2017

Guidance for Structural Strength Assessment of Pump Tower of LNG Carriers

KR

APPLICATION OF "GUIDANCE FOR STRUCTURAL STRENGTH ASSESSMENT OF PUMP TOWER OF LNG CARRIERS "

1. Unless expressly specified otherwise, the requirements in the Guidance apply to LNG Carriers for which contracts for construction are signed on or after 1 July 2017.

CONTENTS

CHAPTER 1   GENERAL

Section 1   General

101. Application

1. This Guidance is to apply to structural strength assessment of the pump tower of the membrane LNG Carriers.

2. The requirements of this guidance shall apply in addition to the other requirement of the Rules.

Section 2   Introduction

201. Outline

1. The pump tower system consists of pipes and pumps to load and discharge the liquid cargo and tubular members to support the structure(see **Fig. 1)**. The pump tower is located close to the aft bulkhead, hanging over the liquid dome and connected to base support at the tank bottom. In addition, pumps are installed at the bottom for loading and discharging of liquid cargo. The structural integrity of these systems is critical for the safe operation of the LNG carrier.

2. Since the pump tower is exposed to the cryogenic cargo in the cargo tank, thermal stresses is to be considered and consideration is to be given at the support, and the LNG motion in the cargo tank and the load due to the motions of the ship should also be taken into account.

3. Approval of the structural design of the pump tower systems has typically been made based on the analysis and assessment provided by the designers of the systems.
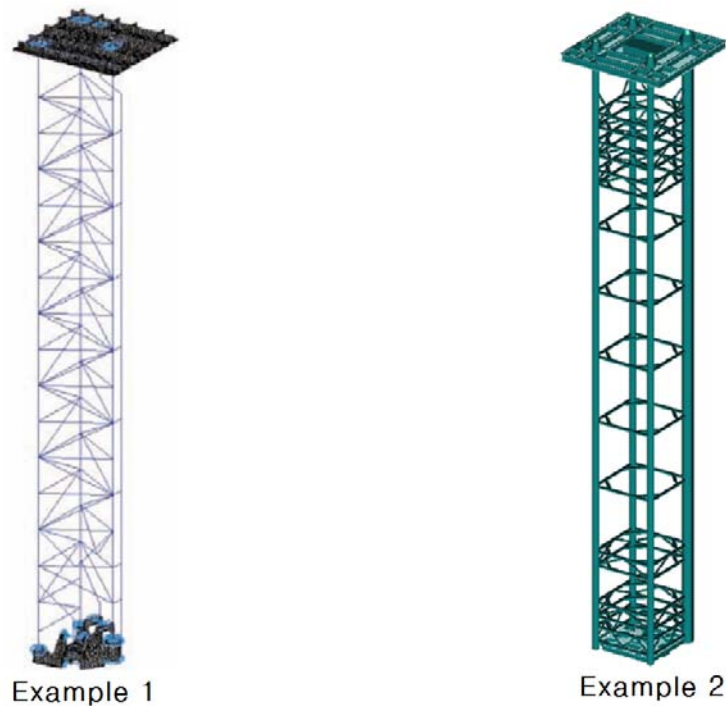

