2 ISO Versus NORSOK for Combined Compression and Bending - Including Local Buckling

9. AXIAL TENSION, BENDING AND HYDROSTATIC PRESSURE

9.1 INTERACTION FORMULAE

The two standards use formulae to compute interaction ratios in the case of combined axial tension, bending and hydrostatic loading. The formulae from the two standards are summarised in Table 9.1.

9.2 DIFFERENCES ISO VERSUS NORSOK

The basic interaction formulae appear to be identical in form. Differences in interaction values will result from:

i. partial safety factors on actions
ii. partial safety factors / formulaic differences in resistances.

The expression for B, see Table 9.1, depends on F_h/γ_{Rh} and $f_{h,Rd}$ for ISO and NORSOK, respectively. In the case of the latter, $f_{h,Rd} = f_h/\gamma_M$ (see Subsection 6.1, Table 6.1, above). The formulae for F_h and f_h are identical, hence differences in B between the two codes stem from the partial safety factors γ_{Rh} (ISO) and γ_M (NORSOK), and these differences have been set out in indicative terms in Subsection 6.2, above.

In the resistance denominators for the case of net axial tension, F_{th} and F_{bh} (ISO), and $f_{th,Rd}$ and $f_{mh,Rd}$ (NORSOK), the differences between the two codes are due to the differences between the partial safety factors set out in Table 9.2.

ISO	NORSOK
γ_{Rt}	γ_M (tension)*
γ_{Rb}	γ_M (bending)

Table 9.2 Potential Sources of Differences

It is not completely clear from the NORSOK code whether the γ_M for bending is to be used for **both** $f_{mh,Rd}$ and $f_{th,Rd}$. Assuming that tension and bending material factors apply to the resistances, then the comparisons between the partial safety factors are as given in Section 3 (tension) and Subsection 5.2 (bending).

In the resistance denominator for the case of net axial compression, differences stem from F_{yc}/γ_{Rc} (ISO) and f_{cl}/γ_M (NORSOK). The expressions for F_{yc} and f_{cl} are virtually identical (see Subsection 4.1), so the differences are due solely to those between γ_{Rc} and γ_M as discussed in Subsection 4.2.

Differences in the remaining interaction formulae in Table 9.1 are due to γ_{Rh} - γ_M and γ_{Rc} - γ_M differences already discussed.

ISO	NORSOK
Method A f_a is tensile	Method A $s_{a.Sd}$ is tensile
$f_a \ge f_q$	$s_{a.Sd} \ge s_{q.Sd}$
$\frac{f_a - f_q}{F_{th}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{s_{a.Sd} - s_{q.Sd}}{f_{th.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$
f_a = calculated axial stress due to forces from factored actions that exclude capped-end actions f_q = compressive stress from forces arising from factored capped-end actions due to hydrostatic pressure	$s_{a.Sd}$ = design axial stress that excludes effect of capped-end axial compression arising from external hydrostatic pressure $s_{q.Sd}$ = capped-end design axial compressive stress due to external hydrostatic pressure $s_{my.Sd}$ = design bending stress about member y-axis [in-plane] $s_{mz.Sd}$ = design bending stress about member z-axis [out-of--plane]
$F_{th} = \frac{F_y}{g_{Rt}} \cdot \left(\sqrt{1 + 0.09 \cdot B^2 - B^{2 \cdot h}} - 0.3 \cdot B\right)$	$f_{th.RD} = \frac{f_y}{g_M} \cdot \left(\sqrt{1 + 0.09 \cdot B^2 - B^{2 \cdot h}} - 0.3 \cdot B\right)$
$F_{bh} = \frac{F_b}{g_{Rb}} \cdot \left(\sqrt{1 + 0.09 \cdot B^2 - B^{2 \cdot h}} - 0.3 \cdot B\right)$	$f_{mh.Rd} = \frac{f_m}{g_M} \cdot \left(\sqrt{1 + 0.09 \cdot B^2 - B^{2 \cdot h}} - 0.3 \cdot B\right)$
$B = \frac{g_{Rh} \cdot f_h}{F_h} \qquad B \le 1.0$	$B = \frac{s_{p.Sd}}{f_{h.Rd}} \qquad B \le 1.0$
$h = 5 - 4 \frac{F_h}{F_y}$	$h = 5 - 4 \frac{f_h}{f_y}$
f_h = hoop stress due to forces from factored hydrostatic pressure	$s_{p.Sd}$ = design hoop stress due to hydrostatic pressure

