BOEMRE Comparison of Offshore Standards - M10PC00108 – TA&R Project No. 677

Progress Meeting No. 2

28 February 2011

MANAGING RISK DNV

Agenda

- Introductions
- Work To-date
- Tasks and Schedule
- Summary/Recap

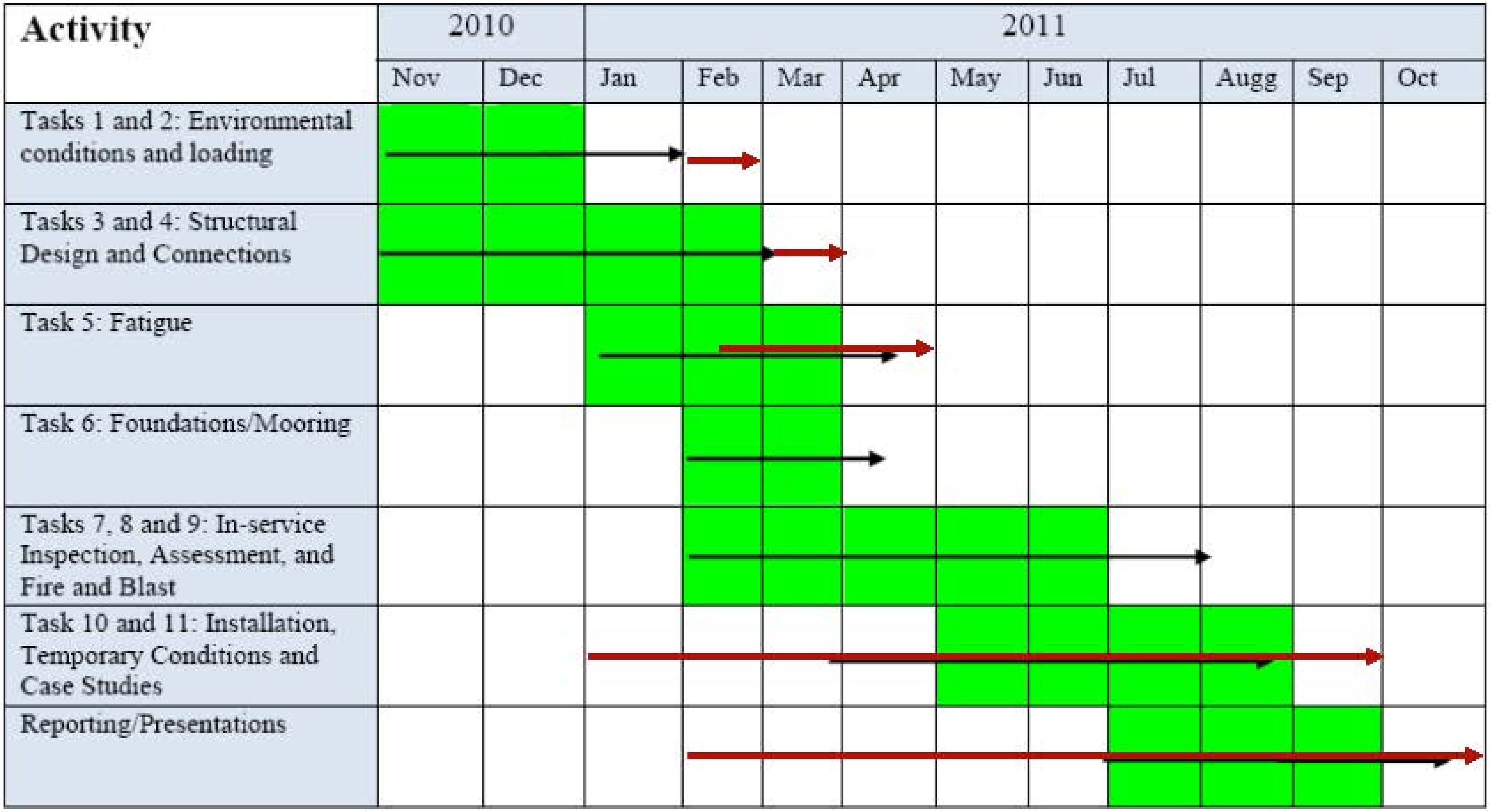
Work to-date

- Review of standards and TA&R reports
- Comparison of environmental loading recipe and loading conditions
- Jacket case study preliminary results
- Comparison of member and joint design formulae in the three Codes
- MATHCAD Calculation Sheets Developed
- Foundation design comparison underway

Tasks

1. Environmental Load Recipes	☑
2. Loading Conditions	☑
3. Structural Steel Design	
4. Connections	
5. Fatigue	
6. Foundation Design	
7. In-service inspection and maintenance	
8. Assessment of existing platforms and floaters	
9. Fire, blast and accidental loadings	
10. Installation, Temporary Conditions, and Case Studies	
11. Reporting	
12. Project Management	

Schedule


Activity
2010
2011
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Augg
Sep
Oct
Tasks 1 and 2: Environmental conditions and loading
Tasks 3 and 4: Structural Design and Connections
Task 5: Fatigue
Task 6: Foundations/Mooring
Tasks 7, 8 and 9: In-service Inspection, Assessment, and Fire and Blast
Task 10 and 11: Installation, Temporary Conditions and Case Studies
Reporting/Presentations

Possible Scope for Case Studies

High Level Scope of Case Study for Jacket Platforms:

- Verify the computer model in GeniE to ensure imported model is ready for analysis
- Run in place analysis for extreme (survival) load case
- Run code check using API RP-2A, ISO 19902, NORSOK N-004
- Preliminary foundation design using 3 codes
- Compare the results of code check (members and joints)
- Summarize the results

Assumptions:

- The case study is intended for a 4 legged-jacket platform of category L1 with production deck of small to medium size.
- The case study is intended to be a code check exercise for primary structural members and corresponding key structural joints of a limited number.

High Level Scope of Case Study for TLP:

- Verify the computer model in SESAM suite of programs to ensure imported model is ready for analysis
- Run in place analysis for extreme (survival) load case
- Run analysis to verify acceptance with criteria as set in API RP-2T, ISO 19904, NORSOK N-004
- Compare the results of analyses
- Summarize the results

Assumptions:

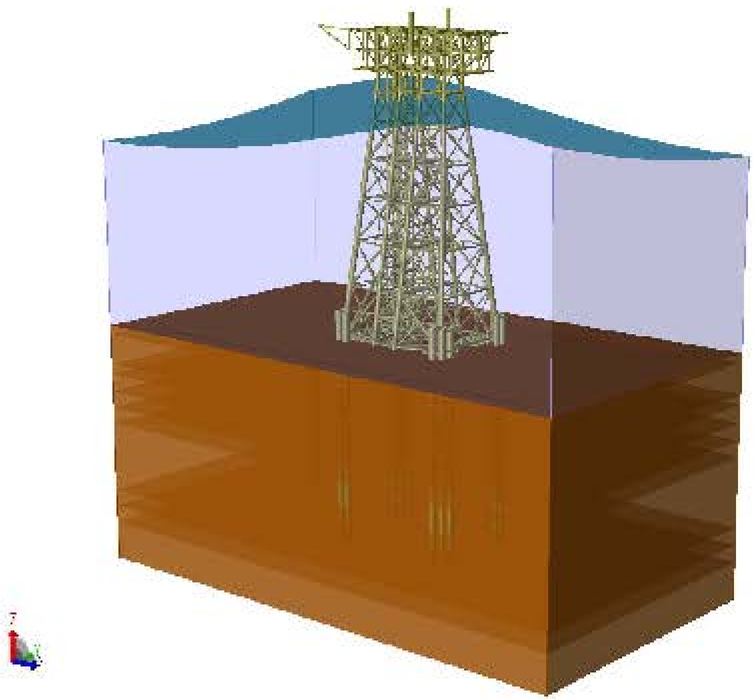
- The case study is intended to be an exercise in acceptance criteria for primary structural members of the hull. Topsides, tendons and foundations are not included as part of this evaluation.