Example 1   Example 2

Fig 1 Example of Pump tower system

202. Pump tower assessment procedure

The analysis procedure provided in this Guidance is a first-principle-based, direct calculation approach to identify the critical sloshing load on the pump tower during its design life and to evaluate the structural integrity of the pump tower under that load. The overall analysis procedure for the strength assessment of pump tower is shown in **Fig. 2**.
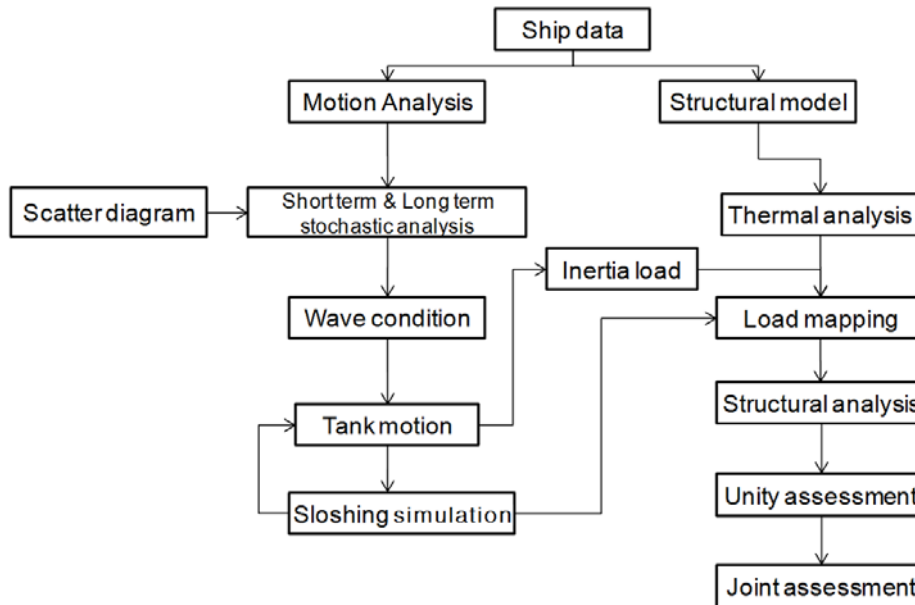

Fig 2 Analysis procedure for strength assessment of pump tower

203. Structural assessment of pump tower

1. Ship motion analysis

Follow **Guidance for Assessment of Sloshing Load and Structural Strength of Cargo Containment System**.

2. Selection of critical sloshing wave conditions

Follow **Guidance for Assessment of Sloshing Load and Structural Strength of Cargo Containment System**.

3. Sloshing analysis

Follow **Guidance for Assessment of Sloshing Load and Structural Strength of Cargo Containment System**.

4. Selection of Load Cases for Structural Analysis

Follow **Ch 2, Sec 2**.

5. FE analysis of pump tower structure

The structural members of the pump tower are to be modeled by appropriate FE models such as plate, shell or beam elements. The boundary conditions at the top and bottom ends of the pump tower may require special attention. Part of the liquid dome structure at the top of the pump tower is to be included in the structural model for accurate definition of the boundary condition at the top.

6. Acceptance criteria

Follow **Ch 3, Sec 3**.

7. Fatigue analysis

Fatigue strength assessment of the pump tower is based on the hot spot stress approach. The struc-

tural details, e.g., tubular joints in the pump tower, need to be evaluated in terms of the fatigue strength. Applicable dynamic loads are considered. Appropriate SCFs (Stress Concentration Factors) are to be applied in the stress range calculation.

8. Vibration analysis

The free and forced vibration(if necessary) of pump tower due to main engine and propeller are considered. Excessive vibration is to be avoided in order to reduce the risk of structural damage such as cracking on the liquid dome, base plate, or tubular joints of pump tower structure. The acceptance criteria for pump tower vibration are provided in terms of the vibration limits for local structures.

Section 3 Equivalency

301. Equivalency

Alternative special method and procedure will be accepted by the Society, provided that the Society is satisfied that such construction, equipment, arrangement and scantlings are equivalent to those required in the Rules.

Section 4 Documents

401. Documents

The following materials should be submitted to the Society and to be reviewed by the Society. In addition, if deemed necessary, the Society may require the submission of date other than those specified below.

1. Motion analysis data

(1) Input data of the motion analysis(loading conditions, the draft, the metacenter height and the gravity center of ship, etc)
(2) Model data of motion analysis
(3) Detail result of motion analysis
(4) Analysis data of critical sea state and wave condition for the model test.

2. CFD data

(1) Verification data of CFD Software
(2) Data of critical sloshing wave condition
(3) CFD analysis model
(4) CFD analysis result
(5) Analysis data of the design sloshing load

3. Structural assessment data of the pump tower

(1) Pump tower modeling and structural analysis
(2) Fatigue analysis result
(3) vibration analysis result

4. Reference data

(1) Main source of the ship
(2) Restrictions on cargo operations, such as limiting the height of the cargo loading, cooling down speed
(3) Layout of cargo containment system in each cargo hold
(4) General arrangement of ship with the cargo containment system installed
(5) Design constraints of the cargo containment system ⚓

CHAPTER 2   LOADS ON PUMP TOWER

Section 1   General

101. General

Sloshing load, thermal load, inertial load and tank internal pressure are to be applied to the structural strength assessment of the pump tower. Pump torque is to be considered separately, as the pump is not used during the voyage of the LNG carrier.

