GUIDANCE NOTES
GD 05-2017

CHINA CLASSIFICATION SOCIETY

GUIDELINES FOR STRESS ANALYSIS OF LOW TEMPERATURE PIPING

2017

Effective from 1 May 2017

Beijing

CONTENTS

Foreword

For low-temperature piping systems, paragraph 5.11.5 of Chapter 5- Process Pressure Vessels and Liquid, Vapour and Pressure Piping Systems of CCS' Rules for Construction and Equipment of Ships Carrying Liquefied Cases in Bulk provides that "When the design temperature is -110°C or lower, a complete stress analysis, taking into account all the stresses due to the weight of pipes, including acceleration loads if significant, internal pressure, thermal contraction and loads induced by hog and sag of the ship for each branch of the piping system shall be submitted to the Administration." At the same time, rules including Rules for LNG Bunkering Ships, Rules for Ships Powered by Natural Gas Fuel, and Rules for LNG Bunkering Pontoons have also provided relevant requirements. The Guidelines have made specific definitions and requirements for loads by identifying several basic loading conditions and load cases accordingly.

The standards adopted for the stress analysis of low-temperature piping systems have directly determined its calculation method and criteria for judgment. The calculation method and criteria for judgment provided in the Guidelines is mainly developed based on Process Piping, ASME Code for Pressure Piping, B31.3. It is noted that Process Piping has some requirements for the qualifications of a designer (pipe stress engineer). A bachelor's degree or above is required in relevant majors such as mechanical engineering and engineering mechanics plus a minimum of 5 years' experience in professional training and the design of related pressure piping under the guidance of senior stress analysis engineers. 10 to 15 years' experience in professional design and supervision are needed for stress analysis engineers without completion of a bachelor's degree. Despite the lack of compulsory requirements for qualifications in the Guidelines, relevant parties are invited to pay more attention to this.

Chapter 1 General

1.1 Scope of application

1.1.1 The Guidelines apply to liquefied natural gas carriers (LNG carriers), LNG bunkering ships, ships powered by natural gas fuel and LNG bunkering pontoons, etc.

1.1.2 The Guidelines apply to low-temperature piping with design temperature of -110℃ or lower.

1.1.3 The Guidelines provide the requirements related to the aspects including modeling, loads, conditions, boundary conditions, calculation methods and criteria during stress analysis of low-temperature piping.

1.1.4 The Guidelines serve only as supplement to relevant rules. In addition to the Guidelines, stress analysis of low-temperature piping should also comply with relevant requirements of CCS Rules for Classification of Sea-going Steel Ships, Rules for Material and Welding, Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk, Rules for LNG Bunkering Ships, Rules for Ships Powered by Natural Gas Fuel and Rules for LNG Bunkering Pontoons.

1.2 Definitions

1.2.1 Displacement strain: strains due to displacement of restraints of pipes caused by thermal expansion and cold contraction of equipment and sagging and hogging of the ship and strains due to temperature change.

1.2.2 Sustained stress: normal stress and shear stress due to sustained loads such as weight and pressure, etc.

1.2.3 Displacement stress: normal stress and shear stress due to displacement strain in pipe components.

1.2.4 Peak stress: stress due to local stress concentration or local uncontinuous structure or local thermal stress.

1.2.5 Normal stress: the component of stress normal to the plane of reference, as defined in 4.28.3.2 of CCS Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.

1.2.6 Shear stress: the component of the stress acting in the plane of reference, as defined in 4.28.3.5 of CCS Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.

1.3 Plans and documents

1.3.1 The following plans and documents are to be submitted for approval:

(1) Arrangement of low-temperature piping.

1.3.2 The following plans and documents are to be submitted for information:

(1) complete stress analysis report for low-temperature piping.