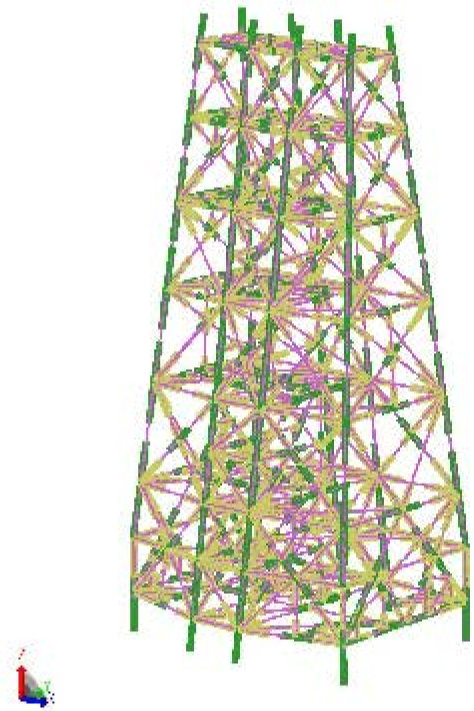
Case Study No. 1 – Fixed Platform in GoM

- Platform Overview

  The platform is located in water depth of 110 m in Central Zone of GoM. The jacket has eight legs with a total of 12 skirt piles installed at the mud line. The piles have 3.41m diameter and are 122 m long.

  The platform topsides has three levels: Drilling Deck, Wellhead Deck and Cellar Deck.





Case Study No. 1 – Fixed Platform in GoM (Contd.)

- In-place Analysis - The structure was modeled as an integrated 3D-space frame including foundation system, using GENIE (Wajac, Sestra, Splice) developed by DNV.
- Basic Load Cases
  - Permanent Loads (G):
    - Structural Self-weight (including modeled and non-modeled members)
    - Equipment loads (Cellar Deck Equipment, Wellhead Equipment, Drilling Deck Equipment)
    - Storage Loads
    - Piping Loads
  - Variable Loads (Q):
    - Area live loads;
    - Crane Loads
    - Rig Loads
  - Environmental Loads (E) :
    - Wind
    - Wave
    - Current
- All three analyses use identical: Permanent and Variable Loads, Marine Growth and Conductor Shielding for one-to-one code check comparison

Case Study No.1 – Fixed Platform in GoM (Contd.)

- **Results Comparisons for Case Study**
  - High level global loads comparison for Environmental Extreme Condition (Maximum Overturning Moment and Base Shear)
  - Comparison of Tubular Member and joint design for the jacket structure, for the following codes (using identical environmental loads)
    - API RP 2A Chapter 3
    - NORSOK N-004 Chapter 6
    - ISO 19902 Chapter 13
  - Comparison of equations and formulas used in three Codes
  - MATHCAD Calculation Sheets Developed

Case Study No.1 – Preliminary Comparison Results

- Global loads (Peak Wave Case)

		Max Base Shear		Max Overturning Mom.	
		MN	Phase	MNm	Phase
API	1	72.3	340	1926	330
	2	69.8	350	1605	330
	3	73.2	350	1683	120
	4	70.9	350	1770	340
	5	69.7	0	2054	340
	6	68.9	350	2170	340
	7	73.3	350	1988	330
	8	72.2	350	2037	330
	MAX	73.3	-	2170	-
ISO	1	72.7	340	1811	330
	2	72.5	350	1539	330
	3	75.6	350	1513	120
	4	71.3	350	1660	340
	5	70.0	0	1901	340
	6	71.4	350	2069	340
	7	75.7	350	1893	330
	8	72.7	350	1990	330
	MAX	75.7	-	2069	-
Norsok	1	70.3	340	1839	330
	2	68.1	350	1582	120
	3	72.1	350	1750	120
	4	67.1	350	1627	330
	5	67.5	0	1927	340
	6	67.2	350	2031	340
	7	72.2	350	1662	330
	8	68.3	350	1958	330
	MAX	72.2	-	2031	-

Case Study – Preliminary Comparison Results

- Maximum Member Utilization for API Code Check

		API		Utilization for Corresponding Members			
				ISO		NORSOK	
	Member	UF	Formula	UF	Formula	UF	Formula
1	513	1.33	3.3.4-3	0.93	13.2-31	0.80	6.15
2	505	1.32	3.3.4-3	0.93	13.2-31	0.79	6.15
3	1651	1.3	3.3.4-3	0.90	13.2-31	0.80	6.15
4	1622	1.29	3.3.4-3	0.90	13.2-31	0.80	6.15
5	96	1.19	3.3.3-1	0.81	13.2-31	0.64	6.15
6	2707	1.09	3.3.3-1	0.55	13.4-12	0.53	6.42
7	350	1.04	3.3.3-1	0.54	13.2-31	0.51	6.42
8	348	1.04	3.3.3-1	0.54	13.4-12	0.50	6.42
9	2708	1.04	3.3.3-1	0.54	13.2-31	0.50	6.42
10	342	1.03	3.3.3-1	0.72	13.2-31	0.54	6.15
11	351	1.02	3.3.3-1	0.54	13.2-31	0.50	6.42
12	3083	0.98	3.3.3-1	0.54	13.2-31	0.50	6.42
13	3090	0.97	3.3.3-1	0.77	13.4-19	0.73	6.15
14	343	0.96	3.3.3-1	0.72	13.2-31	0.54	6.15
15	346	0.95	3.3.3-1	0.54	13.2-31	0.46	6.42

Case Study – Preliminary Comparison Results

- Maximum Member Utilization for ISO and Norsok Code Checks

	ISO				NORSOK		
	Member	UF	Formula		Member	UF	Formula
1	740	1.54	13.6-21		740	1.43	6.71
2	462	1.47	13.6-21		462	1.37	6.71
3	1690	1.43	13.6-21		1690	1.33	6.71
4	461	1.35	13.6-21		461	1.26	6.71
5	41	1.29	13.6-21		41	1.17	6.71
6	36	1.18	13.6-21		36	1.07	6.71
7	31	1.12	13.6-21		31	1.02	6.71
8	749	1.09	13.6-21		749	1.00	6.71
9	10	1.02	13.6-21		10	0.93	6.71
10	21	1.01	13.6-21		21	0.92	6.71
11	647	0.99	13.6-21		647	0.92	6.71
12	646	0.98	13.6-21		646	0.91	6.71
13	748	0.95	13.6-21		748	0.88	6.71
14	2	0.94	13.6-21		2	0.86	6.71
15	505	0.93	13.6-31		432	0.84	6.71