Table 9.1 Interaction Formulae for Combined Axial Tension, Bending and Hydrostatic Pressure (1 of 2)

ISO	NORSOK
$f_a < f_q$	$s_{a.Sd} < s_{q.Sd}$
$\frac{g_{Rc}\cdot\lvert f_a - f_q\rvert}{F_{yc}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{\lvert s_{a.Sd} - s_{q.Sd}\rvert}{f_{cl.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$ $f_{cl.Rd} = \frac{f_{cl}}{g_M}$
when $f_b + f_q - f_a > 0.5\frac{F_{he}}{g_{Rh}}$ and $\frac{F_{xe}}{g_{Rc}} > 0.5\frac{F_{he}}{g_{Rh}}$ then additionally	when $s_{m.Sd} + s_{q.Sd} - s_{a.Sd} > 0.5\frac{f_{cle}}{g_M}$ and $\cdot f_{cle} > 0.5\cdot f_{he}$ then additionally
$\frac{f_b + f_q - f_a - 0.5\frac{F_{he}}{g_{Rh}}}{\frac{F_{xe}}{g_{Rc}} - 0.5\frac{F_{he}}{g_{Rh}}} + \left(\frac{g_{Rh}\cdot f_h}{F_{he}}\right)^2 \le 1.0$	$\frac{s_{c.Sd} - 0.5\frac{f_{he}}{g_M}}{\frac{f_{cle}}{g_M} - 0.5\frac{f_{he}}{g_M}} + \left(\frac{s_{p.Sd}\cdot g_M}{f_{he}}\right)^2 \le 1.0$
	$s_{c.Sd} = s_{m.Sd} + s_{q.Sd} - s_{a.Sd}$
	$s_{m.Sd} = \frac{\sqrt{M_{y.Sd}^2 + M_{z.Sd}^2}}{W}$
Method B f_{ac} is tensile	Method B $s_{ac.Sd}$ is tensile
$\frac{f_{ac}}{F_{th}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{s_{ac.Sd}}{f_{th.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$
f_{ac} = calculated axial stress due to factored actions that include capped-end actions	$s_{ac.Sd}$ = design axial stress that excludes the effect of capped-end axial compression arising from external hydrostatic pressure

Table 9.1 Interaction Formulae for Combined Axial Tension, Bending and Hydrostatic Pressure (2 of 2)

10. AXIAL COMPRESSION, BENDING AND HYDROSTATIC PRESSURE

10.1 INTERACTION FORMULAE

The two standards use formulae to compute interaction ratios in the case of combined axial compression, bending and hydrostatic loading. The formulae from the two standards are summarised in Table 10.1.

The approach taken and general form of the formulae used are identical. Potential sources of divergence are due to differences between the following. These differences are discussed in the following subsection.

ISO	**NORSOK**
F_{ch}	$f_{ch, Rd}$
F_{bh}	$f_{mh, Rd}$
γ_{Rc} / F_{yc}	$f_{cl, Rd}$

Table 10.2 Potential Sources of Difference in Combined Axial Compression, Bending and Hydrostatic Pressure Formulations

10.2 DIFFERENCES ISO VERSUS NORSOK

The formats of the formulations for F_{ch} and $f_{ch,Rd}$ are identical, but with potential for divergence because of the differences between:

ISO	**NORSOK**
F_{yc} = see Table 4.1	f_{cl} = see Table 4.1
$\gamma_{Rc} = 1.18$ (see Subsection 4.2)	$\gamma_M = 1.15$ for $\lambda_s < 0.5$
	$\gamma_M = 0.85 + 0.60\,\lambda_s$ for $0.5 \leqslant \lambda_s \leqslant 1.0$
	$\gamma_M = 1.45$ for $\lambda_s > 1.0$
	$\lambda_s^2 = \frac{f_y}{\sigma_{j,\,sd}}\left(\frac{\sigma_{c,\,sd}}{f_{cle}} + \frac{\sigma_{p,\,sd}}{f_{he}}\right)$
	$\sigma_{j,\,sd} = \sqrt{\sigma_{c,\,sd}^2 - \sigma_{c,\,sd}\,\sigma_{p,\,sd} + \sigma_{p,\,sd}^2}$
	$\sigma_{c,\,sd} = \frac{N_{sd}}{A} + \frac{\sqrt{M_{y,\,sd}^2 + M_{z,\,sd}^2}}{W}$

According to Table 4.1, F_{yc} will for the most part be equal to f_{cl}, so the principal sources of divergence will be due to γ_{Rc} (ISO) and γ_M (NORSOK) as set out in Subsection 4.2.