Section 2   Loads

201. Sloshing load

The sloshing load due to the fluid obtained from the ship's motion analysis and sloshing CFD analysis (see **Fig. 3**) is to be selected for the moment having the maximum value in both the transverse direction and the longitudinal direction, and the load distribution at that time is to be applied to the structure. In this case, the load due to the fluid is to be calculated using the Morrison equation. When applying a load to the pump tower structure, it is to be applied to the distribution load using the Morrison equation in the same way. The sloshing load per unit length of the structure is to be calculated by calculating the fluid acceleration and velocity according to the height at the pump tower position. The Morrison equation for the sloshing load applied to the pump tower is as follows.

$$\frac{dF_s}{ds} = \frac{1}{2}\rho_L C_D U_n |U_n| D_{mem} + \rho_L C_M \frac{dU_n}{dt} A_{mem}$$

dF_s/ds : sectional force due to sloshing on the wetted portion of the structure (N/mm)

s : length coordinate along the tubular member

ρ_L : liquid density (ton/mm^3)

U_n : liquid velocity normal to the member (mm/s)

dU_n/dt : liquid acceleration normal to the member (mm/s^2)

C_D : drag coefficient, 0.7 for cylinder

C_M : inertia coefficient, 2.0 for cylinder

D_{mem}: diameter of the structure (mm)

A_{mem}: vertical cross section area of the structure (mm^2)
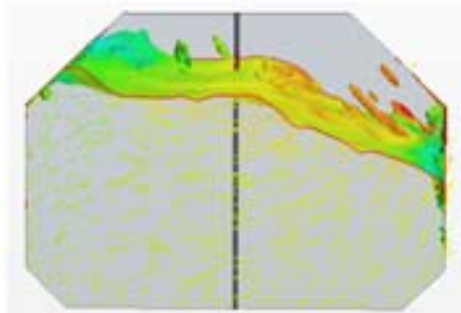

Fig 3   Sloshing simulation using CFD

202. Thermal load

Since the length of the pump tower is very long compared to the cross-sectional area of the structural member, thermal expansion or contraction is a major load factor. According to the stack height of the LNG, as shown in **Fig. 4**, it is assumed that the temperature up to the point of direct contact with LNG is -163 °C , and -30 °C is the bottom surface of liquid dome. It is assumed that from the free surface of the LNG to the bottom surface of liquid dome is linearly distributed.
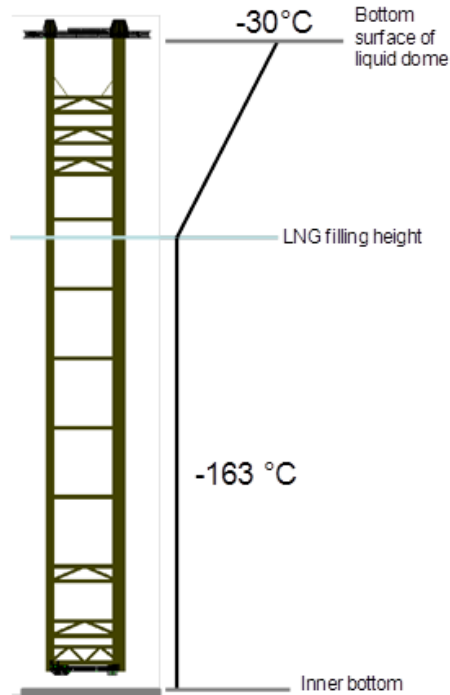

Fig 4   Assumption of temperature distribution

203. Inertial load

The inertial load due to the ship's motion at the time of maximum sloshing load is to be calculated and applied to the pump tower itself. The inertial load consists of the translational acceleration of the ship, the acceleration in the tank position due to the rotational acceleration, and its own weight by the pitch and roll angles.(Refer to **Guidance for Assessment of Sloshing Load and Structural Strength of Cargo Containment System)**