Chapter 2 Stress Analysis of Piping

2.1   General requirements

2.1.1   The following contents are to be considered for the static force analysis of piping stress:

(1) The sustained stress from sustained loads such as weight and pressure is to be calculated to prevent damages from plastic deformations;

(2) The displacement stress resulting from displacement loads such as thermal expansion or cold contraction of piping and additional displacement of end points of piping is to be calculated to prevent fatigue damage;

(3) Forces acting on equipment are to be calculated to prevent excessive acting force and ensure normal operation of equipment based on the requirements of regulation 3.2.1;

(4)   Forces acting on supports and hangers of piping are to be calculated to provide basis for design of supports and hangers;

(5)   Forces acting on flanges of piping are to be calculated to prevent leakage of flanges.

2.1.2   In the design of the piping system, considerations are normally to be given to the dynamic load analysis of piping stress, such as:

(1) The influence of stresses from wind load, acceleration load, load due to action of safety valve, and impact load of liquid hammer induced by the close of ESD valve;

(2) For piping with reciprocating compressors (pump), considerations are normally also to be given to:

① analysis of self-vibration frequency of piping to prevent resonance of piping system;

② response analysis of forced vibration of piping to prevent piping vibration and stresses;

③ analysis of frequency of air (liquid) column to prevent resonance of air column;

④ pressure pulsation analysis to control pressure pulsation value.

2.2   Loads

2.2.1   Weight load: including self-weight of piping, weight of insulation, and weight of medium, etc.

2.2.2   Pressure load: including internal pressure and external pressure.

2.2.3   Displacement load: including displacement due to thermal expansion and cold contraction (temperature load), additional displacement of equipment, change of support position due to thermal expansion or cold contraction of deck and hog and sag of the ship, etc.

2.2.4   Concentrated load: such as concentrated loads due to loading arms and loads of spring hangers,etc.

2.2.5 Occasional load: such as acceleration load and wind load, etc. Requirements for acceleration load are given in paragraph 4.28.2 of CCS' Rules for Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.

2.2.6 Other dynamic force loads: load due to action of safety valve and impact load of liquid hammer induced by the close of ESD valve, etc.

2.2.7 Major loads described in paragraphs 2.2.1 to 2.2.6 are listed in Table 2.2.7.

Major Loads for Stress Analysis Table 2.2.7

Type of load	Symbol	The corresponding specific loads
Weight load (W)	W1	Piping weight load①
	W2	Weight load of cargo medium
	W3	Weight load of strength test medium
Pressure load (P)	P	Piping design pressure
Temperature load (T)	T1	Minimum temperature load
	T2	Maximum temperature load
Additional displacement load (D)	D1	Additional displacement load of equipment under minimum temperatures②
	D2	Additional displacement load of equipment under maximum temperatures②
	D3	Additional displacement load due to hull deformation under loading condition 1③
	D4	Additional displacement load due to hull deformation under loading condition 2③
	D5	Additional displacement load due to hull deformation under loading condition 3③
Concentrated load (F)	F	Concentrated load due to loading arms
	H	Load of spring hangers
Wind load (Wind)	Wind1	Longitudinal wind load
	Wind2	Transverse wind load
Acceleration load (U④)	U1	Vertical acceleration load
	U2	Transverse acceleration load
	U3	Longitudinal acceleration load
Other dynamic force load ®	R1	Load due to action of safety valve
	R2	Impact load of liquid hammer induced by the close of ESD valve

Notes: ① Piping weight load includes the weight of components including pipes, valve accessories and insulations.
② Additional displacement of equipment mainly means displacement of the connections to large equipment and tanks due to thermal expansion or cold contraction.
③ In addition to heavy load and light load conditions, considerations are also to be given to other loading conditions that lead to major hull deformations.
④ Acceleration load is mainly the result of the heaving, pitching and rolling of ships.

2.3 Conditions

2.3.1 For piping systems with a design temperature of -110°C or lower, considerations are to be given to loading factors according to special ambient conditions, refer to Table 2.3.1.