With reference to F_{bh} and $f_{mh,Rd}$, differences between these will be as per Subsection 9.2.

Since $f_{cl,\ Rd} = f_{cl} / \gamma_M$ and $F_{yc} = f_{cl}$, the third potential source of divergence reduces to the differences between γ_{Rc} and γ_M discussed above.

ISO	NORSOK
Method A f_a is compressive	Method A $s_{a.Sd}$ is compressive
$\frac{f_a}{F_{ch}} + \frac{1}{F_{bh}} \cdot \left[\left(\frac{C_{my} \cdot f_{by}}{1 - \frac{f_a}{F_{ey}}}\right)^2 + \left(\frac{C_{mz} \cdot f_{bz}}{1 - \frac{f_a}{F_{ez}}}\right)^2\right]^{0.5} \le 1.0$	$\frac{s_{a.Sd}}{f_{ch.Rd}} + \frac{1}{f_{mh.Rd}} \cdot \left[\left(\frac{C_{my} \cdot s_{my.Sd}}{1 - \frac{s_{a.Sd}}{f_{Ey}}}\right)^2 + \left(\frac{C_{mz} \cdot s_{mz.Sd}}{1 - \frac{s_{a.Sd}}{f_{Ez}}}\right)^2\right]^{0.5} \le 1.0$
$\frac{g_{Rc} \cdot (f_a + f_q)}{F_{yc}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{s_{a.Sd} + s_{q.Sd}}{f_{cl.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$
$F_{ch} = \frac{1}{2} \frac{F_{yc}}{g_{Rc}} \cdot \left(x - \frac{2 \cdot f_q}{F_{yc}} + \sqrt{x^2 + 1.12 \cdot l^2 \frac{f_q}{F_{yc}}}\right)$ for $l < 1.34 \cdot \sqrt{\left(1 - \frac{2 \cdot f_q}{F_{yc}}\right)^{-1}}$	$f_{ch.Rd} = \frac{1}{2} \frac{f_{cl}}{g_M} \cdot \left(x - \frac{2 \cdot s_{q.Sd}}{f_{cl}} + \sqrt{x^2 + 1.12 \cdot l^2 \frac{s_{q.Sd}}{f_{cl}}}\right)$ for $l < 1.34 \cdot \sqrt{\left(1 - \frac{2 \cdot s_{q.Sd}}{f_{cl}}\right)^{-1}}$
$F_{ch} = \frac{0.9}{l^2} \frac{F_{yc}}{g_{Rc}}$ for $l \ge 1.34 \cdot \sqrt{\left(1 - \frac{2 \cdot f_q}{F_{yc}}\right)^{-1}}$	$f_{ch.Rd} = \frac{0.9}{l^2} \frac{f_{cl}}{g_M}$ for $l \ge 1.34 \cdot \sqrt{\left(1 - \frac{2 \cdot s_{q.Sd}}{f_{cl}}\right)^{-1}}$
$x = 1 - 0.28 \cdot l^2$	$x = 1 - 0.28 \cdot l^2$
when $f_a + f_b + f_q > 0.5 \frac{F_{he}}{g_{Rh}}$ and $\frac{F_{xe}}{g_{Rc}} > 0.5 \frac{F_{he}}{g_{Rh}}$	when $s_{a.Sd} + s_{m.Sd} + s_{q.Sd} > 0.5 \frac{f_{he}}{g_M}$ and $\cdot f_{cle} > 0.5 \cdot f_{he}$
then also treat as in method A for combined tension, bending & hydrostatic pressure	then also treat as in method A for combined tension, bending & hydrostatic pressure

Table 10.1   Interaction Formulae for Combined Axial Compression, Bending and Hydrostatic Pressure (1 of 2)