204. Tank internal pressure

The vapor pressure present in the cargo tank is applied to the bottom of the liquid dome cover. In general, a pressure of 0.25 bar or more(refer to IGC code) is to be considered as static pressure. ⚓

CHAPTER 3 STRUCTURAL STRENGTH ASSESSMENT

Section 1 Structure modeling

101. Analysis Model Scope and Structure Modeling

The pump tower structure consists of liquid dome cover, tubular members, and base plate (see **Fig. 5**). To assess the strength of the tubular members, the liquid dome cover and the base plate is to be included in the model. The liquid dome cover is connected to the hatch coaming of the cargo tank of the vessel and the lower support is connected to another support fixed to the inner bottom. The model for the lower support is sufficient for the evaluation of the tubular members. The strength assessment for the liquid dome cover and the base plate is to be evaluated in separate models and boundary conditions.
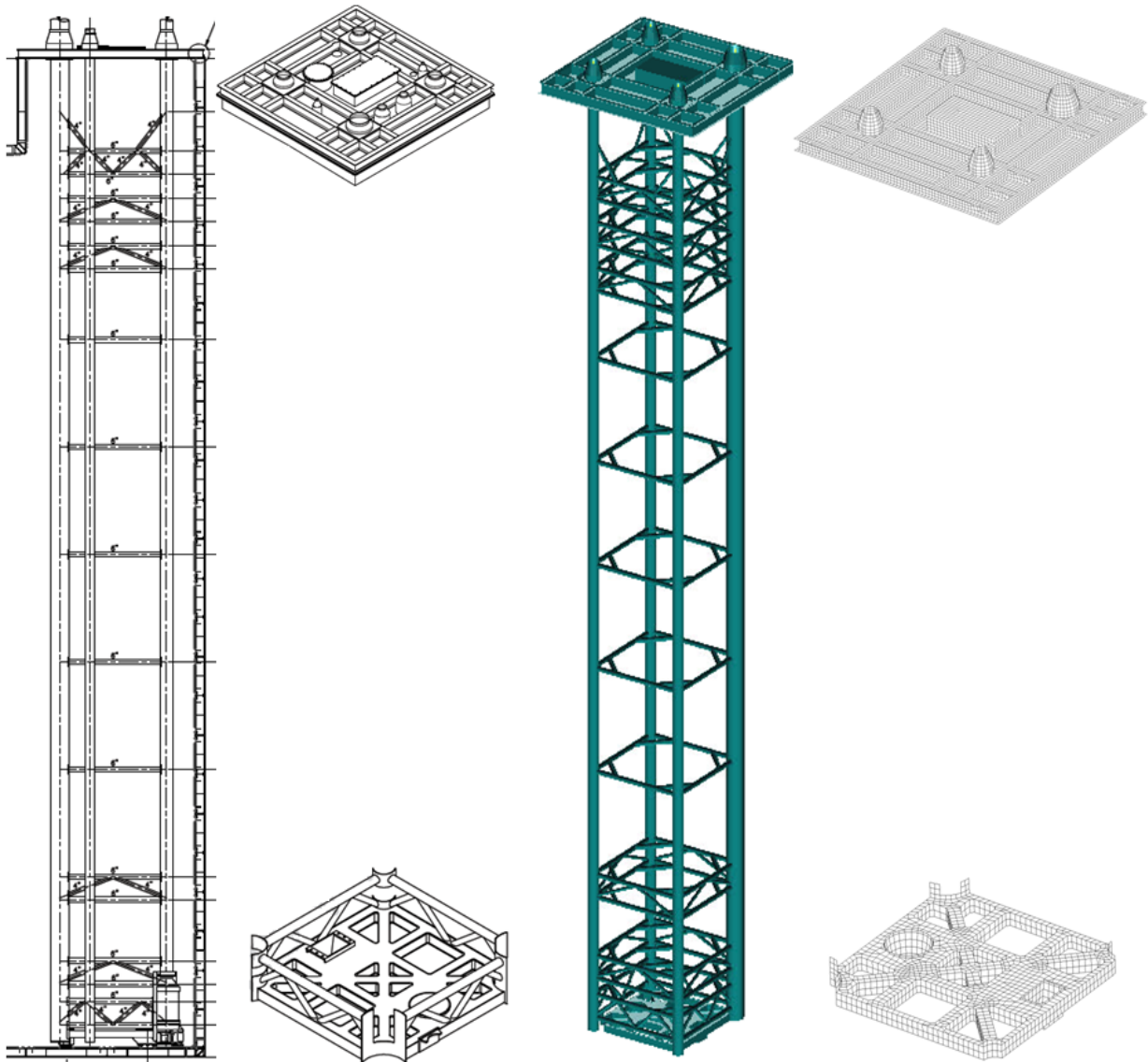