Examples of basic conditions and loads **Table 2.3.1**

Basic condition \ load		W			D			T		P		F	U	Wind
		W1	W2	W3	D1	D2	D3	T1	T2	P1	P2			
		Weight of piping	Weight of cargo medium	Weight of test medium	Additional displacement of equipment in low temperatures teminals	Additional displacement of equipment in high temperatures	Additional displacement due to hull deformation	Minimum temperature	Maximum temperature	Piping design pressure	Strength test pressure	Concentrated load	Acceleration in all directions	wind load
Strength test		×		×							×			
Loading and unloading	Outside the tank	×	×		×		×	×	×	×		×		
	Inside the tank[①]	×	×					×						
Other operations	Outdoors	×	×		×	×	×	×	×	×		×	×	×
	Indoor	×	×				×	×	×	×		×	×	
	Inside the tank[①]	×	×					×					×	

Notes: ① The stress analysis range for the piping system inside the tank is to be determined based on the actual arrangement of the piping system.

② The symbol “x” means applicable.

2.3.2 Combinations of conditions and loads should be made as reasonable and necessary to meet specific requirements in relevant documents of actual projects.

2.3.3 For piping system within the cargo tank, the combinations of conditions in Table 2.3.3 may be considered.

Typical combinations of conditions within the cargo tank **Table 2.3.3**

Serial number	Combination of conditions	Condition description
L1	W1+W3+P2	Strength test
L2	W1+W2+P1	Consider sustained loads due to weight and pressure
L3	W1+W2+P1+T1	Loading and unloading, operational condition
L4	W1+W2+P1+U	Other operations, occasional loading condition
L5	L3- L2	Low-temperature contraction condition, calculation of displacement stress

2.3.4 For piping on open decks, consideration may be given to the combinations of conditions in Table 2.3.4.

Typical combinations of conditions for piping on open decks Table 2.3.4

Serial number	Combination of conditions	Condition description
L1	W1+W3+P2	Strength test
L2	W1+W2+P1	Consider sustained loads due to weight and pressure
L3	W1+W2+P1+F	Consider sustained loads due to weight, pressure and loading arms, etc.
L4	W1+W2+D1+D3+P1 +T1	Other operations, transfer or re-liquefaction
L5	W1+W2+D1+D3+P1+F+T1	Loading and unloading at the dock, operational condition
L6	W1+D1+D3+P1+T2	Relevant piping in maximum temperature
L7	L4- L2	Other operations, low-temperature contraction condition, calculation of displacement stress
L8	L5- L3	Loading and unloading of cargo, low-temperature contraction condition, calculation of displacement stress
L9	L6- L2	High-temperature expansion condition of piping, calculation of displacement stress
L10	W1+W2+P1+Wind+U	Other operations, considering occasional conditions of wind load and acceleration

2.3.5 For piping within compartments, combinations of conditions in Table 2.3.5 may be considered.

Typical combinations of conditions for piping within compartments Table 2.3.5

Serial number	Combination of conditions	Condition description
L1	W1+W3+P2	Strength test
L2	W1+W2+P1	Consider sustained loads due to weight and pressure
L3	W1+W2+P1+D3+T1	Consider operational condition of loading and unloading of cargo, transfer and re-liquefaction
L4	W1+W2+P1+D3+T2	High temperature of piping in other operations
L5	L3-L2	Low-temperature contraction condition, calculation of displacement stress
L6	L4-L2	High-temperature expansion condition, calculation of displacement stress
L7	W1+W2+P1+U	Other operations, consider occasional conditions of acceleration

2.4 Conditions and loads

2.4.1 For specific projects, considerations should also be given to the conditions and loads that may exist in actual situations, such as icing and accumulated snow, etc.

2.5 Models

2.5.1 The beam finite element calculation model for piping systems should be established based on the specific arrangements and restraints.

2.5.2 The straight pipe model is to include basic parameters, such as the length, diameter, wall thickness, material type, insulation properties, design temperature, design pressure, and medium properties.

2.5.3 For bend model, based on the straight pipe model, the bending radius, types of bends, and the angle of turn in each partial node should be identified.

2.5.4 The reducer model and its corresponding decreasing straight pipe models are to be in line with the practical types of reducers.

