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SCOPE

This Design Practice covers the structural analysis and design of steel and concrete pipe supports. The objective of this practice is to provide a methodology for analyzing and designing structures that support process piping. The focus is primarily on the design of new pipe supports, however, the procedures provided in this section can also be used in the evaluation of existing piperacks. The **APPENDIX** provides detailed guidelines in applying these procedures to existing piperacks. The design of foundations for pipe support structures is outside of the scope of this section and is covered in [Section XXIX-G](#).

REFERENCES

GLOBAL PRACTICES

GP 4-1-1	Concrete Selection and Mix Criteria
GP 4-1-2	Structural Steel Design
GP 4-1-3	Design Loads for Structures
GP 4-2-2	Pipe Supports
GP 4-6-2	Reinforced Concrete Foundations

DESIGN PRACTICES

DP XV-G	Safety in Plant Design - Equipment Spacing
DP XXIX-D	Design Loads for Plant Structures
DP XXIX-G	Foundations for Process Vessels and Equipment Structures

OTHER REFERENCES

Guidelines for Seismic Evaluation and Design of Petrochemical Facilities, American Society of Civil Engineers, 1997.
Windloads and Anchor Bolt Design for Petrochemical Facilities, American Society of Civil Engineers, 1997.
Manual of Steel Construction Allowable Stress Design Ninth Ed., Chicago, American Institute of Steel Construction.
Manual of Steel Construction Load & Resistance Factor Design Second Ed., Chicago, American Institute of Steel Construction.
ACI 318 - Building Code Requirements for Reinforced Concrete.
Structural Design Criteria, PIP STC01015, Process Industry Practices, 1998.
Uniform Building Code, International Conference of Building Officials, 1994.

DESIGN CONSIDERATIONS

Piperacks are usually constructed with structural steel or reinforced concrete. Steel is often used for piperacks due to ease of field installation and modification. However, at certain locations in a plant where there is potential for fires, steel piperacks need to be fireproofed whereas reinforced concrete piperacks do not require any additional fireproofing. Reinforced concrete piperacks may be either cast-in-place or precast construction. They are however, inherently more difficult to modify or expand once they are constructed.

The required capacity (number of support levels) is a key consideration in the design of new piperacks. Local plant practice and/or project specific requirements may provide for a minimum number of support levels to be included in the design basis. It is not uncommon to design a new bent for at least one level of pipe beyond the minimum number needed. The reserve capacity facilitates future expansion. Some plants require that all new major piperacks be designed to support a total of 5 support levels (**Figure 1**). In such cases the piperack is designed for the number of levels currently needed plus the future levels required, but only needed levels are erected. In some cases, in addition to piping, piperacks also support equipment such as air cooled heat exchangers, steam drums, access platforms and other process equipment.



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DESIGN CONSIDERATIONS (Cont)

LAYOUT / SPACING

A number of considerations affect the layout and spacing of bents for piperacks within a refinery or petrochemical facility, including:

- Available plot space.
- Access requirements for emergency response.
- Access requirements for maintenance.
- Topography and subsurface conditions.
- Local and general plant safety spacing standards.
- Potential for future expansion.
- Pipe line sizes and type(s) of equipment to be supported.
- Security and public relations.

Section XV-G provides the minimum horizontal spacing distances between piperacks and other general process equipment.

The average horizontal spacing between bents is normally 20 - 30 ft (6 - 9 m). The allowable pipe span frequently governs the distance between bents. Sometimes, smaller lines (3 in. or less) are supported from larger lines or, where this is not practical, intermediate steel framing can be used to control their deflections and stresses. Height between tiers (support levels) should be a minimum of 4 ft (1.2 m).