Case Study – Preliminary Comparison Results

- Maximum Joint Utilization for API Code Check

		API		Utilization for Corresponding Members			
				ISO		NORSOK	
	Joint	UF	Formula	UF	Formula	UF	Formula
1	13	4.97	4.3-5 o	3.62	14.3-11 o	3.94	6.57 o
2	23	3.98	4.3-5 o	2.94	14.3-11 o	3.25	6.57 o
3	33	3.86	4.3-5	2.91	14.3-11	3.07	6.57
4	321	2.86	4.3-5	2.07	14.3-11	2.26	6.57
5	347	2.83	4.3-5	2.52	14.3-11 o	2.61	6.57 o
6	373	2.07	4.3-5	1.52	14.3-11	1.59	6.57
7	335	1.51	4.3-5	1.04	14.3-11	1.08	6.57
8	221	1.45	4.3-5 o	1.21	14.3-11 o	1.26	6.57 o
9	165	1.40	4.3-5 o	0.65	14.3-11	0.67	6.57
10	198	1.40	4.3-5 o	0.85	14.3-11	0.90	6.57 o
11	341	1.38	4.3-5	0.99	14.3-11	1.03	6.57
12	324	1.36	4.3-5	0.98	14.3-11 o	0.99	6.57
13	73	1.33	4.3-5 o	0.91	14.3-11 o	0.94	6.57 o
14	76	1.26	4.3-5 o	1.27	14.3-11 o	1.04	6.57 o
15	75	1.26	4.3-5 o	0.97	14.3-11 o	0.99	6.57 o

Case Study – Preliminary Comparison Results

- Maximum Joint Utilization for ISO and Norsok Code Checks

	ISO				NORSOK		
	Joint	UF	Formula		Joint	UF	Formula
1	13	3.62	14.3-11 o		13	3.94	6.57 o
2	23	2.94	14.3-11 o		23	3.25	6.57 o
3	33	2.91	14.3-11		33	3.07	6.57
4	347	2.52	14.3-11 o		347	2.61	6.57 o
5	321	2.07	14.3-11		321	2.26	6.57
6	373	1.52	14.3-11		373	1.59	6.57
7	76	1.27	14.3-11 o		221	1.26	6.57 o
8	221	1.21	14.3-11 o		335	1.08	6.57
9	335	1.04	14.3-11		15	1.06	6.57 o
10	15	1.02	14.3-11 o		76	1.04	6.57 o
11	341	0.99	14.3-11		341	1.03	6.57
12	324	0.98	14.3-11 o		75	0.99	6.57 o
13	75	0.97	14.3-11 o		324	0.99	6.57
14	73	0.91	14.3-11 o		73	0.94	6.57 o
15	181	0.86	14.3-11 o		181	0.91	6.57 o

Task 1 and Task 2 Summary

The following comparisons have been performed for Tasks 1 & 2 including:

- A direct comparison between environmental (Metocean) loads as stated in the three standards (API, NORSOK, and ISO).
- The provisions that impact on the magnitude of environmental loads e.g. directional wave criteria have been reviewed and compared.
- The elements that comprise the total environmental forces include wind, waves, tides, currents, and earthquakes.
- Load factors and material allowable factors are compared for the various elements of the structure (e.g. jacket, hull, deck, foundation, etc.).
- The manner in which the codes require the combination of appropriate dead and live loads has also been directly compared. This includes the following loads: operational environmental, extreme environmental, dead, live, and temporary.

Task 1 and Task 2 Summary (Cont'd)

- For the purpose of direct analysis, the governing weather condition (e.g. survival load case) is taken into account.
- Other load conditions (e.g., operating load case) are also considered if found necessary due to the associated safety factors and relative value of the environmental to permanent loading.
- Code requirements for strength and ductility level earthquakes (SLE & DLE) are also compared.

Comparison of equations and formulas in Codes

- Tubular Members Code Provisions – Table 1

COMPARISON - TABLE 1

API WSD

Stress/ Parameter	Formulation	Limits
	AXIAL TENSION	
	$F_t = 0.6F_y$	
	AXIAL COMPRESSION	
	Column Buckling	
	$F_a = \frac{(1-(Kl/r)^2/2Cc^2)F_y}{5/3+3(Kl/r)/8C_c-(Kl/r)^3/8C_c^3}$	$Kl/r<C_c$
	$F_a = 12\pi^2E/23(Kl/r)^2$	$Kl/r>C_c$
		$Cc = (2\pi^2E/F_y)^{1/2}$
	F_y in above eqn is lesser of F_{xe}, F_{xc}, or F_y	
	Local Buckling	
Elastic Local Buckling Stress		
	$F_{xe} = 2CEt/D$, $C=0.3$	$60< D/t <300$; $t>= 6$ mm
Inelastic Local Buckling Stress		
	$F_{xc} = F_y[1.64-0.23(D/t)^{1/4}]$	$60< D/t <300$; $t>= 6$ mm
	$F_{xc} = F_y$	
	BENDING	
	$F_b = 0.75F_y$	$D/t <= 10340/F_y$ (SI Units)
	$F_b = [0.84-1.74F_yD/Et]F_y$	$10340/F_y < D/t <= 20680/F_y$
	$F_b = [0.72-0.58F_yD/Et]F_y$	$20680/F_y<D/t<=300$
	SHEAR	
Beam Shear		
	$F_v = 0.4F_y$	
Torsional Shear		
	$F_{vt} = 0.4F_y$	

API LRFD

Stress/ Parameter	Formulation	Limits
	AXIAL TENSION	
f_t	$f_t <= \phi_t F_y$	$\phi_t = 0.95$
	AXIAL COMPRESSION	
f_c	$f_c <= \phi_c F_{cn}$	$\phi_c = 0.85$
	Column Buckling	
	$F_{cn} = (1-0.25\lambda^2)F_y$	$\lambda < 2^{0.5}$
	F_y/λ^2	$\lambda > 2^{0.5}$
	$\lambda = Kl/\pi r(F_y/E)^{1/2}$	
	F_y in above eqn is lesser of F_{xe}, F_{xc}, or F_y	
	Local Buckling	
Elastic Local Buckling Stress		
	$F_{xe} = 2CEt/D$, $C=0.3$	$60< D/t <300$; $t>= 6$ mm
Inelastic Local Buckling Stress		
	$F_{xc} = F_y[1.64-0.23(D/t)^{1/4}]$	$60< D/t <300$; $t>= 6$ mm
	$F_{xc} = F_y$	
	BENDING	
	$f_b <= \phi_b F_{bn}$	$\phi_b = 0.95$
	$F_{bn} = (Z/S)F_y$	$D/t <= 10340/F_y$ (Fy in MPa)
	$F_{bn} = [1.13-2.58F_yD/Et](Z/S)F_y$	$10340/F_y < D/t <= 20680/F_y$
	$F_{bn} = [0.94-0.76F_yD/Et](Z/S)F_y$	$20680/F_y<D/t<=300$
	SHEAR	
Beam Shear		
f_v	$f_v <= \phi_v F_{vn}$	$\phi_v = 0.95$
Torsional Shear		
f_{vt}	$f_{vt} <= \phi_v F_{vtn}$	$\phi_v = 0.95$

