ENGINEERING STANDARD

FOR

FLEXIBILITY ANALYSIS

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1. SCOPE

This Standard specification covers the basic requirements for the flexibility analysis of piping systems in Oil, Gas and Petrochemical Industries.

2. REFERENCES

Throughout this Standard the following standards and codes are referred to. The editions of these standards and codes that are in effect at the time of publication of this Standard shall, to the extent specified herein, form a part of this Standard. The applicability of changes in standards and codes that occur after the date of this Standard shall be mutually agreed upon by the Company and the Vendor.

ASME (AMERICAN SOCIETY OF MECHANICAL ENGINEERS)

ASME Section VIII Division I	"Rules for Construction of Pressure Vessels"
ASME Section III Part NB-3647.1	"Boiler and Pressure Vessel Code"

ANSI (AMERICAN NATIONAL STANDARD INSTITUTE)

ANSI/ASME B.16.9	"Factory-Made Wrought Steel Buttwelding Fittings"
ANSI/ASME B.16.25	"Buttwelding Ends"
ANSI/ASME B.31.1	"Power Piping"
ANSI/ASME B.31.3	"Chemical Plant and Petroleum Refinery Piping"
ANSI/ASME B.73.1 M	"Horizontal End Suction Centrifugal Pumps for Chemical Process"

API (AMERICAN PETROLEUM INSTITUTE)

API RP 520	"Sizing, Selection, and Installing Pressure Relieving Devices"
API STD. 610	"Centrifugal Pumps for General Refinery Services"
API STD. 617	"Centrifugal Compressors for General Refinery Service"

EJMA (EXPANSION JOINT MANUFACTURERS ASSOCIATION)

NEMA (NATIONAL ELECTRICAL MANUFACTURERS ASSOCIATION)

NEMA SM 23	"Steam Turbines for Mechanical Drive Service"

3. DEFINITIONS AND TERMINOLOGY

3.1 Creep

Plastic flow of metal, usually occurring at high temperatures, subject to stress appreciably less than its yield strength. Progresses through first, second, and third stage to fracture or results in stress relaxation.

3.2 Cold Spring

A piping system fabricated to slightly shorter dimensions that is required to extend between its terminal points and, during erection, is pulled into place.

3.3 Flexibility Factor

Flexibility factor is defined as the ratio of the rotation per unit length of the part in question produced by a moment, to the rotation per unit length of a straight pipe of the same nominal size and schedule or weight produced by the same moment.

3.4 Stress Intensification Factor

Will be defined as the ratio of the bending moment producing fatigue failure in a given number of cycles in a straight pipe of nominal dimensions, to that producing failure in the same number of cycles in the part under consideration.

3.5 Section Modulus

The ratio of the moment of inertia of the cross section of a pipe undergoing flexure to the greatest distance of an element of the pipe from the center line.

4. UNITS

This Standard is based on International System of Unit (SI) except where otherwise specified.

5. PIPING STRESS ANALYSIS

Piping systems are subject to a diversity of loadings creating stresses of different types and patterns, of which only the following more significant ones need generally be considered in piping stress analysis:

1) Pressure, internal or external.

2) Weight of pipe, fittings and valves, contained fluid and insulation, wind and earthquake loads, and allowable loads on machinery.

3) Thermal expansion of the line.

5.1 Pressures

5.1.1 Internal pressure

Internal design pressure shall be calculated as per ANSI 31.3.

5.1.2 External pressure

The procedure outlined in the ASME Code Section VIII Division I paragraphs UG-28, 29, 30 shall be followed for determining external pressure.

5.2 Weights and Loads

5.2.1 Weights (w):

Weights shall be per ANSI B 31.3.

5.2.2 Wind loads (W_w):

The wind load shall be calculated by the equation shown below:

$$W_w = 0.7\ Aq$$

Where:

W_w = wind load

A = Projected area (outside diameter of the piping including the insulation multiplied by the unit length of the piping)

q = wind pressure (specific value)

5.2.3 Earthquake load (W_e):

The earthquake load shall be the total weight of the piping system multiplied by the design vertical or lateral earthquake coefficient.

$$W_e = K_e W$$

Where:

W_e = lateral or vertical earthquake load

K_e = design lateral or vertical earthquake coefficient (specific value)

W = weight of the piping system

5.2.4 Impact load

Impact loads caused by pressure relief through a safety valve shall be calculated in accordance with API RP 520.