ISO	NORSOK
Method B f_{ac} is compressive	Method B $s_{ac.Sd}$ is compressive
$f_{ac} > f_q$	$s_{ac.Sd} > s_{q.Sd}$
$\frac{f_{ac}-f_q}{F_{ch}} + \frac{1}{F_{bh}} \cdot \left[\left(\frac{C_{my} \cdot f_{by}}{1-\frac{f_{ac}-f_q}{F_{ey}}} \right)^2 + \left(\frac{C_{mz} \cdot f_{bz}}{1-\frac{f_{ac}-f_q}{F_{ez}}} \right) \right]^{0.5} \le 1.0$	$\frac{s_{ac.Sd}-s_{q.Sd}}{f_{ch.Rd}} + \frac{1}{f_{mh.Rd}} \cdot \left[\left(\frac{C_{my} \cdot s_{my.Sd}}{1-\frac{s_{ac.Sd}-s_{q.Sd}}{f_{Ey}}} \right)^2 + \left(\frac{C_{mz} \cdot s_{mz.Sd}}{1-\frac{s_{ac.Sd}-s_{q.Sd}}{f_{Ez}}} \right)^2 \right]^{0.5} \le 1.0$
$\frac{g_{Rc} \cdot f_{ac}}{F_{yc}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{s_{ac.Sd}}{f_{cl.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$
when $f_{ac} + f_b > 0.5 \frac{F_{he}}{g_{Rh}}$ and $\frac{F_{xe}}{g_{Rc}} > 0.5 \frac{F_{he}}{g_{Rh}}$	when $s_{a.Sd} + s_{m.Sd} > 0.5 \frac{f_{he}}{g_M}$ and $\cdot f_{cle} > 0.5 \cdot f_{he}$
then also treat as in method A for combined tension, bending & hydrostatic pressure	then also treat as in method A for combined tension, bending & hydrostatic pressure
$f_{ac} \le f_q$	$s_{ac.Sd} \le s_{q.Sd}$
$\frac{g_{Rc} \cdot f_{ac}}{F_{yc}} + \frac{\sqrt{f_{by}^2 + f_{bz}^2}}{F_{bh}} \le 1.0$	$\frac{s_{ac.Sd}}{f_{cl.Rd}} + \frac{\sqrt{s_{my.Sd}^2 + s_{mz.Sd}^2}}{f_{mh.Rd}} \le 1.0$
when $f_{ac} + f_b > 0.5 \frac{F_{he}}{g_{Rh}}$ and $\frac{F_{xe}}{g_{Rc}} > 0.5 \frac{F_{he}}{g_{Rh}}$	when $s_{a.Sd} + s_{m.Sd} > 0.5 \frac{f_{he}}{g_M}$ and $\frac{f_{cle}}{g_M} > 0.5 \frac{f_{he}}{g_M}$
then also treat as in method A for combined tension, bending & hydrostatic pressure	then also treat as in method A for combined tension, bending & hydrostatic pressure

Table 10.1 Interaction Formulae for Combined Axial Compression, Bending and Hydrostatic Pressure (2 of 2)

11. DEFINITIONS OF CHARACTERISTIC EQUATIONS

The commentary to the ISO document gives some indications as to the criteria used in developing the characteristic equations given. No information is provided in NORSOK.

The screening of test data for use in developing characteristic equations was such that data were rejected if any of the following was true:

- absence of yield strength measurements
- absence of critical geometrical measurements
- initial geometry outside API RP 2A tolerances (with the exception of specimens subjected to external pressure)
- column strengths in excess of the Euler buckling load
- steel thickness ≤ 1.8 mm.

The characteristic equations for local buckling failure under axial compression (according to subsection A.13.2.2.2 of the ISO document) were developed by screening test data and establishing a curve with 95% survival at the 50% confidence interval that satisfied the following conditions:

- the material had a plateau of material characteristic yield strength over the range $0<F_y/F_{xe}<=0.17$
- the general form of the failure equation was as given in Table 4.1
- the failure equation converged to the elastic critical buckling curve with increasing member slenderness ratio
- the difference between the mean minus 1.645 standard deviations of test data and the developed equations was a minimum.

The ISO document also gives biases and coefficients of variation (COVs) for the ratio of experimentally observed resistance to that predicted by the characteristic equation corresponding to a number of the loading combinations. These statistics have been re-appraised using an amended database (derived from the original ISO databases) in a study commissioned by HSE [4]. The ISO document and study statistics are given in Table 11.1, below.