VERTICAL CLEARANCES

Piperacks should not be located directly above any of the following:

- Sewer manhole lids or catch basins
- Pumps or compressors handling flammable materials
- Air Fin Coolers

The minimum vertical clearances between finished grade paving (or top of floor plate) and the bottom of the piping, insulation or support beam (whichever controls) are as follows:

VERTICAL CLEARANCES FOR PIPE SUPPORTS

LOCATION	MINIMUM CLEARANCE	
	ft	(m)
a. Above major roads open to unrestricted traffic (such as periphery of process unit area limits)	20 ft	(6.1)
b. Within process unit areas: • Above internal roadways provided for access of maintenance and firefighting equipment • Under pipeways where access is: 1. required for vehicular equipment 2. required only for portable (temporary) service equipment	16 ft 12 ft 10 ft	(4.88) (3.65) (3.05)
c. Above walkways and elevated platforms	6 ft 9 in.	(2.05)
d. Under any low level piping in paved or unpaved areas	1 ft	(0.3)

STRUCTURAL DESIGN

Piperacks are normally designed as rigid or braced frames in the transverse direction and as cantilevered or braced frames in the longitudinal direction. The column bases can be either fixed or pinned. Pinned bases are desirable when the moments on the foundations are to be kept to a minimum, such as when there are low allowable soil pressures. Fixed bases have the effect of reducing column and beam bending moments and lateral deflections, but they increase foundation moments.

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DESIGN LOADS

Section XXIX-D, *Design Loads*, provides a detailed explanation of the type and nature of the basic design loads and combinations that act on process plant structures. The following sections describe the basic design loads as they apply specifically to pipe support structures (piperacks). For more information concerning loads and combinations, refer to **Section XXIX-D**.

Basic Loads

- Dead Loads (D)
- Live Loads (L)
- Fluid Load (F)
- Transverse Wind Load (W_T)
- Longitudinal Wind Load (W_L)
- Earthquake Loads (E)
- Anchor Loads (A)
- Thermal Friction Forces (T)

GRAVITY LOADS

Gravity loads act vertically downward and are directly attributable to the weight of components permanently fixed in position or which occur during construction or service. These include dead load, live load, and fluid load.

Dead loads for piperacks include the self-weight of all beams, columns, bracing, fireproofing and other structural and non-structural components. The dead load also includes the weight of the pipes, trays, and other equipment supported by the piperacks.

In many instances, the actual pipe sizes will be available such that the weight of piping can be accurately calculated. The pipe load can be applied as an equivalent uniform load on the beams. Where there are large lines, greater than 12 in. (304 mm), the pipe load should be applied as a concentrated load. Any empty space on the rack should be considered filled to allow for future additions.

In other cases the pipe weights need to be estimated and then later compared to the actual loads once the final pipe sizes become available. In the absence of known piping loads, a minimum uniform pipe dead load of 24 psf (1.1 kPa) of deck area can be assumed. This corresponds to an equivalent load of 8 in. (200 mm) diameter pipes spaced on 16 in. (400 mm) centers.

Cable trays loads can be estimated at 20 psf (0.92 kPa) for a single level tray.

Live loads on piperacks occur as a result of its use or operation but do not include environmental loads produced by wind, snow, ice, rain or earthquake. Personnel loading on platforms supported by a piperack is an example of a live load.

Fluid loads are due to weights of liquid or solid materials in the equipment or piping during operation or hydrotest. These loads should be considered in all dead load combinations except for the empty condition. The uniform pipe deck load corresponding to the equivalent fluid weight (water) from 8 in. (200 mm) diameter pipes spaced on 16 in. (400 mm) centers is 16 psf. (0.7 kPa).

TRANSVERSE WIND LOADS

Section XXIX-D, *Design Loads* provides detailed procedures for calculating wind loads on process plant structures. In addition, **Section XXIX-A**, *Civil Design Data* provides specific information relative to design wind speeds for ExxonMobil locations. For convenience, the following section provides a summary of the wind load procedures as they apply to piperacks.

When calculating the wind force on a piperack, the design wind pressure (q_z) should be evaluated at increments over the height of the structure. The pressure can be assumed to be constant over each increment of height (determined at the top of each increment) with the lowest increment extending up to 15 ft (5 m) above grade. The number and position of increments should be chosen with consideration to the total height of a bent. For structural analysis purposes, the wind load on the support framing is calculated and applied as a uniform load (lbs/ft (kN/m)) normal to the face of the piperack columns. The wind load on the piping is usually calculated for each level separately and applied at the centerline of the beam to column connection.