5.2.5 Allowable loads on machinery

The allowable forces and moments on nozzles of machinery such as pumps, compressors and turbines shall be specified by the Manufacturer.

As a minimum requirement, Manufacturer shall use the following guides in determining the allowable nozzle loads.

5.2.5.1 Pumps

a) API 610 Pumps

The allowable nozzle loads on horizontal centrifugal pumps with steel or alloy casing shall meet the load criteria of API 610, Table 2.

b) ANSI Pumps

The allowable nozzle loads on horizontal centrifugal pumps shall be designed to ANSI B73.1.

c) Vertical Turbine and In-Line Pumps

The combined bending, torsional and thermal stress in the piping attached to the nozzle shall be limited to 25 percent of the allowable stress range as specified in ANSI B31.3. Also, the combined stress due to deadload shall be limited to 25 percent of the allowable hot stress.

d) Reciprocating and Other Type Pumps

The load criteria for these pumps shall follow those of Paragraph (a) above.

5.2.5.2 Compressors

a) API 617 Compressors

The allowable forces and moments acting on the nozzles of centrifugal compressors shall be designed in accordance with API 617, the forces and moments shall be 1.85 times the values based on the load criteria of NEMA SM23.

b) Reciprocating Compressors

The allowable nozzle loads on these compressors shall meet the load criteria of NEMA SM23 for individual nozzles.

5.2.5.3 Thrust loads and moments imposed on mechanical equipment shall not exceed the equipment manufacturer's recommended values except for the following:

a) Steam turbines and compressors with piping connections ≤ DN 80 (NPS 3) shall conform to applicable API Standard.

b) Centrifugal pumps with piping connections ≤ DN 80 (NPS 3): the external force and moment limitations shall be specified in purchase documents for the pumps.

c) Steam turbines, compressors, and centrifugal pumps with piping connection ≥ DN 80 (NPS 3):

I) Piping shall be supported such that nozzle loads due to weight in the operating condition are eliminated or minimized.

II) Analysis shall verify, that nozzle loads (forces and moments) and deflection do not exceed allowable values for the load cases tabulated below.

TABLE FOR LOAD CASES

EQUIPMENT	LOAD CASES[1], [2]	CONDITION OR CONFIGURATION	EVALUATION CRITERIA
Compressors other than Reciprocating Type Steam Turbines	Flange alignment	1) Piping not connected to equipment flange. 2) Spring supports active. 3) Piping at "cold condition".	Piping installed to meet allowable flange misalignment criteria.
	Weight and thermal expansion	1) Piping connected to equipment. 2) Spring supports active. 3) All normal and abnormal operating conditions.	Maximum allowable nozzle forces and moments: 1) Compressors-1.85 times values per NEMA SM-23. 2) Steam Turbines. Values per NEMA SM-23.
	Weight thermal expansion and friction[3]		
Centrifugal Pumps	Weight and thermal expansion	1) Piping connected to equipment. 2) Spring supports active. 3) All normal and abnormal operating conditions.	Maximum allowable nozzle forces and moments and related baseplate construction per Appendix A
	Weight thermal expansion and friction[3]		

Notes:

1) "Weight" loads include the weight of piping, insulation, heat tracing and process fluid .

2) "Thermal Expansion" load considerations shall be governed by the following:

a) Casing expansion. The expected thermal movements at equipment flanges due to casing expansion shall be obtained from the equipment vendors.

b) Heat traced piping. For the case of "process flow off heat tracing on", process piping metal temperature shall be considered equal to the heat tracing design temperature unless the average metal temperature is determined by heat transfer calculations.

c) Compressor recycle system. Proposed method of evaluating the effect of a recycle operation shall be reviewed with the Owner's Engineer.

d) Pressure relief system. Proposed method of evaluating the effect of discharge from pressure relief devices shall be reviewed with the Owner's Engineer.

e) Spared pump installation. If no warm-up facilities are required, interconnecting piping metal temperature shall be considered to be at minimum ambient temperatures. If warm-up facilities are required, the metal temperature shall be taken as the average of the design and ambient temperatures.

f) Spring supports. The variation of spring force with deflection shall be included in the analyses.