ISO

Stress/ Parameter	Formulation	Limits	
	AXIAL TENSION		
σ_t	$\sigma_t <= f_y/\gamma_{R,t}$	$\gamma_{R,t} = 1.05$	
	AXIAL COMPRESSION		
σ_c	$\sigma_c <= f_c/\gamma_{R,c}$	$\gamma_{R,c} = 1.05$	
	Column Buckling		
	$f_c = (1-0.28\lambda^2)f_{yc}$	$\lambda < 1.34$	
	$0.9f_{yc}/\lambda^2$	$\lambda > 1.34$	
	$\lambda = Kl/\pi r(f_{yc}/E)^{1/2}$		
	F_{yc} in above eqn is given by lesser of expressions below		
	$f_{yc} = f_y$	$f_y/f_{xe} <= 0.17$	
	$f_{yc} = (1.047 - 0.274f_y/f_{xe})f_y$	$0.17 < f_y/f_{xe}$	
	$f_{xe} = 2C_xEt/D$	$C_x=0.3$	
	BENDING		
	$\sigma_b = M/Z_e <= f_b/\gamma_{R,b}$	$\gamma_{R,b} = 0.95$	
	$f_b = (Z_p/Z_e)F_y$	$f_yD/Et <= 0.0517$	
	$f_b = [1.13-2.58F_yD/Et](Z_p/Z_e)F_y$	$0.0517 < f_yD/Et <= 0.1034$	
	$f_b = [0.94-0.76F_yD/Et](Z_p/Z_e)F_y$	$0.1034< f_yD/Et <= 120f_y/E$	
	$Z_e = \pi/64[D^4-(D-2t)^4]/(D/2)$		
	$Z_p = [D^3-(D-2t)^3]/6$		
	SHEAR		
Beam Shear			
	$\tau_b = 2V/A <= f_v/\gamma_{R,v}$	$f_v = f_y/3^{0.5}$	$\gamma_{R,v} = 1.05$
Torsional Shear			
	$\tau_t = M_vD/2I_p <= f_v/\gamma_{R,v}$	$f_v = f_y/3^{0.5}$	$\gamma_{R,v} = 1.05$

NORSOK

Stress/ Parameter	Formulation	Limits
	AXIAL TENSION	
	$N_{Sd} <= N_{t,Rd} = Af_y/\gamma_M$	$\gamma_M = 1.15$
	AXIAL COMPRESSION	
	$N_{Sd} <= N_{c,Rd} = Af_c/\gamma_M$	see below
	$\gamma_M = 1.15$	$\lambda < 0.5$
	$\gamma_M = 0.85+0.60\lambda_s$	$0.5 <= \lambda <= 1.0$
	$\gamma_M = 1.45$	$\lambda < 1.0$
	$\lambda_s = \sigma_{c,Sd}(f_y/f_{cle})^{1/2}/f_{cl} + (\sigma_{p,Sd}/f_{cl})^2(f_y/f_{he})^{1/2}$	
	$f_c = (1-0.28\lambda^2)f_y$	$\lambda < 1.34$
	$0.9f_y/\lambda^2$	$\lambda > 1.34$
	$\lambda = Kl/\pi r(f_{cl}/E)^{1/2}$	
	f_{cl} in above eqn is given by lesser of expressions below	
	$f_{cl} = f_y$	$f_y/f_{cle} < 0.17$
	$f_{cl} = (1.047 - 0.274f_y/f_{cle})f_y$	$0.17 < f_y/f_{cle} < 1.911$
	$f_{cl} = f_{cle}$	$f_y/f_{cle} > 1.911$
	$f_{cle} = 2C_eEt/D$	$C_e=0.3$
	BENDING	
	$M_{Sd} <= M_{Rd} = f_m W/\gamma_M$	see above for γ_M
	$f_m = (Z/W)F_y$	$f_yD/Et <= 0.0517$
	$f_m = [1.13-2.58F_yD/Et](Z/W)F_y$	$0.0517 < f_yD/Et <= 0.1034$
	$f_m = [0.94-0.76F_yD/Et](Z/W)F_y$	$0.1034< f_yD/Et <= 120f_y/E$
	$W = (\pi/32)(D^4-(D-2t)^4)/D$	
	$Z = [D^3-(D-2t)^3]/6$	
	SHEAR	
Beam Shear		
	$V_{Sd} <= V_{Rd} = 0.5Af_y/(3^{0.5}\gamma_M)$	$\gamma_M = 1.15$
Torsional Shear		
	$M_{T,Sd} <= 2I_pf_y/(D3^{0.5}\gamma_M)$	$\gamma_M = 1.15$

Comparison of equations and formulas in Codes (Cont'd)