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DESIGN LOADS (Cont)

Piping and Cable Trays

According to the **ASCE guidelines** and [Section XXIX-D](#), shielding effects for a group of overhead parallel pipes or cable trays may be calculated based on an angle of incidence of wind ± 5.7 degrees with the horizontal. The following equations are based on these procedures.

$$A_T = [D + 0.10 w] L \quad \text{and}$$

$$P_z = q_z G A_T C_f$$

where: A_T = Tributary area of piping or cable trays on a piperack level, ft² (m²)

D = Diameter of the largest pipe or height of cable tray in the level of the rack, including insulation, ft. (m). (When determining D , consideration should be given to possible future expansion of the piperack). If unknown, assume a 12 in. (304 mm). Insulated pipe, outside diameter equal to 1.3 ft (0.4 m).

w = width of rack, ft (m)

L = length of rack, ft (m)

P_z = total wind force on a piperack level at elevation z on the rack, lbs (N)

q_z = velocity pressure determined at elevation z , psf (Pa)

G = gust response factor for piperack

C_f = Force coefficient

Piping: A value of 0.7 should be used based on a moderately smooth, long round shape (length/diameter > 25). If the largest pipe is insulated, then C_f should reflect pipe based on the roughness coefficient of the insulation corrugations.

Cable Trays: Use a $C_f = 2.0$

Structural Framing

The additional load due to the structural framing is added separately. The tributary area is the sum of all structural member wind areas without considering shielding. For all structural members a force coefficient of 1.8 may be used.

LONGITUDINAL WIND LOADS

Ordinarily, the longitudinal wind load on a piperack is minor and can be disregarded. However, in cases where there is equipment located on the piperack, such as air fin coolers, or at changes in elevation, such as a road crossing, this load should be considered. In these situations, the procedures outlined in [Section XXIX-D](#) should be followed.

EARTHQUAKE LOADS

[Section XXIX-D](#) provides the procedures for calculating the loads on structures subjected to earthquakes based on the equivalent static and dynamic analysis methods. As with wind loads, the following is presented to summarize the procedures as they apply to piperacks.

Piperacks should be treated as building-like structures and analyzed according to the earthquake design provisions of the UBC. They are generally considered "regular" structures because of their symmetrical geometric configuration and reasonably uniform mass and stiffness distributions. The UBC static force procedure is considered adequate for calculating earthquake design loads for such structures. This procedure involves the calculation of a total base shear, V , based on certain seismic design parameters as outlined below. The base shear is distributed as seismic forces over the structure based on mass and height.

Base Shear

The base shear, V , can be calculated by the UBC formula:

$$V = Z I C W / R_w$$

where: Z = seismic zone factor per **APPENDIX B** of [Section XXIX-A](#)

I = importance factor

C = numerical coefficient dependent on the soil conditions at the site and the fundamental period of the structure

W = dead load of the structure

R_w = factor which represents the ductility of the structural system.



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DESIGN LOADS (Cont)

Structural System Coefficient, R_w and Base Shear, V

Pipe support structures can be classified into structural systems per UBC as noted below. The following table suggests appropriate values of R_w and the base shear, V . The values of the base shear were determined considering the maximum value of $C = 2.75$, which will be the case in most situations.

BASIC STRUCTURAL SYSTEMS	LATERAL-LOAD-RESISTING SYSTEM -- DESCRIPTION ⁽¹⁾	R_w	V
Steel	Special Moment Resisting Frame	8	0.34 ZIW
	Ordinary Moment Resisting Frame	6	0.46 ZIW
	Braced Frame	6	0.46 ZIW
	Cantilever Column	4	0.69 ZIW
Concrete	Special Moment Resisting Frame	8	0.34 ZIW
	Intermediate Moment Resisting Frame	6 (2)	0.46 ZIW
	Ordinary Moment Resisting Frame	5 (3)	0.55 ZIW
	Cantilever Column	4	0.69 ZIW

Notes:

- (1) Basic structural systems are discussed in more detail in this **Section XXIX-D**.
- (2) Not permitted in Seismic Zones 3 and 4.
- (3) Not permitted in Seismic Zones 2, 3, and 4.