3) The effects of friction shall be considered. When it is apparent that frictional effects will significantly increase nozzle loadings, analysis shall include frictional effects. No credit shall be taken for frictional effects when they result in reduced nozzle loadings.

5.2.6 Allowable loads on equipment

5.2.6.1 Air fin coolers

The allowable nozzle loads on air fin coolers shall be specified by the Manufacturer.

5.2.6.2 Vessels and heat exchangers

Unless detailed calculations are made of the nozzle connection to the vessel, the combined thermal, bending and torsional stress in the piping attached to the nozzle shall be limited to 33 1/3 percent of the allowable stress range as specified in ANSI B31.3.

5.2.6.3 Fired heaters

The allowable nozzle loads and moments on fired heaters shall be specified by the Manufacturer.

Displacement of heater tubes shall be approved by the heater manufacturer and the effect of expansion and or displacement of the tubes shall be reflected in the computer analysis of the piping system.

Any heater designed with a floating coil (all spring or counter weight mounted) shall be provided with fail-safe limit stops in all directions. Computer analysis of piping system connected to floating heater coils shall include the heater coil or an approximate model of the coil as part of the systems and the effects of internal guides and restraints. In floating heater coils the support of the connecting piping system shall be completely and independently balanced so that no dead load is imposed on the coil.

5.2.7 Allowable forces and moments on flanges

To avoid leakage at flanges, the bending moments and forces on the flanges shall be limited by the formula listed in the ASME Code, Section III Part NB-3647.1

5.2.8 Spring hangers

In general, spring hangers shall be used only where vertical expansion limits the use of rigid supports. Spring hangers shall be used to relieve the dead load weight on equipment where rigid supports are not practical. All spring hangers shall be sized according to operating conditions.

5.2.9 Combination of loads

The combinations of the loads shall conform to the applicable piping code. The wind load and earthquake load shall be regarded as acting separately in two (2) lateral directions 90° apart.

5.3 Stresses Due to Thermal Expansion

Reference shall be made to relevant sections of ANSI B 31.3.

6. FLEXIBILITY REQUIREMENTS

6.1 Piping systems shall be designed to have sufficient flexibility to prevent thermal expansion or contraction from causing excessive stresses in the piping material, excessive bending or unusual loads at joints, or undesirable forces or moments at points of connection to equipment or at anchorage or guide points.

6.2 Startup, shut-down, steam-out where applicable and upset conditions including short-term excursions to higher temperatures or pressures as well as normal operating conditions, shall be considered in flexibility analysis. This is particularly pertinent to loads applied to connecting equipment. The effect of vibration from machinery on connecting piping shall also be assessed.

6.3 The increase in allowable design stress permitted for occasional variations above design conditions shall not be used for flexibility analysis.

6.4 Expansion of piping or associated equipment should be accommodated wherever possible by the inherent flexibility of the pipework. If necessary the route of the piping should be modified, or expansion loops should be incorporated, to obtain sufficient flexibility.

6.5 Sufficient flexibility shall be provided in the piping to enable pressure relief valves, spades, line blinds or bursting discs to be changed.

6.6 Bends, loops, or offsets shall be provided for flexibility in piping system, especially for noxious or hazardous fluids.

6.7 Expansion joints or couplings of the slip joint type or expansion joints of the bellows type may be used when limited space or other reasons will not give sufficient flexibility with the above methods. Expansion joints shall be used only with adequate guides and anchors and when the fluid plugging properties cannot make the expansion joint ineffective.

6.8 A design specification shall be prepared for each Expansion Joint application.

6.9 In preparing the Expansion Joint design specification it is imperative that the system designer completely review the piping system layout, flowing medium, pressure, temperature, movements, etc. The Standard Expansion Joint specification Sheet Form 1 can be used as a guide. Particular attention shall be given to the following items:

6.9.1 To determine the location and type of Expansion Joint most suitable for the application, the designer shall consider the requirements of EJMA Standard which provide numerous examples to assist him in this respect. He should also take into account availability of supporting structures for anchoring and guiding of the line and the direction and magnitude of thermal movements to be absorbed.