In the main, the differences between the biases and COVs of [3] and [4] are very small. The exceptional cases appear to be those for interaction equations involving hydrostatic pressure. In these cases, the differences are probably due to the way the statistical calculations were performed; whether on the interaction ratio [3], or iteratively along the individual load axes in failure space [4].

	ISO Document [3]			Study Document [4]		
Loading Type	Number	Bias	COV	Number	Bias	COV
Axial Compression (Local Buckling)	38	1.065	0.068	38	1.068	0.068
Axial Compression (Column Buckling)	84	1.057	0.041	84	1.063	0.045
Bending	Not given	1.109	0.085	57	1.109	0.085
Hydrostatic Pressure	Not given	1.142	0.124	44	1.142	0.124
Axial Compression, plus Bending (Local Buckling)	19	1.246	0.067	19	1.251	0.066
Axial Compression, plus Bending (Column Buckling)	49	1.029	0.082	49	1.029	0.082
Axial Compression, Bending, plus Hydrostatic Pressure (Local Buckling)	69	1.199	0.134	69	1.294	0.155
Axial Compression, Bending, plus Hydrostatic Pressure (Column Buckling)	26	1.197	0.091	26	1.252	0.112
Axial Tension plus Hydrostatic Pressure	34	1.075	0.098	34	1.103	0.112

Table 11.1   Statistics of Resistance Equations

12. CONCLUSIONS

Direct comparisons between the NORSOK [1] and ISO [3] provisions for the strength of tubular members are possible because they give formulations for tubular members under:

- axial tension
- bending
- compression
- hydrostatic pressure
- combined axial tension and bending
- axial compression combined with bending
- combined axial tension, bending and hydrostatic pressure
- combined axial compression bending and hydrostatic pressure

The 4th Edition Guidance Notes [2] do not contain specific formulations.

With the exception of the case of combined axial tension and bending for which additionally the actual interaction formulae in NORSOK and ISO differ, differences between the two standards in all loading cases are primarily due to partial safety factor differences. ISO uses constant partial safety factors in resistance formulations; whereas NORSOK uses variable partial safety factors that depend on the slenderness of the component and the severity of the loading. Thus, in the case of NORSOK, partial safety factors for both resistance and loading/actions may occur on the resistance side of the design equation.

A qualitative summary of the relative conservatisms of ISO versus NORSOK is given in Table 12.1. It should be emphasised that any such comparisons only deal with the resistance side. Any differences identified may be radically altered if there are differences between ISO and NORSOK with respect to partial safety factors on loading. Reliability studies, such as [5] may be the most suitable medium to explore such overall differences.

Load Action / Combination	Comment
tension	NORSOK more conservative, about 10%
bending	NORSOK more conservative, about 10%
compression	Negligible difference in practical cases
hydrostatic pressure	NORSOK can be more or less conservative, 16% or 8%
tension + bending	NORSOK can be more or less conservative, ± 10%
compression + bending	NORSOK more conservative, varies < ~ 15%
tension + bending + hydrostatic pressure	Difficult to assess because of pressure component
compression + bending + hydrostatic pressure	Difficult to assess because of pressure component

Table 12.1 Qualitative Comparison of Resistances ISO versus NORSOK

13. REFERENCES

1. NORSOK Standard. Design of Steel Structures. N-004. Rev 1, December 1998.

2. HSE 4th Edition Guidance Notes. Offshore Installations: Guidance on Design, Construction and Certification. 1993 Consolidated Edition with Amendment 3.

3. ISO. Petroleum and Natural Gas Industries - Offshore Structures - Part 2: Fixed Steel Structures. ISO/CD 13819-2. Draft 14.05.99.

4. MSL Engineering Limited. Load Factor Calibration for ISO 13819 Regional Annex - Component Resistances. Report prepared for HSE. Doc Ref C242R001, Rev 0, February 2000.

5. PAFA Consulting Engineers. Implications for Fixed Steel Structures of ISO 13819-2 Member Strength Formulations. Report prepared for HSE (draft final report). Doc Ref C031-002-R, Rev 0, March 1998.