Fig 5 Example of Pump tower model

1. The liquid dome cover and the base plate are modeled using plate elements, the element size is to be sufficient to express the shape and the maximum size is 100 mm x 100 mm. The tubular members are modeled as beam elements.

   The rigid link element is used because the area where the tubular members and the liquid dome cover are welded and the area where the base plate and the tubular members are in contact are modeled by the plate elements and the beam elements.

2. The pump tower is typically made of 300 series stainless steel. The material properties used in the analysis, such as elastic modulus and thermal expansion coefficient, are shown in **Table 1** (Example: stainless steel 304L). The temperature-dependent elastic modulus and thermal expansion coefficient are calculated by linear interpolation using the values for the temperatures given in **Table 1**.

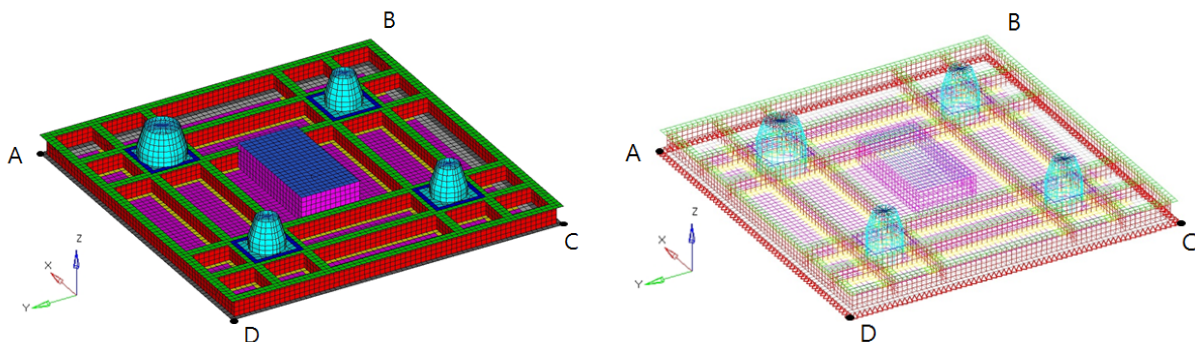**Table 1 Material properties of stainless steel 304L**

Elastic modulus	193 GPa (20 °C) 203 GPa (-163 °C)
Poisson's ratio	0.3
Density	7.85 x 10^{-9} ton/mm3
Thermal expansion coefficient	-185°C : 1.33 x 10^{-5} mm/mm/°C -130°C : 1.39 x 10^{-5} mm/mm/°C -70°C : 1.48 x 10^{-5} mm/mm/°C -20°C : 1.57 x 10^{-5} mm/mm/°C 0 ~ 100°C : 1.72 x 10^{-5} mm/mm/°C

Section 2   Boundary conditions

201. Boundary conditions

The example of boundary conditions is to comply with the following.