6.9.2 The bellows material shall be specified and must be compatible with the flowing medium, the external environment and the operating temperature. Particular consideration shall be given to possible corrosion including stress corrosion. The 300 series stainless steels may be subject to chloride ion stress corrosion. High nickel alloys are subject to caustic induced stress corrosion. The presence of sulfur may also be detrimental to such nickel alloys. The material chosen shall also be compatible with any water treatment or pipeline cleaning chemicals. In some cases, leaching of corrodents from insulating materials can be a source of corrosion.

6.9.3 Internal sleeves shall be specified in all applications involving flow velocities which could induce resonant vibration in the bellows or cause erosion of the convolutions resulting in substantially reduced bellows life.

6.9.4 Bellows type expansion joints should be avoided in a service that coking can occur. If a suitable piping configuration can not be designed to eliminate the joint, connections shall be provided to enable flushing of the area between bellows and liner to be carried out in a non-coking medium.

6.9.5 Torsional rotation of the bellows should be avoided. This twisting generally produces extremely high shear stresses in the bellows so where torsional rotation cannot be avoided, special hardware shall be used to limit the amount of torsional shear stress in the bellows.

6.9.6 The system design pressure and test pressure shall be specified realistically without adding arbitrary safety factors. Excess bellows material thickness required for unreal pressures may produce an adverse effect on the bellows fatigue life. In the case of extreme high temperature operating conditions, it may not be practical to test the Expansion Joint to a pressure equal to 1.5 times the equivalent cold pressure rating of the piping. This is due to the various materials employed in the Expansion Joint, temperature gradient utilized in design, pressure stability criteria, anchor strength, etc.

6.9.7 The maximum, minimum and installation temperatures shall be accurately stated in data sheet to be prepared by the designer. where the ambient temperature can vary significantly during pipe line construction, pre-positioning of the Expansion Joint at installation may be required.

6.9.8 The Expansion Joint manufacturer shall be advised if the Expansion Joint will be insulated and the manner by which the Expansion Joint will be insulated in order to properly design the component parts.

6.9.9 The movements to be absorbed by the Expansion Joint shall include not only piping elongation or contraction, but also movement of attached vessels, anchors, etc. and the possibility of misalignment during installation. Unless included in the design requirements, misalignment of the Expansion Joint must be avoided. Where movements are cyclic, the number of cycles expected shall be specified. As in the case of pressure, the movement specified must be realistic. An excessive safety factor can result in an Expansion Joint which is unnecessarily flexible; thus its stability under pressure is unnecessarily reduced.

6.9.10 If the flowing medium can pack or solidify, provisions shall be made to prevent entrapment or solidification of the material in the convolutions which could result in damage to the Expansion Joint or pipeline.

6.9.11 Internal sleeves are usually installed in the direction of flow. If the stagnant flow medium trapped behind the sleeve is undesirable, drain holes in the sleeve or purge connections shall be specified. Where backflow will be encountered, an extra heavy sleeve shall be specified to prevent buckling of the sleeve and possible damage to the bellows.

6.9.12 The predicted amplitude and frequency of external mechanical vibrations to be imposed on the bellows, such as caused by reciprocating or pulsating machinery, shall be specified. A resonant condition in the bellows will result in a grossly reduced fatigue life and must be avoided. The Expansion Joint designer will attempt to provide a non-resonating design; however, the ability to always assure non-resonance is impossible. Therefore, field modifications to the Expansion Joint or other system components may be necessary.

FORM 1 - STANDARD EXPANSION JOINT SPECIFICATION SHEET

COMPANY: DATE / /

SHEET OF

PROJECT: INQUIRY No.

JOB No.