2.5.5 The in-plane stress intensification factor and out-of-plane stress intensification factor for tee model are to match the chosen tee type. The thickness and length of reinforcing plates are to be consistent with the piping layout drawing.

2.5.6 The valve and flange model may be considered as rigidity elements with clear length and weight.

2.5.7 The axial rigidity, transverse rigidity or bending rigidity, and torsional rigidity of the expansion joint model are to be consistent with specifications of expansion joints.

2.6 Boundary conditions

2.6.1 Boundaries restraining pipes mainly include supports and hangers, penetrations, and equipment nozzles.

2.6.2 The linear displacement and angle displacement allowable in all directions of ordinary supports and hangers are to be clearly defined in the specifications of supports.

2.6.3 The concentrated force and concentrated moment in all directions of spring supports and hangers are to be consistent with the system design requirements.

2.6.4 For the supports, hangers and penetrations fixed on hull structures, considerations are to be given to the additional displacement induced by hull deformations.

2.6.5 The restraint of equipment nozzles to the piping is to be determined based on the practical situation of the equipment. Piping connection to low-temperature vessel should be considered as fixed restraint and consideration is also to be given to additional displacement due to thermal expansion or cold contraction of vessels.

Chapter 3 Piping stress calculation and criteria

3.1   Stress calculation

3.1.1 Calculation and analysis is to be carried out for piping on sustained stress due to sustained loads, displacement stress due to displacement and temperature, and peak stress due to occasional loads.

3.1.2   Sustained stress σ_1 is to be calculated according to the following formula:

$$\sigma_1 = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where: $S_a = I_a \frac{F_a}{A_p}$

$$S_b = \frac{\sqrt{(I_i M_i)^2 + (I_o M_o)^2}}{W}$$

$$S_t = I_t \frac{M_t}{2W}$$

where：σ_1—— sustained stress due to sustained loads such as weight and pressure, in N/mm^2;

S_a—— stress due to sustained longitudinal force, in N/mm^2;

S_b—— stress due to sustained bending moments， in N/mm^2;

S_t—— stress due to sustained torsional moment， in N/mm^2;

A_p—— cross-sectional area of pipe, in mm^2;

For piping material, cross-sectional area of the pipe wall is

$A_p = \pi\delta(D_o - \delta)$

F_a—— longitudinal force due to sustained loads such as weight and pressure， in N;

I_a—— sustained longitudinal force index. Normally I_a =1.0;

I_i —— sustained in-plane moment index. Normally I_i is taken as the greater of 0.75i_i or 1;

I_o—— sustained out-plane moment index. Normally I_o is taken as the greater of 0.75i_o or 1;

i_i—— in-plane stress intensification factor; see Annex 1: Stress Intensification Factor for Piping Components;

i_o—— out-plane stress intensification factor; see Annex 1: Stress Intensification Factor for Piping Components;

M_i—— in-plane bending moment due to sustained loads such as pressure and weight, in N·mm. Its direction is given in Figures 3.1.2(1) and 3.1.2(2);

M_o—— out-plane bending moment due to sustained loads such as pressure and weight, in N·mm. Its direction is given in Figures 3.1.2(1) and 3.1.2(2);

W—— sustained section modulus, in mm^3;

For piping material, the formula for anti-bending section modulus is:

$$W = \frac{\pi}{32D_o}(D_o^4 - D_i^4)$$

D_o—— outside diameter of pipe, in mm;

D_i—— inside diameter of pipe, in mm;

I_t—— sustained torsional moment index. Normally I_t =1.0;

M_t—— torsional moment due to sustained loads such as pressure and weight, etc., in N·mm;