- Tubular Members Code Provisions – Table 2

COMPARISON - TABLE 2

API WSD		API LRFD		ISO		NORSOK	
Stress/ Parameter Formulation	Limits	Stress/ Parameter Formulation	Limits	Stress/ Parameter Formulation	Limits	Stress/ Parameter Formulation	Limits
Hoop Buckling		Hoop Buckling		Hoop Buckling		Hoop Buckling	
$f_h = pD/2t <= F_{hc}/SF_h$		$f_h = pD/2t <= \phi_h F_{hc}$	$\phi_h = 0.80$	$\sigma_h = pD/2t <= f_h/\gamma_{Rh}$	$\gamma_{Rh} = 1.25$	$\sigma_{p,Sd} = p_{Sd}D/2t <= f_{hRd} = f_h/\gamma_M$	γ_M See Table 1
SF_h: safety factor;see section 3.3.5 in API							
$F_{hc} = F_{he}$	$F_{he} < 0.55F_y$	$F_{hc} = 0.7F_y(F_{he}/F_y)^{0.4} <= F_y$	$F_{he} > 0.55F_y$	$F_h = F_y$	$2.44F_y < F_{he}$	$f_h = f_y$	$2.44F_y < F_{he}$
$F_{hc} = 0.45F_y + 0.18F_{he}$	$0.55F_y < F_{he} < 1.6F_y$	$F_{hc} = F_{he}$	$F_{he} <= 0.55F_y$	$F_h = 0.7F_y(F_{he}/F_y)^{0.4}$	$0.55F_y < F_{he} < 2.44F_y$	$f_h = 0.7f_y(f_{he}/f_y)^{0.4}$	$0.55F_y < F_{he} < 2.44F_y$
$F_{hc} = 1.31F_y/(1.15 + F_y/F_{he})$	$0.55F_y < F_{he} < 1.6F_y$			$F_h = F_{he}$	$F_{he} < 0.55F_y$	$f_h = f_{he}$	$F_{he} < 0.55F_y$
$F_{hc} = F_y$	$6.2F_y < F_{he}$						
$F_{he} = 2C_hEt/D$		$F_{he} = 2C_hEt/D$		$F_{he} = 2C_hEt/D$		$f_{he} = 2C_hEt/D$	
$C_h = 0.44t/D$	$1.6D/t < M$	$C_h = 0.44t/D$	$1.6D/t < M$	$C_h = 0.44t/D$	$1.6D/t < \mu$	$C_h = 0.44t/D$	$1.6D/t < \mu$
$C_h = 0.44t/D + 0.21(D/t)^3/M^4$	$0.825D/t < M < 1.6D/t$	$C_h = 0.44t/D + 0.21(D/t)^3/M^4$	$0.825D/t < M < 1.6D/t$	$C_h = 0.44t/D + 0.21(D/t)^3/\mu^4$	$0.825D/t < \mu < 1.6D/t$	$C_h = 0.44t/D + 0.21(D/t)^3/\mu^4$	$0.825D/t < \mu < 1.6D/t$
$C_h = 0.736/(M-0.636)$	$3.5 <= M < 0.825D/t$	$C_h = 0.737/(M-0.636)$	$1.5 <= M < 0.825D/t$	$C_h = 0.737/(\mu-0.636)$	$1.5 <= \mu < 0.825D/t$	$C_h = 0.737/(\mu-0.636)$	$1.5 <= \mu < 0.825D/t$
$C_h = 0.755/(M-0.559)$	$1.5 <= M < 3.5$	$C_h = 0.8$	$M < 1.5$	$C_h = 0.8$	$\mu < 1.5$	$C_h = 0.8$	$\mu < 1.5$
$C_h = 0.8$	$M < 1.5$						
$M = L/D\,(2D/t)^{1/2}$		$M = L/D\,(2D/t)^{1/2}$		$\mu = L/D\,(2D/t)^{1/2}$			
TENSION and BENDING		TENSION and BENDING		TENSION and BENDING		TENSION and BENDING	
$f_t/0.6F_y + (f_{bx}^2 + f_{by}^2)^{1/2}/F_b < 1.0$		$1-\cos[\pi/2\, f_t/(\phi_t F_{y})] + (f_{by}^2 + f_{bz}^2)^{0.5}/\phi_b F_{bn} < 1$		$\gamma_{Rt} f_t/F_y + \gamma_{Rb}(f_{by}^2 + f_{bz}^2)^{1/2}/F_b < 1.0$		$(N_{Sd}/N_{tRd})^{1.75} + (M_{y,Sd}^2 + M_{z,Sd}^2)^{1/2}/M_{Rd} <= 1.0$	
COMPRESSSION and BENDING		COMPRESSSION and BENDING		COMPRESSSION and BENDING		COMPRESSSION and BENDING	
$f_a/F_a + C_m(f_{bx}^2 + f_{by}^2)^{1/2}/[(1-f_a/F_e')F_b] < 1.0$ or $f_a/F_a + \{[C_{mx}f_{bx}/(1-f_a/F_{ex}')]^2 + [C_{my}f_{by}/(1-f_a/F_{ey}')]^2\}^{1/2}/F_b < 1.0$ and $f_a/0.6F_y + (f_{bx}^2 + f_{by}^2)^{1/2}/F_b < 1.0$		$f_c/(\phi_c F_{cn}) + \{[C_{my}f_{by}/(1-f_c/(\phi_c F_{ey}))]^2 + [C_{mz}f_{bz}/(1-f_c/(\phi_c F_{ez}))]^2\}^{0.5}/(\phi_b F_{bn}) < 1.0$ and $1-\cos[\pi/2\, f_c/(\phi_c F_{xc})] + (f_{by}^2 + f_{bz}^2)^{0.5}/(\phi_b F_{bn}) < 1$ $F_c < \phi_c F_{xc}$		$\gamma_{Rc}\sigma_c/f_c + \gamma_{Rb}/f_b\{[C_{my}\sigma_{by}/(1-\sigma_c/f_{ey})]^2 + [C_{mz}\sigma_{bz}/(1-\sigma_c/f_{ez})]^2\}^{0.5} <= 1.0$ and $\gamma_{Rc}\sigma_c/f_{yc} + \gamma_{Rb}(\sigma_{by}^2 + \sigma_{bz}^2)^{0.5}/f_b <= 1.0$ $f_{ey} = \pi^2E/(K_yL_y/r)^2$	$f_{ez} = \pi^2E/(K_zL_z/r)^2$	$N_{Sd}/N_{cRd} + 1/M_{Rd}\{[C_{my}M_{y,Sd}/(1-N_{Sd}/N_{Ey})]^2 + [C_{mz}M_{z,Sd}/(1-N_{Sd}/N_{Ez})]^2\}^{0.5} <= 1.0$ and $N_{Sd}/N_{cRd} + (M_{y,Sd}^2 + M_{z,Sd}^2)^{1/2}/M_{Rd} <= 1.0$ $N_{cl,Rd} = f_cA/\gamma_M$ $N_{Ey} = \pi^2EA/(kl/i)_y^2$	$N_{Ez} = \pi^2EA/(kl/i)_z^2$

Comparison of equations and formulas in Codes (Cont'd)