	ITEM NO.					
1	QUANTITY					
2	NOMINAL DIAMETER					
3	EXPANSION JOINT TYPE					
4a	FLUID INFORMATION	MEDIUM GAS/LIQUID				
4b		VELOCITY (m/SEC)				
4c		FLOW DIRECTION				
5	DESIGN PRESSURE					
6	TEST PRESSURE					
7a	TEMPERATURE	DESIGN (°C)				
7b		Maximum/Minimum (°C)				
7c		INSTALLATION (°C)				
8a	Maximum INSTALLATION MOVEMENT	AXIAL COMPRESSION (Cm)				
8b		AXIAL EXTENSION (Cm)				
8c		LATERAL (Cm)				
8d		ANGULAR (DEG.)				
9a	Maximum DESIGN MOVEMENTS	AXIAL COMPRESSION (Cm)				
9b		AXIAL EXTENSION (Cm)				
9c		LATERAL (Cm)				
9d		ANGULAR (DEG.)				
9e		NO. OF CYCLES				
10a	OPERATING FLUCTUATIONS	AXIAL COMPRESSION (Cm)				
10b		AXIAL EXTENSION (Cm)				
10c		LATERAL (Cm)				
10d		ANGULAR (DEG.)				
10e		NO. OF CYCLES				
11a	MATERIALS OF CONSTRUCTION	BELLOWS				
11b		LINERS				
11c		COVER				
11d		PIPE SPECIFICATION				
11e		FLANGE SPECIFICATION				
12	RODS (TIE/LIMIT/CONTROL)					
13	PANTOGRAPHIC LINKAGE					
14	ANCHOR BASE (MAIN/INTERMEDIATE)					
15a	DIMENSIONAL LIMITATIONS	OVERALL LENGTH (Cm)				
15b		OUTSIDE DIAMETER (Cm)				
15c		INSIDE DIAMETER (Cm)				
16a	SPRING RATE LIMITATIONS	AXIAL (kg/m)				
16b		LATERAL (kg/m)				
16c		ANGULAR (kg.m/DEG.)				
17	INSTALLATION POSITION HORIZ/VERT.					
18a	QUALITY ASSURANCE REQUIREMENTS	BELLOWS	LONG. SEAM			
18b		WELD NDT	ATTACH.			
18c		PIPING NDT				
18d		DESIGN CODE REQRD.				
18e		PARTIAL DATA REQRD.				
18f						
18g						
19	VIBRATION AMPLITUDE/FREQUENCY					

6.10 Particular attention should be paid to the design of lines subject to severe temperature changes during start-up or emergency conditions, such as high temperature steam lines.

6.11 Flare system piping shall be designed to take care of expansion, movement or vibration caused by the most severe operating or emergency conditions, and is to be constrained against a tendency to move off its supports. Pipe shoes or saddles shall be furnished on the main flare header at all supports.

6.12 An antisloshing baffle shall be installed in the flare stack water seal.

6.13 Cold spring shall be used as much as practical to reduce forces on equipment, and to prevent interferences from expanding lines.

6.14 Horizontal piping expansion loops in pipe tracks or on pipe bridges shall have vertical offset to stay clear of adjacent piping.