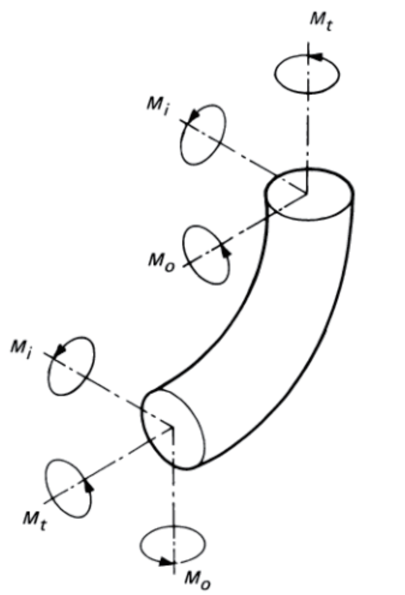


Figure 3.1.2(1) Direction of Moments in Bends

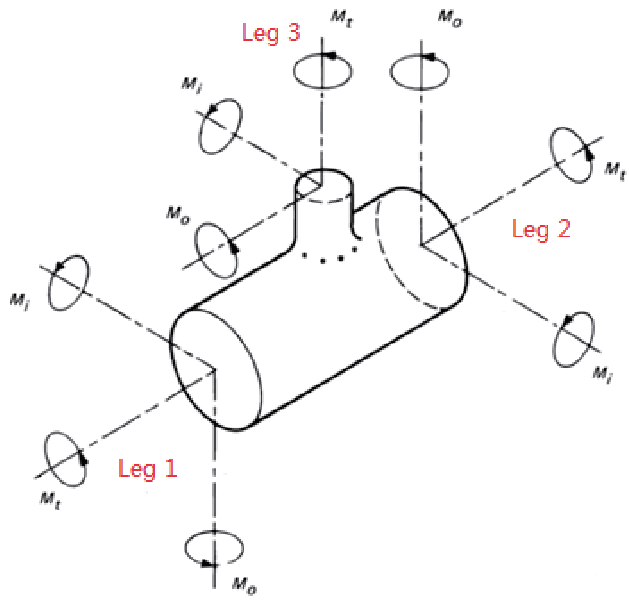


Figure 3.1.2(2) Direction of Moments in Branch Connections

3.1.3 Sustained stress σ_1 is to comply with the following requirements:

$$\frac{\sigma_1}{\sigma_h} \le 1$$

where: σ_h—— allowable stress of material under design temperature, in N/mm^2.

3.1.4 Displacement stress σ_2 is to be calculated according to the following formula:

$$\sigma_2 = \sqrt{(|S_a| + S_b)^2 + (2S_t)^2}$$

where: $S_a = i_a \dfrac{F_a}{A_p}$

$$S_b = \frac{\sqrt{\left(i_i M_{i,d}\right)^2 + \left(i_o M_{o,d}\right)^2}}{W}$$

$$S_t = i_t \frac{M_t}{2W}$$

where: σ_2—— displacement stress due to displacement and temperature, in N/mm²;

S_a—— axial stress due to displacement strains, in N/mm²;

S_b—— bending stress due to displacement strains, in N/mm²;

S_t—— torsional stress range due to displacement strains, in N/mm²;

A_p—— cross-sectional area of pipe wall, in mm²;

F_a—— axial force due to alternating displacement loads, in N;

i_a—— torsional stress intensification factor. In the absence of more applicable data, i_a =1.0 for elbows, and $i_a = i_o$ for other components;

i_i—— in-plane stress intensification factor; see Annex 1: Stress Intensification Factor for Piping Components;

i_o—— out-plane stress intensification factor; see Annex 1: Stress Intensification Factor for Piping Components;

$M_{i,d}$—— in-plane bending moment range due to alternating displacement loads, in N·mm. Its direction is given in Figures 3.1.2(1) and 3.1.2(2);

$M_{o,d}$—— out-plane bending moment range due to alternating displacement loads, in N·mm. Its direction is given in Figures 3.1.2(1) and 3.1.2(2);

W—— anti-bending section modulus, in mm³;

i_t—— torsional stress intensification factor. Normally i_t =1.0;

M_t—— torsional moment range due to alternating displacement loads, in N·mm.

Unless otherwise specified, displacement stress is to be calculated based on the reference ambient temperature 21℃.