- Tubular Members Code Provisions – Table 3

COMPARISON - TABLE 3

API WSD	API LRFD	ISO	NORSOK
Stress/ Parameter Formulation	Stress/ Parameter Formulation	Stress/ Parameter Formulation	Stress/ Parameter Formulation
TENSION, BENDING AND HYDROSTATIC PRESSURE $A^2 + B^2 + 2\nu\|A\|B \le 1.0$ $A = [(f_t + f_b - 0.5f_h)/F_y]SF_t$ $B = [f_h/F_{hc}]SF_h$ $\nu = 0.3$ SF_t = Axial Tension Safety Factor SF_h = Hoop Compression Safety Factor	TENSION, BENDING AND HYDROSTATIC PRESSURE $A^2 + B^2 + 2\nu\|A\|B \le 1.0$ $A = (f_t + f_b - 0.5f_h)/\phi_t F_y$ $B = f_h/(\phi_h F_{hc})$ $\nu = 0.3$ $\eta = 5 - 4F_{hc}/F_y$	TENSION, BENDING AND HYDROSTATIC PRESSURE $\gamma_{R,t}\sigma_t/f_{th} + \gamma_{R,b}(\sigma_{by}^2 + \sigma_{bz}^2)^{0.5}/f_{bh} \le 1.0$ $f_{th} = f_t[(1+0.09B^2-B^{2\eta})^{0.5} - 0.3B]$ $f_{bh} = f_b[(1+0.09B^2-B^{2\eta})^{0.5} - 0.3B]$ $B = \gamma_{R,h}\sigma_h/f_h$ $B \le 1.0$ $\eta = 5 - 4f_h/f_y$	TENSION, BENDING AND HYDROSTATIC PRESSURE Method A If $\sigma_{a,Sd} \ge \sigma_{p,Sd}$ (net axial tension condition) $(\sigma_{a,Sd} - \sigma_{p,Sd})/f_{t,h,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{m,h,Rd} \le 1.0$ $f_{t,h,Rd} = f_y/\gamma_M[(1+0.09B^2-B^{2\eta})^{0.5} - 0.3B]$ $f_{m,h,Rd} = f_m/\gamma_M[(1+0.09B^2-B^{2\eta})^{0.5} - 0.3B]$ γ_M = see Table 1 $\lambda = Kl/\pi i(f_y/E)^{1/2}$ $\eta = 5 - 4f_h/f_y$ $B = \sigma_{p,Sd}/f_{h,Rd}$ $B \le 1.0$ If $\sigma_{a,Sd} < \sigma_{p,Sd}$ (net axial compression condition) $(\sigma_{a,Sd} - \sigma_{p,Sd})/f_{c,h,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{m,h,Rd} \le 1.0$ $f_{c,h,Rd} = f_y/\gamma_M$ when $\sigma_{c,Sd} > 0.5 f_{he}/\gamma_M$ and $f_{cle} > 0.5f_{he}$, the following eqn should be satisfied. $(\sigma_{c,Sd} - 0.5f_{he}/\gamma_M)/(f_{cle}/\gamma_M - 0.5f_{he}/\gamma_M) + (\sigma_{p,Sd}/(f_{he}/\gamma_M))^2 \le 1.0$ $\sigma_{c,Sd} = \sigma_{a,Sd} + \sigma_{m,Sd} - \sigma_{q,Sd}$ $\sigma_{m,Sd} = (M_{y,Sd}^2 + M_{z,Sd}^2)^{0.5}/W$ Method B ($\sigma_{a,Sd}$ is in tension) $\sigma_{at,Sd}/f_{th,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{mh,Rd} \le 1.0$
COMPRESSION, BENDING AND HYDROSTATIC PRESSURE $[(f_a + 0.5f_h)/F_{xc}]SF_x + [f_b/F_y](SF_b) \le 1.0$ $[f_h/F_{hc}]SF_h \le 1.0$ If $f_x > 0.5F_{ha}$ then $(f_x - 0.5F_{ha})/(F_{aa} - 0.5F_{ha}) + (f_h/F_{ha})^2 \le 1.0$ $F_{ha} = F_{hc}/SF_h$ $F_{aa} = F_{xc}/SF_x$	COMPRESSION, BENDING AND HYDROSTATIC PRESSURE $f_h = pD/2t \le \phi_h = 0.80$ $F_{hc} = 0.7F_y(F_{he}/F_y)^{0.4}$ $F_{he} > 0.55F_y$ $F_{hc} = F_{he}$ $F_{he} < 0.55F_y$ and $f_c/(\phi_c F_{cn}) + ([C_{my}f_{by}/(1-f_c/\phi_c F_{ey})]^2 + [C_{mz}f_{bz}/(1-f_c/\phi_c F_{ez})]^2)^{0.5}/\phi_b F_{bn} < 1.0$ and $1 - \cos[(\pi/2)(f_c/\phi_c F_{xc})] + (f_{by}^2 + f_{bz}^2)^{0.5}/\phi_b F_{bn} < 1$ and $F_c < \phi_c F_{xc}$ If $f_x > 0.5\phi_h F_{hc}$ then $(f_x - 0.5\phi_h F_{hc})/(\phi_t F_{xc} - 0.5\phi_h F_{hc}) + (f_h/\phi_h F_{hc})^2 \le 1.0$	COMPRESSION, BENDING AND HYDROSTATIC PRESSURE $\gamma_{R,c}\sigma_c/f_{ch} + \gamma_{R,b}(\sigma_{by}^2 + \sigma_{bz}^2)^{0.5}/f_{bh} \le 1.0$ and $\gamma_{R,c}\sigma_c/f_{ch} + \gamma_{R,b}/f_{bh}\{[C_{my}\sigma_{by}/(1-\sigma_c/f_{ey})]^2 + [C_{mz}\sigma_{bz}/(1-\sigma_c/f_{ez})]^2\}^{0.5} \le 1.0$ $f_{ch} = 0.5f_{yc}[(1.0-0.278\lambda^2) - 2\sigma_h/f_{yc} + [(1.0-0.278\lambda^2)^2 + 1.12\lambda^2\sigma_h/f_{yc}]^{0.5}]$ for $\lambda \le 1.34[1-2\sigma_h/f_{yc}]^{-0.5}$ $f_{ch} = 0.9f_{yc}/\lambda^2$ for $\lambda > 1.34[1-2\sigma_h/f_{yc}]^{-0.5}$ If $\sigma_c > 0.5f_{he}/\gamma_{R,h}$ and $f_{xe}/\gamma_{R,c} > 0.5f_{he}/\gamma_{R,h}$, the following eqn shall also be satisfied: $(\sigma_c - 0.5f_{he}/\gamma_{R,h})/(f_{xe}/\gamma_{R,c} - 0.5f_{he}/\gamma_{R,h}) + (\gamma_{R,h}\sigma_h/f_{he})^2 \le 1.0$	COMPRESSION, BENDING AND HYDROSTATIC PRESSURE Method A ($\sigma_{a,Sd}$ is in compression) $\sigma_{a,Sd}/f_{c,h,Rd} + 1/f_{m,h,Rd}\{[C_{my}\sigma_{my,Sd}/(1-\sigma_{a,Sd}/f_{Ey})]^2 + [C_{mz}\sigma_{mz,Sd}/(1-\sigma_{a,Sd}/f_{Ez})]^2\}^{0.5} \le 1.0$ and $(\sigma_{a,Sd} + \sigma_{p,Sd})/f_{th,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{mh,Rd} \le 1.0$ $f_{Ey} = \pi^2E/(k_y l_y/i_y)^2$ $f_{Ez} = \pi^2E/(k_z l_z/i_z)^2$ $f_{c,h,Rd} = 0.5f_y/\gamma_M[\xi - 2\sigma_{p,Sd}/f_y + (\xi^2 + 1.12\lambda^2\sigma_{p,Sd}/f_y)^{0.5}]$ for $\lambda < 1.34[1-2\sigma_{p,Sd}/f_y]^{-0.5}$ $f_{c,h,Rd} = 0.9f_y/(\lambda^2\gamma_M)$ for $\lambda \ge 1.34[1-2\sigma_{p,Sd}/f_y]^{-0.5}$ when $\sigma_{c,Sd} > 0.5 f_{he}/\gamma_M$ and $f_{cle} > 0.5f_{he}$, the following eqn should be satisfied. $(\sigma_{c,Sd} - 0.5f_{he}/\gamma_M)/(f_{cle}/\gamma_M - 0.5f_{he}/\gamma_M) + (\sigma_{p,Sd}/(f_{he}/\gamma_M))^2 \le 1.0$ $\sigma_{c,Sd} = \sigma_{a,Sd} + \sigma_{m,Sd} + \sigma_{q,Sd}$ Method B ($\sigma_{a,Sd}$ in Compression) (a) ($\sigma_{a,Sd} > \sigma_{q,Sd}$) $(\sigma_{a,Sd} - \sigma_{q,Sd})/f_{c,Rd} + 1/f_{m,Rd}\{[C_{my}\sigma_{my,Sd}/(1-(\sigma_{a,Sd}-\sigma_{q,Sd})/f_{Ey})]^2 + [C_{mz}\sigma_{mz,Sd}/(1-(\sigma_{a,Sd}-\sigma_{q,Sd})/f_{Ez})]^2\}^{0.5} \le 1.0$ and $\sigma_{at,Sd}/f_{th,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{mh,Rd} \le 1.0$ when $\sigma_{c,Sd} > 0.5 f_{he}/\gamma_M$ and $f_{cle} > 0.5f_{he}$, the following eqn should be satisfied. $(\sigma_{c,Sd} - 0.5f_{he}/\gamma_M)/(f_{cle}/\gamma_M - 0.5f_{he}/\gamma_M) + (\sigma_{p,Sd}/(f_{he}/\gamma_M))^2 \le 1.0$ $\sigma_{c,Sd} = \sigma_{m,Sd} + \sigma_{at,Sd}$ $\sigma_{m,Sd} = (M_{y,Sd}^2 + M_{z,Sd}^2)^{0.5}/W$ (b) ($\sigma_{a,Sd} < \sigma_{q,Sd}$) $\sigma_{at,Sd}/f_{th,Rd} + (\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)^{0.5}/f_{mh,Rd} \le 1.0$ when $\sigma_{c,Sd} > 0.5 f_{he}/\gamma_M$ and $f_{cle} > 0.5f_{he}$, the following eqn should be satisfied. $(\sigma_{c,Sd} - 0.5f_{he}/\gamma_M)/(f_{cle}/\gamma_M - 0.5f_{he}/\gamma_M) + (\sigma_{p,Sd}/(f_{he}/\gamma_M))^2 \le 1.0$ $\sigma_{c,Sd} = \sigma_{m,Sd} + \sigma_{at,Sd}$ $\sigma_{m,Sd} = (M_{y,Sd}^2 + M_{z,Sd}^2)^{0.5}/W$