6.15 Thermally expanding piping shall be anchored at the plot limit.

6.16 The use of cold spring for piping systems which connect to rotating equipment is prohibited.

7. FLEXIBILITY ANALYSIS

7.1 Flexibility analysis shall be made in accordance with requirements of ANSI B31.1 and B 31.3.

7.2 Extent of Analysis

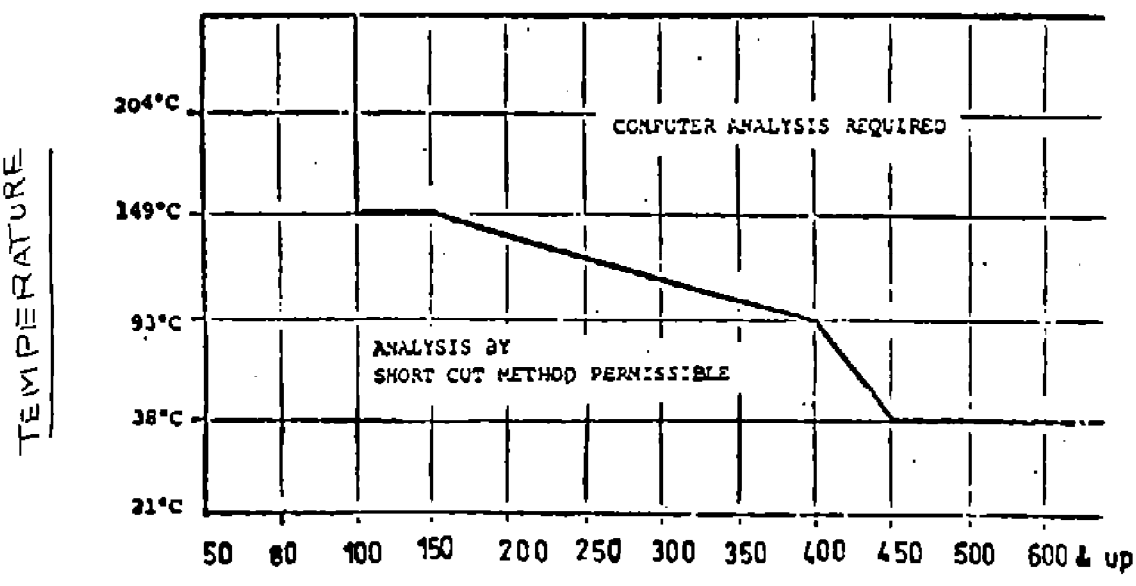
Formal computer analysis shall be required on all of the following lines:

7.2.1 All process, regeneration and decoking lines to and from fired heaters, and steam generators.

7.2.2 All process lines to and from centrifugal compressors and blowers.

7.2.3 All steam lines to and from turbines.

7.2.4 All pump lines that fall above the curve on the chart, shown below:



PIPE MANIFOLD SIZE DN

7.2.5 All lines over 427°C.

7.3 Analysis by visual inspection of mechanical layout, configuration anchoring etc. and/or manual calculation is required on all of the following lines not listed in Section 7.2.

7.3.1 Lines DN80 and larger connected to rotating equipment such as pumps, turbines, compressors, and blowers.

7.3.2 Lines DN100 and larger to air coolers.

7.3.3 All lines DN400 and larger.

7.3.4 Line to vessels which can not be disconnected for purging.

7.3.5 Lines DN150 and larger at operating temperatures over 260°C.

7.3.6 All relief systems. (Must include analysis for dynamic load from the worst possible flow conditions including slugs if there is a possibility that one could occur.)

7.3.7 Vacuum lines.

7.3.8 All nonmetallic piping.

7.3.9 Lines subject to excessive settlement.

7.3.10 Lines to and from reciprocating pumps and compressors.

7.4 All analysis shall include the effects of thermal expansion and or contraction, wind, earthquake, operating and test dead loads, guides, anchors, restraints, settlement, branches, supports and terminal displacements as described in the codes and specifications listed herein.

7.5 Lines to be analyzed shall be marked on the line list.

7.6 Basic Assumption and Requirements

Reference shall be made to ANSI B 31.1.

7.7 Movements

Reference shall be made to ANSI B 31.3 or B 31.1.

7.8 Cold Spring

Reference shall be made to ANSI B 31.3 or B 31.1.

APPENDICES

APPENDIX A
EXTERNAL FORCES AND MOMENTS

Piping force and moment limitations shall be per the following:

a) Nozzle force limitation (imposed at the nozzle flange from external piping) shall not exceed the following :

1) For forces parallel to the nozzle axis:

$F \leq 200$ lbf per in. of nominal nozzle diameter

2) For forces perpendicular to the nozzle axis:

$F \leq 100$ lbf per in. of nominal nozzle diameter.

3) For tensile forces parallel to the nozzle axis in top discharge and top suction nozzles ≤ 4 in. NPS (100 mm):

$F \leq 100$ lbf per in. of nominal nozzle diameter.

b) Nozzle bending moment limitation (imposed at the nozzle flange from external piping) shall not exceed the value determined per the following formula:

$$\mathbf{M = S \times Z}$$

Where:

M = Nozzle bending moment limitation, lbf-in. (N.m)
S = Nozzle bending stress limitation, psi, equivalent to the lesser of:

1) Carbon or alloy steel pumps: $0.75\ S_h$ or $\frac{1.5}{D} S_h$ psi (bar)

2) Cast iron pumps: $0.75\ S_h$ or $\frac{18.000}{D}$, psi (bar)

S_h = Allowable hot stress for the pump casing material, psi (stresses per ANSI B31.3 Appendix A, Table 1)
D = Nominal nozzle size, in. (mm)

Z = Section modulus of pipe, in.^{3}; (mm^3) for pipe of Diameter D, and thickness equivalent to:

1) ANSI Class 400 or lower rating flanges: Schd standard.
2) ANSI Class 600 or higher rating flanges: Schd extra strong.