3.1.5 Displacement stress is to comply with the following requirements:

$$\frac{\sigma_2}{\sigma_A} \le 1$$

where: σ_A—— allowable stress, in N/mm², calculated according to the following formula:

$$\sigma_A = (1.25\sigma_c + 0.25\sigma_h)$$

where: σ_c—— allowable stress of the material at ambient temperature, in MPa;

f—— stress reduction factor, normally taken as 1 for low-temperature piping of LNG vessels.

If allowable stress σ_h of the material at design temperature is greater than sustained stress σ_1, then:

$$\sigma_A = f(1.25\sigma_c + 0.25\sigma_h - \sigma_1)$$

3.1.6 For occasional stress, the sum of sustained stress due to sustained loads and occasional loads is not to exceed 1.33 times of σ_h.

3.1.7 Piping stress analysis may also be carried out according to other standards and /or relevant rules acceptable to CCS.

3.2 Additional requirements to be complied for stress analysis

3.2.1 Thrusts and moments of piping on the equipment nozzles should be within the permitted range for equipment.

3.2.2 For maximum displacement of piping, spacing required during piping arrangement should be considered.

3.2.3 For piping subject to dynamic stress analysis, calculations of compressors (pumps) should comply with industrial standards and operation frequency of which should avoid natural frequency of piping.

Chapter 4 Main Contents of Piping Stress Analysis Report

4.1 Basic parameters

4.1.1 Standards used in stress analysis.

4.1.2 Conditions and loads and specific elements considered.

4.1.3 Design pressure, design temperature, installation temperature, material type and material allowable stress of piping, pipe size, pipe insulation properties and medium in piping should be specified.

4.1.4 Lists of valves and fittings which indicate relevant sizes and quality.

4.1.5 The above parameters should be consistent with the following documents:

(1) Technical specifications of pipes;

(2) Technical specifications of piping insulations;

(3) Technical specifications of piping supports (including hangers);

(4) Technical specifications of expansion joints, if any;

(5) Piping design pressure and wall thickness calculations;

(6) Relevant piping schematic diagram;

(7) List of goods;

(8) Relevant documents containing operation conditions of goods;

(9) Relevant documents on hull deformation (including sagging, hogging, thermal expansion and cold contraction of deck, etc.) in typical conditions.

4.2 List of main nodes of model for analysis

4.2.1 Sequence of establishment for nodes, node types and corresponding serial number of piping;

4.2.2 Relevant sizes of nodes;

4.2.3 Parameters specified in 4.1.3 corresponding to nodes.

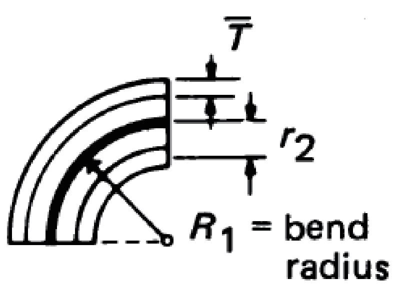
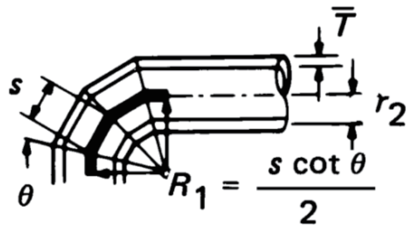
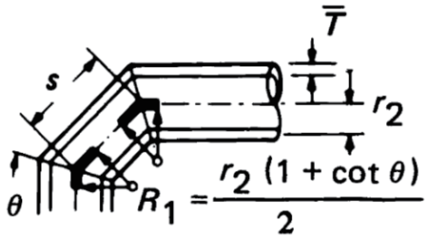
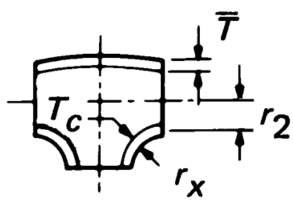
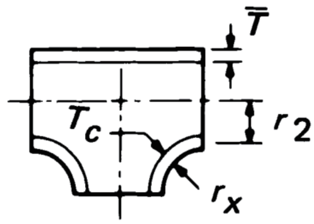
4.3 Single-line piping diagram for stress analysis model