APPENDIX A
LISTS OF SYMBOLS

ISO NOMENCLATURE	
m	geometric parameter
r	radius of gyration
t	wall thickness
B	ratio of hoop stress due to forces from factored hydrostatic pressure to factored characteristic hoop buckling strength
D	outside diameter
E	Young's modulus of elasticity
K	effective length factor
L	unbraced length in y or z direction, or length between stiffening rings, diaphragms or end connections
S	elastic section modulus
Z	plastic section modulus
f_a	calculated axial stress due to forces from factored actions that exclude capped-end actions
f_b	bending stress due to forces from factored actions
f_c	axial compressive stress due to forces from factored actions
f_h	hoop stress due to forces from factored hydrostatic pressure
f_t	axial tensile stress due to forces from factored actions
f_q	compressive stress from forces arising from factored capped-end actions due to hydrostatic pressure
f_{ac}	calculated axial stress due to forces from factored actions that include the capped-end actions
f_{by}	bending stress about member y-axis (in-plane) due to forces from factored actions
f_{bz}	bending stress about member z-axis (out-of-plane) due to forces from factored actions
C_h	[elastic hoop buckling strength coefficient]
C_x	critical elastic buckling coefficient
F_b	characteristic bending strength
F_c	characteristic axial compressive strength
F_h	characteristic hoop buckling strength
F_y	characteristic yield strength
C_{my}	moment reduction factor for the member y-direction
C_{mz}	moment reduction factor for the member z-direction
F_{bh}	design bending capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]

ISO NOMENCLATURE	
F_{ch}	design axial compression capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]
F_{ey}	Euler buckling strength corresponding to the member y-direction
F_{ez}	Euler buckling strength corresponding to the member z-direction
F_{he}	elastic hoop buckling strength
F_{th}	design axial tensile capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]
F_{xe}	characteristic elastic local buckling strength
F_{yc}	characteristic local buckling strength
λ	column slenderness parameter
η	factor
ξ	factor
γ_{Rb}	partial resistance factor for bending strength
γ_{Rc}	partial resistance factor for axial compressive strength
γ_{Rh}	partial resistance factor for hoop buckling strength
γ_{Rt}	partial resistance factor for axial tensile strength

NORSOK NOMENCLATURE	
radius of gyration	i
effective length factor	k
unbraced length in y or z direction, or length between stiffening rings, diaphragms or end connections	l
wall thickness	t
cross-sectional area	A
ratio of hoop stress due to forces from factored hydrostatic pressure to factored characteristic hoop buckling strength	B
outside diameter	D
Young’s modulus of elasticity	E
elastic section modulus	W
plastic section modulus	Z
characteristic axial compressive strength	f_c
characteristic hoop buckling strength	f_h
characteristic bending strength	f_m
characteristic yield strength	f_y
characteristic local buckling strength	f_{cl}
Euler buckling strength corresponding to the member y-direction	f_{Ey}
Euler buckling strength corresponding to the member z-direction	f_{Ez}
elastic hoop buckling strength	f_{he}
characteristic elastic local buckling strength	f_{cle}
[design hoop buckling resistance] [including partial safety factor]	$f_{h,Rd}$
design axial compression capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{ch,Rd}$
design characteristic local buckling strength [including partial safety factor]	$f_{cl,Rd}$
design bending capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{mh,Rd}$
design axial tensile capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{th,Rd}$
critical elastic buckling coefficient	C_e
[elastic hoop buckling strength coefficient]	C_h
moment reduction factor for the member y-direction	C_{my}
moment reduction factor for the member z-direction	C_{mz}
Euler buckling force corresponding to the member y-direction	N_{Ey}
Euler buckling force corresponding to the member z-direction	N_{Ez}
design axial force	N_{Sd}

NORSOK NOMENCLATURE	
design bending resistance [including partial safety factor]	M_{Rd}
design bending moment	M_{Sd}
design compressive resistance [including partial safety factor]	$N_{c,Rd}$
design tensile resistance [including partial safety factor]	$N_{t,Rd}$
design bending moment about member y-axis (in-plane)	$M_{y,Sd}$
design bending moment about member z-axis (out-of-plane)	$M_{z,Sd}$
column slenderness parameter	λ
geometric parameter	μ
factor	η
factor	ξ
partial material factor	γ_M
[slenderness parameter]	λ_s
calculated axial stress due to forces from factored actions that exclude capped-end actions	$\sigma_{a,Sd}$
bending stress due to forces from factored actions	$\sigma_{m,Sd}$
[design] hoop stress due to forces from factored hydrostatic pressure	$\sigma_{p,Sd}$
compressive stress from forces arising from factored capped-end actions due to hydrostatic pressure	$\sigma_{q,Sd}$
calculated axial stress due to forces from factored actions that include the capped-end actions	$\sigma_{ac,Sd}$
bending stress about member y-axis (in-plane) due to forces from factored actions	$\sigma_{my,Sd}$
bending stress about member z-axis (out-of-plane) due to forces from factored actions	$\sigma_{mz,Sd}$