Note:

In calculations using SI terms for Nozzle Force (F) and Nozzle Moment (M).
Per sub-par. a) and b) above:

Specified Term	Acceptable Metric Equivalent
$F \leq 200$, lbf/in.	$F \leq 35.6$, N/mm
$F \leq 100$, lbf/in.	$F \leq 17.8$, N/mm
M. lbf in	M. N.m
$\frac{1.5}{D} S_h$. psi	$\frac{0.26}{D} S_h$. N/mm²
$\frac{18.000}{D}$, psi	$\frac{3100}{D}$, N/mm²
S_h. psi	No change Use ANSI B 31.3 values, psi
D. in	(25) × in. = mm
Z. in^3	$(1.65 \times 10^{-5}) \times in^3 = m^3$

(to be continued)

APPENDIX A (continued)

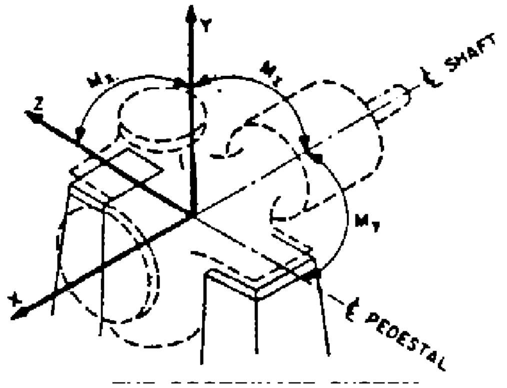
c) Combined moment limitation. For the orientation shown below, the combined moments from external piping reactions on nozzles for horizontal pumps shall not exceed the following:

For calculation in SI Units:

$\Sigma \mathbf{M_x} = 3.0$ W ft-lb	$\Sigma \mathbf{M_x} = 8.9$ W N.m
$\Sigma \mathbf{M_y} = 2.0$ W ft-lb	$\Sigma \mathbf{M_y} = 6.0$ W N.m
$\Sigma \mathbf{M_Z} = 1.5$ W ft-lb	$\Sigma \mathbf{M_Z} = 3.0$ W N.m
Where:	**Where:**
$\mathbf{M_x}$ = moment in Y-Z plane	Minimum W is 454 kg
$\mathbf{M_y}$ = moment in X-Z plane	
$\mathbf{M_Z}$ = moment in X-Y plane	
W = weight of pump only, lb	

Minimum W is 1.000 lb in these computations.

In each coordinate direction, the combined moments shall include the piping moment reactions in that direction from all pump nozzles as well as the moments resulting from piping forces resolved about the center of the pump casing.



THE COORDINATE SYSTEM
Fig. 2

Deviations permitting higher loads require approval of Owner's Engineer. Such approval will be based on proof submitted by pump vendor that the specified pump coupling deflection will not be exceeded.

Piping force and moment limitations may be increased by 50% for reactions which occur only when a pump is not operating: e.g., the case of an idle pump (installed spare) or a condition during equipment steamout.

Use of a more rigid baseplate and support assembly for horizontal pumps shall be evaluated as an alternative to revised piping layout when computations indicate that the combined piping moment limitations would be exceeded.

The more rigid support assemblies shall have the characteristic of limiting shaft displacement, measured at the coupling, to 0.005 in. (0.13 mm) for:

2X (designation): twice allowable combined moments
4X (designation): four times allowable combined moments

For in-line pumps, piping forces shall be determined with the pump considered as a rigid, but unanchored segment of the piping system.

The effects of piping weight and friction force due to thermal expansion shall be included in the evaluation of loads on pump nozzles.