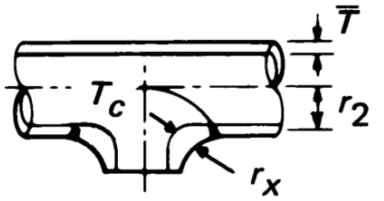
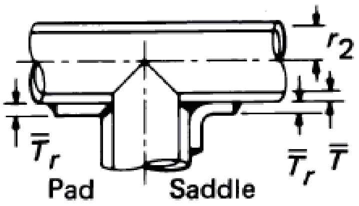
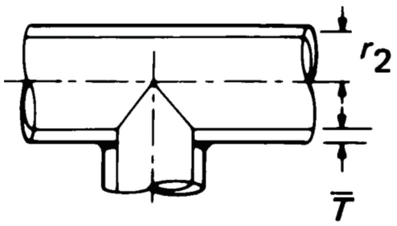
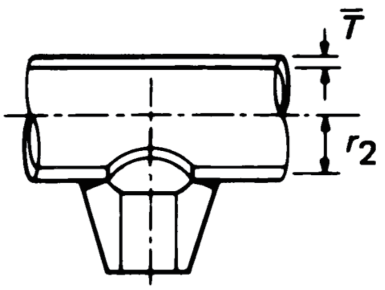
4.3.1 Routes and arrangement of piping corresponding to the numbered nodes;

4.3.2 The diagram should also include technical descriptions such as pipe specifications, specifications of pipe fittings, specifications of supports and hangers, insulation properties of piping;

4.3.3 The drawing of Arrangement of Low Temperature Piping should be in consistence with Single-line Piping Diagram. If the drawing of Arrangement of Low Temperature Piping is not available, the approved Single-line Piping Diagram may be regarded as equivalent diagram.

Annex 1: Stress Intensification Factor for Piping Components

Description	Stress Intensification Factor [Notes (1)(2)]		Flexibility Characteristic h	Sketch
	Out-of-Plane i_o	In-Plane i_i		
Welding elbow or pipe bend [Notes (1), (3)～(6)]	$\frac{0.75}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\overline{T}R_1}{r_2^2}$	
Closely spaced miter bend $s < r_2(1+\tan\theta)$ [Notes (1)(3)(4)(6)]	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{\cos\theta}{2}(\frac{s\overline{T}}{r_2^2})$	
Single miter bend or widely spaced miter bend $s \geq r_2(1+\tan\theta)$ [Notes (1)(3)(6)]	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$\frac{1+\cos\theta}{2}(\frac{\overline{T}}{r_2})$	
Ordinary welding tee with $r_x \geq D_b/8$ $T_c \geq 1.5\overline{T}$ [Notes (1)(3)(5)(7)(8)]	$\frac{0.9}{h^{2/3}}$	$\frac{3i_0}{4}+\frac{1}{4}$	$3.1\frac{\overline{T}}{r_2}$	
Extruded welding tee with $r_x \geq D_b/20$ $T_c < 1.5\overline{T}$ [Notes (1)(3)(8)]	$\frac{0.9}{h^{2/3}}$	$\frac{3i_0}{4}+\frac{1}{4}$	$(1+\frac{r_X}{r_2})\frac{\overline{T}}{r_2}$	