1. Liquid dome cover

Example of boundary conditions

	Coord.	Displacement			Rotation		
Position		U_x	U_y	U_z	θ_x	θ_y	θ_z
$\overline{AB}$, $\overline{BC}$, $\overline{CD}$, $\overline{DA}$		1	1	1	1	1	1
(Remark) 1 : Fixed 0 : Free							

2. Base plate
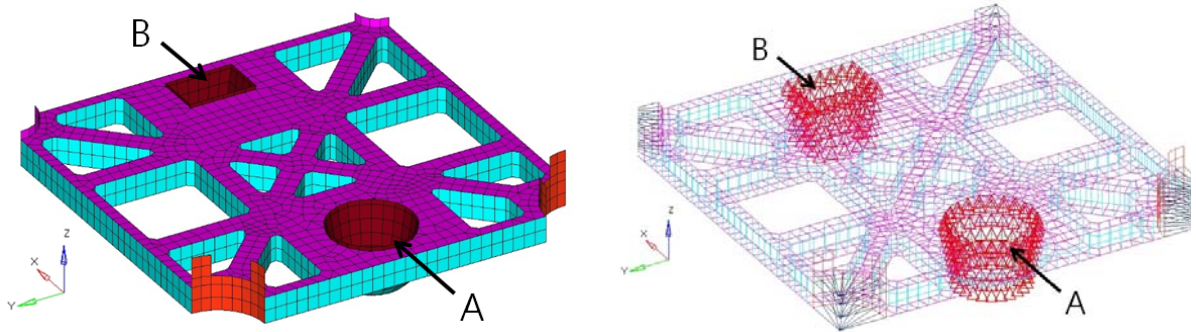
Example of boundary conditions

Position \ Coord.	Displacement			Rotation		
	U_x	U_y	U_z	θ_x	θ_y	θ_z
A(main support)	1	1	0	1	1	0
B(sub support)	0	1	0	1	0	1
(Remark) 1 : Fixed 0 : Free						

Section 3   Strength assessment

301. Tubular members

Strength assessment for tubular members is performed for yielding and buckling etc.. If there is an approach based on experimental data on the material used for the pump tower, acceptance criteria is to be determined based on this. When a detailed analysis is not available, the equations provided below are to be used to assess the yielding and buckling strength for tubular members in the pump tower.

1. Axial tension and shear

$$\sigma_{a\_t} \leq \eta_a \sigma_y$$

σ_{a_t} : tensile stress from FE analysis

η_a : 0.9 (normal stress), 0.52 (shear stress)

σ_y : 170 (N/mm^2)

2. Axial Compression

$$\sigma_{a\_c} \leq \eta_a \sigma_{cr}$$

σ_{a_c} : compressive stress from FE analysis

η_a : 0.783 (if $\sigma_{el} \leq \sigma_y$)

$$0.9 - 0.0827 \sqrt{\sigma_y / \sigma_{el}} \quad (\text{if } \sigma_{el} > \sigma_y)$$

σ_{el} : elastic buckling stress(N/mm^2)

$$\sigma_{el} = \pi^2 E / (\frac{k\ell}{r})^2$$

E : elastic modulus for stainless steel (N/mm^2)

k : 1.0 (for filling, discharge, emergency pipe)

    0.8 (for brace, strut)

ℓ : length of members (mm)

r : radius of gyration (mm)

$$r = \sqrt{I/A}$$

I : moment of inertia (mm^4)

A : cross sectional area (mm^2)

σ_{cr} : critical buckling stress (N/mm^2)

$$\sigma_{cr} = \pi^2 E_t / (\frac{k\ell}{r})^2$$

E_t : tangent modulus for stainless steel

$$E_t = E[1 + 0.002 \frac{E\,n}{\sigma_y} (\frac{\sigma_{cr}}{\sigma_y})^{n-1}]^{-1}$$

n : 7.2, knee factor

3. Bending moment

$$\sigma_{b\_act} \leq \eta_b \sigma_b$$

σ_{b_act} : bending stress from FE analysis

$$\sigma_{b\_act} = M / Z_e$$

M : Bending moment (N-mm)

Z_e : elastic section modulus (mm^3)

$$Z_e = (\pi/64) [D^4 - (D - 2t)^4] / (D/2)$$

D, t : as specified in **Fig 6.** (mm)