Comparison of equations and formulas in Codes (Cont'd)

- Tubular Joint Code Provisions (General and Qu Factors)

API WSD

Validity Range

$0.2 <= \beta <= 1.0$
$10 <= \gamma <= 50$
$30^\circ <= \theta <= 90^\circ$
$F_y <= 72$ ksi (500 MPa)
$g/D > -0.6$ (for K joints)

Basic Capacity

$P_a = Q_u Q_f F_{yc} T^2/(FS\sin\theta)$
$M_a = Q_u Q_f F_{yc} T^2 d/(FS\sin\theta)$
(plus 1/3 increase in both cases where applicable)
$FS = 1.60$

Strength Check

$IR = |P/P_a| + (M/M_a)_{ipb}^2 + |M/M_a|_{opb} <= 1.0$

Strength Factor Q_u

Joint	Brace Load: Axial Tension	Axial Compr.	IPB	OPB
K	$(16+1.2\gamma)\beta^{1.2}Q_g$ but $<= 40\beta^{1.2}Q_g$	$(16+1.2\gamma)\beta^{1.2}Q_g$ but $<= 40\beta^{1.2}Q_g$	$(5+0.7\gamma)\beta^{1.2}$	$2.5+(4.5+0.2\gamma)\beta^{2.6}$
T/Y	30β	$2.8+(20+0.8\gamma)\beta^{1.6}$ but $<= 2.8+36\beta^{1.6}$		
X	23β for $\beta <= 0.9$; $20.7+(\beta-0.9)(17\gamma-220)$ for $\beta > 0.9$	$[2.8+(12+0.1\gamma)\beta]Q_\beta$		

$Q_\beta = 0.3/[\beta(1-0.833\beta)]$ for $\beta > 0.6$
$Q_\beta = 1.0$ for $\beta <= 0.6$

$Q_g = 1+0.2[1-2.8g/D]^3$ for $g/D >= 0.05$
but $>= 1.0$

$Q_g = 0.13+0.65\phi\gamma^{0.5}$ for $g/D <= -0.05$ where $\phi = tF_{yb}/(TF_y)$

Chord Load Factor Q_f

$Q_f = [1+C_1(FSP_c/P_y)-C_2(FSM_{ipb}/M_p)-C_3A^2]$
$A = [(FSP_c/P_y)^2 + (FSM_c/M_p)^2]^{0.5}$
where 1/3 increase applicable, FS=1.20

Value for C_1, C_2, C_3

Joint Type	C_1	C_2	C_3
K joints under brace axial loading	0.2	0.2	0.3
T/Y joints under brace axial loading	0.3	0	0.8
X joints under brace axial loading $\beta <= 0.9$	0.2	0	0.5
$\beta = 1.0$	-0.2	0	0.2
All joints under brace moment loading	0.2	0	0.4

API LRFD

The connections at the ends of tension and compression members:
$(\gamma\sin\theta)\beta[11+1.5/\beta](F_a/F_y) <= 1.0$

Ultimate Capacity

$P_{uj} = F_y T^2 Q_u Q_f/\sin\theta$
$M_{uj} = F_y T^2 (0.8d) Q_u Q_f/\sin\theta$

Strength Check

$P_D < \phi_j P_{uj}$
$M_D < \phi_j M_{uj}$
$1-\cos[\pi/2(P_D/\phi_j P_{uj})] + [(M_D/\phi_j M_{uj})_{ipb}^2 + (M_D/\phi_j M_{uj})_{opb}^2]^{0.5} <= 1.0$

$\phi_j = 0.95$ except for tension loaded Y, T and X joints when $\phi_j = 0.90$

Values for Q_u

Joint	Axial Tension	Axial Compr.	IPB	OPB
K	$(3.4+19\beta)Q_g$		$(3.4+19\beta)$	$(3.4+19\beta)Q_\beta$
T & Y	$(3.4+19\beta)$		$(3.4+19\beta)$	$(3.4+19\beta)Q_\beta$
Cross Joint W/O diaphragms	$(3.4+19\beta)$	$(3.4+19\beta)Q_\beta$		
Cross Joint W diaphragms	$(3.4+19\beta)$			

$Q_\beta = 0.3/[\beta(1-0.833\beta)]$ for $\beta > 0.6$
$Q_\beta = 1.0$ for $\beta <= 0.6$

$Q_g = 1.8-0.1g/T$ for $\gamma <= 20$
$Q_g = 1.8-4g/D$ for $\gamma > 20$
but $Q_g >= 1.0$

$Q_f = 1.0-\lambda A^2$
$\lambda = 0.030$ for brace axial stress
0.045 for brace IPB stress
0.021 for brace OPB stress

$A = (f_{AX}^2 + f_{IP}^2 + f_{OP}^2)^{1/2}/(\phi_c F_y)$
$\phi_c = 0.95$

Set $Q_f = 1.0$ when all extreme fibre stresses in the chord are tensile

ISO 19902

Validity Range

$0.2 <= \beta <= 1.0$
$10 <= \gamma <= 50$
$30^\circ <= \theta <= 90^\circ$
$f_y <= 500$ N/mm²
$g/T > -1.2\gamma$ (for K joints)

Basic Capacity

$P_{uj} = Q_u Q_f f_y T^2/(\sin\theta)$
$M_{uj} = Q_u Q_f f_y T^2 d/(\sin\theta)$

Strength Check

$IR = |P_d/P_j| + (M_d/M_j)_{ipb}^2 + |M_d/M_j|_{opb} <= 1.0$ for all joints

$IR = |P_d/P_j| + (M_d/M_j)_{ipb}^2 + |M_d/M_j|_{opb} <= U_j/\gamma_{R}$ for critical joints
$\gamma_R = 1.17$