Description	Stress Intensification Factor [Notes (1)(2)]		Flexibility Characteristic h	Sketch
	Out-of-Plane i_o	In-Plane i_i		
Welded-in contour insert with $r_x \geq D_b/8$ $T_c \geq 1.5T$ [Notes (1)(3)(7)(8)]	$\frac{0.9}{h^{2/3}}$	$\frac{3i_0}{4}+\frac{1}{4}$	$3.1\frac{\bar{T}}{r_2}$	
Reinforced fabricated tee with pad or saddle [Notes (1)(3)(8)(9)(10)]	$\frac{0.9}{h^{2/3}}$	$\frac{3i_0}{4}+\frac{1}{4}$	$\frac{\left(\bar{T}+\frac{\bar{T}_r}{2}\right)^{2.5}}{\bar{T}^{1.5} r_2}$	
Unreinforced fabricated tee [Notes (1)(3)(8)(10)]	$\frac{0.9}{h^{2/3}}$	$\frac{3i_0}{4}+\frac{1}{4}$	$\frac{\bar{T}}{r_2}$	
Branch welded-on fitting(integrally reinforced) [Notes (1)(3)(10)(11)]	$\frac{0.9}{h^{2/3}}$	$\frac{0.9}{h^{2/3}}$	$3.3\frac{\bar{T}}{r_2}$	

Notes:

Calculation methods for stress factors in the above table and relevant notes are from ASME Code for Pressure Piping, B31.3: Process Piping "Appendix D Flexibility and Stress Intensification Factors".

Stress intensification factor data in the above Table are for use in the absence of more directly applicable data. Their validity has been demonstrated for $D_o/\bar{T} \leq 100$.

(1) The stress intensification factor should not be less than 1 and it shall apply over the effective arc length (shown by heavy centerlines in the illustrations) for curved and miter bends, and to the intersection point for tees.

(2) A single intensification factor equal to $\frac{0.9}{h^{2/3}}$ may be used for both i_o and i_i if desired.

(3) Nomenclature is as follows:

i_i = in-plane stress intensification factor;

i_o = out-plane stress intensification factor;

h = flexibility characteristic of pipe component;

D_o = outside diameter of pipe, in mm;

D_b = outside diameter of branch, in mm;

R_1 = mean radius of welding elbow or pipe bend, in mm;

r_x = radius of curvature of external contoured portion of outlet, measured in the plane containing the axes of the header and branch, in mm;

r_2 = mean radius of matching pipe, in mm;

s = miter spacing at centerline, in mm;

$\overline{T}$ = for elbows and miter bends, the nominal wall thickness of the fitting; for tees, the nominal wall thickness of the matching pipe, in mm;

T_c = crotch thickness of branch connections measured at the center of the crotch where shown in the illustrations, in mm;

$\overline{T_r}$ = pad or saddle thickness, in mm;

θ = one-half angle between adjacent miter axes.

(4) Where flanges are attached to one or both ends, stress intensification factors in the above table should be corrected by the factor C_1.

One end flanged: $C_1 = h^{1/6}$

Two ends flanged: $C_1 = h^{1/3}$

(5) The designer is cautioned that cast buttwelded fittings may have considerably heavier walls than that of the pipe with which they are used. Large errors may be introduced unless the effect of these greater thicknesses is considered.

(6) In large diameter thin-wall elbows and bends, pressure can significantly affect the magnitudes of stress intensification factors. To correct values from the above table, stress intensification factor should be divided by C_2.

$$C_2 = 1 + 3.25\left(\frac{P_j}{E_j}\right)\left(\frac{r_2}{\overline{T}}\right)^{5/2}\left(\frac{R_1}{r_2}\right)^{2/3}$$

Use kPa for pressure and mm for size.

(7) If $r_X \geq \frac{D_b}{8}$ and $T_c \geq 1.5\overline{T}$, a flexibility characteristic of $h = 4.4\frac{\overline{T}}{r_2}$ may be used.

(8) Stress intensification factors for branch connections are based on tests with at least two diameters of straight run pipe on each side of the branch centerline. More closely loaded branches may require special consideration.

(9) When $\overline{T_r} > 1.5\overline{T}$, use $h = 4\frac{\overline{T}}{r_2}$.

(10) The out-of-plane stress intensification factor (SIF) for a reducing branch connection with branch-to-run diameter ratio of $0.5 < d/D < 1.0$ may be non-conservative. A smooth concave weld contour has been shown to reduce the SIF. Selection of the appropriate SIF is the designer's responsibility.

(11) The designer must be satisfied that this fabrication has a pressure rating equivalent to straight pipe.