η_b : 0.9

σ_b : bending strength (N/mm^2)

$$\sigma_b = (Z_p/Z_e)\sigma_y \quad (\text{for } \sigma_y D/(Et) \le 0.02)$$
$$\sigma_b = \left[1.038 - 1.9\,\sigma_y D/(Et)\right](Z_p/Z_e)\sigma_y \quad (\text{for } 0.02 < \sigma_y D/(Et) \le 0.1)$$
$$\sigma_b = \left[0.921 - 0.73\,\sigma_y D/(Et)\right](Z_p/Z_e)\sigma_y \quad (\text{for } \sigma_y D/(Et) > 0.1)$$

Z_p : plastic section modulus (mm^3)

$$Z_p = (1/6)\left[D^3 - (D - 2t)^3\right]$$

4. Combined Loads(Axial Tension and Bending Moment)

$$\left[\sigma_{a\_t}/(\eta_a\sigma_y)\right] + \left[\sigma_{b\_act}/(\eta_b\sigma_b)\right] \le 1$$

5. Combined Loads(Axial Compression and Bending Moment)

$$\left[\sigma_{a\_c}/(\eta_a\sigma_{cr})\right] + \left[C_m\sigma_{b\_act}/\left\{\eta_b\sigma_b(1 - \sigma_{a\_c}/(\eta_a\sigma_{el}))\right\}\right] \le 1 \quad (\text{for } (\sigma_{a\_c}/\sigma_{cr}) > 0.15)$$
$$\left[\sigma_{a\_c}/(\eta_a\sigma_{cr})\right] + \left[\sigma_{b\_act}/(\eta_a\sigma_b)\right] \le 1 \quad (\text{for } (\sigma_{a\_c}/\sigma_{cr}) \le 0.15)$$

C_m: which is the lesser of 0.85 or $1 - 0.4\left[\sigma_{a\_c}/(\eta_a\sigma_{el})\right]$

6. Local buckling

$$\sigma_{a\_b} \le \eta_{local}\,\sigma_{local}$$

$$\sigma_{a\_b} = \sigma_{a\_c} + \sigma_{b\_act}$$
η_{local} : 0.75 (if $\sigma_{local} \le 0.55\,\sigma_y$)
$\qquad 0.566 + 0.334\,\sigma_{local}/\sigma_y$ (if $\sigma_{local} > 0.55\,\sigma_y$)
σ_{local} : critical local buckling stress
$\qquad = 0.6\,E_t\,t/D$

302. Tubular Joints

The tubular joints are the part where the chord and the brace are welded and each chord/brace inter-section is to be classified as T, Y or K, according to their configuration and load pattern for each load case.

The assessment of tubular joints is to be evaluated in consideration of bending, punching shear, and axial stress. **Fig 6** shows the force and general shape of a tubular joint.
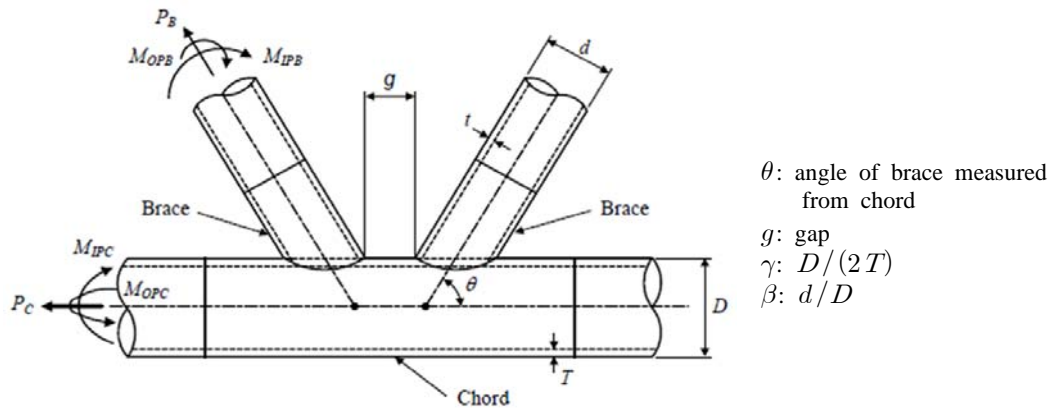
θ: angle of brace measured from chord

g: gap

γ: $D/(2\,T)$

β: d/D

Fig 6 Geometry and geometric parameters of tubular joint

1. The strength of tubular joints is to comply with the following formula.

$$\left|\frac{F_A}{\mu F_{U\_A}}\right| + \left(\frac{M_{IPB}}{\mu\,M_{U\_IPB}}\right)^2 + \left|\frac{M_{OPB}}{\mu M_{U\_OPB}}\right| \leq 1$$