$P_j = P_{uj}/\gamma_{Rj}$
$M_j = M_{uj}/\gamma_{Rj}$ $\gamma_{Rj} = 1.05$

Values for Q_u

Joint	Axial Tension	Axial Compression	IPB	OPB
K	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$
Y	30β	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$
X	20β for $\beta <= 0.9$; $20.7+(\beta-0.9)(17\gamma-220)$ for $\beta > 0.9$	$[2.8+(12+0.1\gamma)\beta]Q_\beta$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$

$Q_\beta = 0.3/[\beta(1-0.833\beta)]$ for $\beta > 0.6$
$Q_\beta = 1.0$ for $\beta <= 0.6$

$Q_g = 1.9-0.7\gamma^{-0.5}(g/T)^{0.5}$ for $g/T >= 2.0$, but $Q_g >= 1.0$
for $-2.0 < g/T < +2.0$, the gap factor Q_g may be found by linear interpolation.
$Q_g = 0.13+0.65\phi\gamma^{0.5}$ for $g/T <= -2.0$
where $\phi = f_{yb}t/(Tf_y)$

$Q_f = 1.0-\lambda q_A^2$
$\lambda = 0.030$ for brace axial stress
0.045 for brace IPB stress
0.021 for brace OPB stress
$q_A = [C_1(P_c/P_y)^2 + C_2(M_c/M_p)_{ipb}^2 + C_2(M_c/M_p)_{opb}^2]^{0.5}\gamma_{R,q}$
$\gamma_{R,q} = 1.05$

Values for the coefficient C_1 and C_2

Joint Type	C_1	C_2
forces	25	11
X joints for calculating strength against brace axial	20	22
K joints for calculating strength against brace axial	14	43
All Joints for calculating strength against brace moments	25	43

NORSOK N-004

Validity Range

$0.2 <= \beta <= 1.0$
$10 <= \gamma <= 60$
$30^\circ <= \theta <= 90^\circ$
$g/D > -0.6$ (for K joints)

Basic Resistance

$N_{Rd} = Q_u Q_f f_y T^2/(\gamma_M \sin\theta)$
$M_{Rd} = Q_u Q_f f_y T^2 d/(\gamma_M \sin\theta)$
$\gamma_M = 1.15$

Strength Check

$N_{Sd}/N_{Rd} + (M_{y,Sd}/M_{y,Rd})^2 + M_{z,Sd}/M_{z,Rd} <= 1$

Values for Q_u

Joint	Axial Tension	Axial Compression	IPB	OPB
K	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$
Y	30β	$(1.9+19\beta)Q_\beta^{0.5}Q_g$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$
X	20β for $\beta <= 0.9$; $20.7+(\beta-0.9)(17\gamma-220)$ for $\beta > 0.9$	$[2.8+(12+0.1\gamma)\beta]Q_\beta$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$

$Q_\beta = 0.3/[\beta(1-0.833\beta)]$ for $\beta > 0.6$
$Q_\beta = 1.0$ for $\beta <= 0.6$

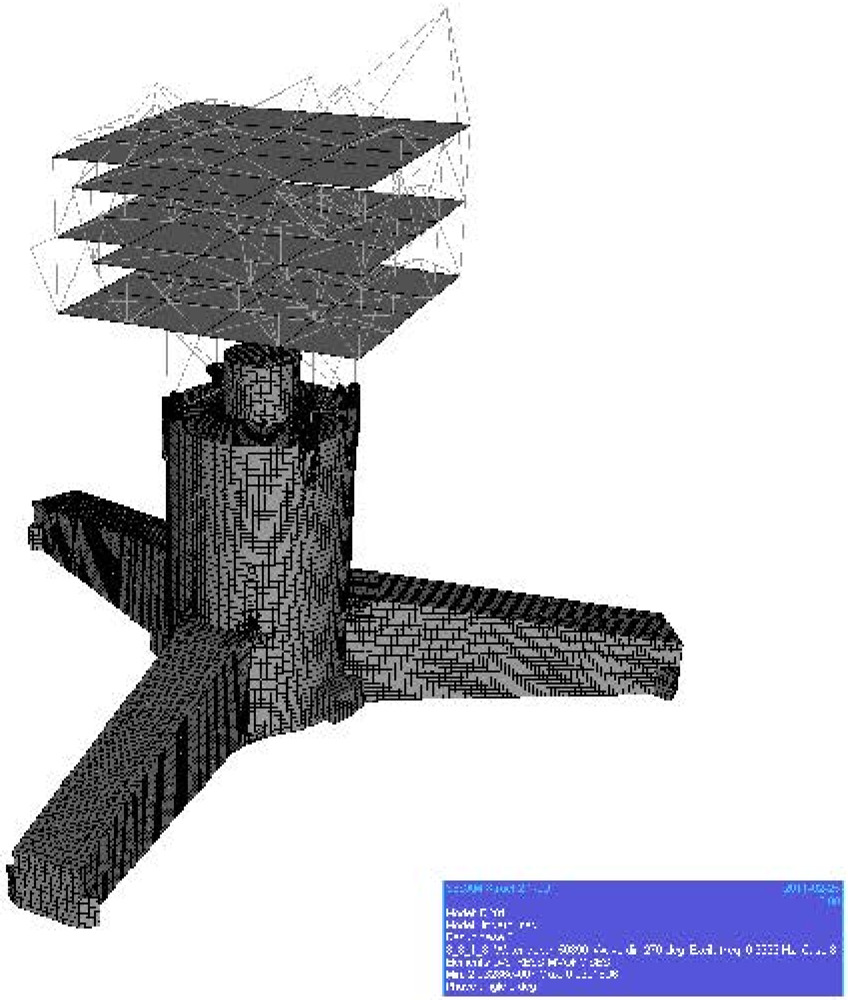
$Q_g = 1.9-0.7\gamma^{-0.5}(g/T)^{0.5}$ for $g/T >= 2.0$, but $Q_g >= 1.0$
but $>= 1.0$
$Q_g = 0.13+0.65\phi\gamma^{0.5}$ for $g/T <= -2.0$
where $\phi = f_{yb}t/(Tf_y)$

$Q_f = 1.0-\lambda A^2$
$\lambda = 0.030$ for brace axial stress
0.045 for brace IPB stress
0.021 for brace OPB stress
$A^2 = C_1(\sigma_{a,Sd}/f_y)^2 + C_2(\sigma_{my,Sd}^2 + \sigma_{mz,Sd}^2)/(1.62f_y^2)$

Values for C_1 and C_2

Joint Type	C_1	C_2
T/Y joints under brace axial forces	25	11
X joints under brace axial forces	20	22
K joints under balanced brace axial forces	20	22
All Joints under brace moments	25	30

TLP Model Plot for Floater Case Study



Summary

- Reviewed project progress to date
- Case studies status
- API, NORSOK, and ISO Standards applied to a Jacket platform case study Preliminary results presented.
- Tasks 3, 4 and 6 Underway
- Future tasks
- Next deliverable
- Next Progress GoToMeeting

Further comments

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