ISO	EQUIVALENCE	NORSOK
f_t	axial tensile stress due to forces from factored actions	
	design axial force	N_{Sd}
F_y	characteristic yield strength	f_y
	design tensile resistance [including partial safety factor]	$N_{t,Rd}$
γ_{Rt}	partial resistance factor for axial tensile strength	
	partial material factor	γ_M
f_c	axial compressive stress due to forces from factored actions	
	cross-sectional area	A
F_c	characteristic axial compressive strength	f_c
	design compressive resistance [including partial safety factor]	$N_{c,Rd}$
γ_{Rc}	partial resistance factor for axial compressive strength	
λ	column slenderness parameter	λ
F_{yc}	characteristic local buckling strength	f_{cl}
	design characteristic local buckling strength [including partial safety factor]	$f_{cl,Rd}$
K	effective length factor	k
L	unbraced length in y or z direction, or length between stiffening rings, diaphragms or end connections	l
r	radius of gyration	i
E	Young’s modulus of elasticity	E
F_{xe}	characteristic elastic local buckling strength	f_{cle}
C_x	critical elastic buckling coefficient	C_e
D	outside diameter	D
t	wall thickness	t
f_b	bending stress due to forces from factored actions	$\sigma_{m,Sd}$
	design bending moment	M_{Sd}
F_b	characteristic bending strength	f_m
	design bending resistance [including partial safety factor]	M_{Rd}
γ_{Rb}	partial resistance factor for bending strength	
Z	plastic section modulus	Z
S	elastic section modulus	W
f_h	[design] hoop stress due to forces from factored hydrostatic pressure	$\sigma_{p,Sd}$
F_h	characteristic hoop buckling strength	f_h
γ_{Rh}	partial resistance factor for hoop buckling strength	
	[design hoop buckling resistance] [including partial safety factor]	$f_{h,Rd}$

ISO	EQUIVALENCE	NORSOK
F_{he}	elastic hoop buckling strength	f_{he}
C_h	[elastic hoop buckling strength coefficient]	C_h
m	geometric parameter	μ
f_{by}	bending stress about member y-axis (in-plane) due to forces from factored actions	$\sigma_{my,Sd}$
f_{bz}	bending stress about member z-axis (out-of-plane) due to forces from factored actions	$\sigma_{mz,Sd}$
	design bending moment about member y-axis (in-plane)	$M_{y,Sd}$
	design bending moment about member z-axis (out-of-plane)	$M_{z,Sd}$
C_{my}	moment reduction factor for the member y-direction	C_{my}
C_{mz}	moment reduction factor for the member z-direction	C_{mz}
F_{ey}	Euler buckling strength corresponding to the member y-direction	f_{Ey}
F_{ez}	Euler buckling strength corresponding to the member z-direction	f_{Ez}
	Euler buckling force corresponding to the member y-direction	N_{Ey}
	Euler buckling force corresponding to the member z-direction	N_{Ez}
f_a	calculated axial stress due to forces from factored actions that exclude capped-end actions	$\sigma_{a,Sd}$
f_q	compressive stress from forces arising from factored capped-end actions due to hydrostatic pressure	$\sigma_{q,Sd}$
F_{th}	design axial tensile capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{th,Rd}$
F_{bh}	design bending capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{mh,Rd}$
B	ratio of hoop stress due to forces from factored hydrostatic pressure to factored characteristic hoop buckling strength	B
η	factor	η
f_{ac}	calculated axial stress due to forces from factored actions that include the capped-end actions	$\sigma_{ac,Sd}$
F_{ch}	design axial compression capacity/resistance in the presence of external hydrostatic pressure [including partial safety factor]	$f_{ch,Rd}$
ξ	factor	ξ

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