F_A : axial load in the brace member (N)

M_{IPB} : in-plane bending moment in the brace member (N-mm)

M_{OPB} : out-of-plane bending moment in the brace member (N-mm)

μ : 0.9, safety factor

F_{U_A} : tubular joint strength for brace axial load (N)

M_{U_IPB} : tubular joint strength for brace in-plane bending moment (N-mm)

M_{U_OPB}: tubular joint strength for brace out-of-plane bending moment (N-mm)

$$F_{U\_A} = \frac{\sigma_y\,T^2}{\sin\theta}\,Q_u\,Q_f$$

$$M_{U\_IPB} \text{ or } M_{U\_OPB} = \frac{\sigma_y\,T^2\,d}{\sin\theta}\,Q_u\,Q_f$$

F_{U_A} : critical joint axial strength (N)

M_{U_IPB} : critical joint bending moment strength for in-plane bending (N-mm)

M_{U_OPB}: critical joint bending moment strength for out-of plane bending (N-mm)

θ : as specified in **Fig 6**

σ_y : as specified in 301. 1.

Q_u : strength factor depending on the joint loading and classification, as determined in **Table 2**

Q_f : chord load factor

       $Q_f = 1 - \lambda\gamma A^2$

     λ : 0.030   (for brace axial load)

          0.045   (for brace in-plane bending moment)

          0.021   (for brace out-of-plane bending moment)

     γ : as specified in **Fig 6**

$$A = \frac{\sqrt{\sigma_{nominal\_a}^2 + \sigma_{nominal\_IPB}^2 + \sigma_{nominal\_OPB}^2}}{\mu \sigma_y}$$

$\sigma_{nominal\_a}$: nominal axial stress in the chord member (N/mm^2)

$\sigma_{nominal\_IPB}$: nominal in-plane bending stress in the chord member (N/mm^2)

$\sigma_{nominal\_OPB}$: nominal out-of-plane bending stress in the chord member (N/mm^2)

μ : 0.9, safety factor

Table 2 Strength Factor, Q_u

Joint Classification	Axial load		Bending load	
	Compression	Tension	In-plane	Out-of-plane
K	$(0.5 + 12\beta)\gamma^{0.2} Q_\beta^{0.5} Q_g$	$(0.65 + 15.5\beta)\gamma^{0.2} Q_\beta^{0.5} Q_g$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$
T & Y	$(0.5 + 12\beta)\gamma^{0.2} Q_\beta^{0.5}$	$(0.65 + 15.5\beta)\gamma^{0.2} Q_\beta^{0.5}$	$4.5\beta\gamma^{0.5}$	$3.2\gamma^{(0.5\beta^2)}$

$$Q_\beta = 0.3/[\beta(1 - 0.833\beta)] \quad \text{for} \ \beta > 0.6$$
$$\quad\quad = 1.0 \quad \text{for} \ \beta \leq 0.6$$
$$Q_g = 1 + 0.85\,e^{(-4g/D)} \quad \text{for} \ g/D \geq 0$$

g : as specified in **Fig 6.** (mm)

γ, β : as specified in **Fig 6**

303. Liquid dome cover and base plate

1. FE model

The evaluations of the liquid dome cover and base plate structure require more detailed FE models than **101.**.

2. Strength Criterion

The strength of the liquid dome cover and base plate structure is to comply with the following formula.

$$\sigma_e \leq \mu \sigma_y$$

$$\sigma_e = \sqrt{\sigma_X^2 - \sigma_X \sigma_Y + \sigma_Y^2 + 3\tau^2}$$

σ_X : calculated direct stress in the x-direction (N/mm^2)

σ_Y : calculated direct stress in the y-direction (N/mm^2)

τ : calculated shear stress (N/mm^2)

σ_y : 170 (N/mm^2)

μ : 1.0, safety factor ⭘

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