As indicated in the table, certain framing systems are more ductile or will absorb more energy than others, hence they have larger R_w coefficients. However in practice, piperacks are normally constructed as ordinary moment resisting frames or concentrically braced frames instead of SMRF and IMRF because of the high cost of special detailing.

Distribution Of Lateral Force V

As described in **Section XXIX-D**, the base shear V is distributed over the height of the structure as a force at each level plus an extra force at the top if the period of the structure is more than 0.7 second. For piperacks the force per level is usually taken at the pipe elevation.

ANCHOR LOADS AND FRICTIONAL FORCES

Anchor loads caused by pipe restraints should be obtained from the results of a thermal stress (piping flexibility) analysis and should be resisted by the structural member(s) to which the restraint is attached. Anchor loads should be considered as dead load forces for determining the load factors for design. When more than one line is anchored on a pipe support, the design of the support should be based on the most stringent combination of forces per **GP 4-2-2**.

In addition to anchor loads, the piperack can also be subjected to thermal frictional forces. These forces develop from the expansion and contraction of the pipe with temperature changes. In most cases the precise determination of these forces is not possible. In a typical piperack, the opposing forces developed from adjacent pipes may be adequate to prevent movement of the pipe support. These forces can also be relieved by a minor deflection of the piperack or support beam.

For design purposes a value of 7.5% of the total pipe weight should be used for the design of local members of a piperack (beams and columns). A value of 2.5% should be accumulated and used for design of struts, bracing, and foundations. These values are only approximations to be considered for new designs where the potential cost to the design is minor. The subject of thermal frictional forces on existing piperacks is discussed in the **APPENDIX**.

The thermal friction forces should be resisted by longitudinal spandrels or struts located in the line of each column. A braced anchor bay should be installed for every 350 ft (107 m) of longitudinal spandrels or struts. The braced bay should preferably be located in the middle of the spandrel run.

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DESIGN LOADS (Cont)

LOAD COMBINATIONS

The load combinations for designing plant structures are specified in **GP 4-1-3** and discussed in [Section XXIX-D](#). For convenience the more common combinations that apply to piperacks are summarized below.

Typical Loads

D	=	Dead Load of Pipe and Structure
F	=	Fluid Load in Pipe
W_T	=	Wind Transverse to the Pipe Support
A	=	Anchor Load
T	=	Longitudinal Thermal Friction Load
E	=	Seismic Load

Allowable Stress Design

LOAD CONDITION	LOAD COMBINATION	ALLOWABLE STRESS MULTIPLIER
1. Empty Condition with Wind or Seismic	$0.9 (D + F^{(2)}) + (W_T \text{ or } E^{(5)})$	1.33
2. Test Condition	$D + F^{(1)}$	1.20
3. Test Condition with Wind	$D + F^{(1)} + W_T^{(3)}$	1.33
4. Normal Operating Condition	$D + F^{(2)} + A + T$	1.00
5. Normal Operating Condition with Wind or Seismic	$D + F^{(2)} + (W_T \text{ or } E^{(5)}) + A^{(4)}$	1.33

Strength Design - ACI, for Concrete Structures

LOAD CONDITION	LOAD COMBINATION
1. Empty Condition with Wind or Seismic	$0.9 (D + F^{(2)}) + (1.3 W_T \text{ or } 1.4 E^{(5)})$
2. Test Condition	$0.83 (1.4 D + 1.4 F^{(1)})$
3. Test Condition with Wind	$0.75 (1.4 D + 1.4 F^{(1)} + 1.7 W_T^{(3)})$
4. Normal Operating Condition	$1.4 D + 1.4 F^{(2)} + 1.4 A + 1.4 T$
5. Normal Operating Condition with Wind or Seismic	$0.75 (1.4 D + 1.4 F^{(2)} + (1.7 W_T \text{ or } 1.9 E^{(5)}) + 1.4 A^{(4)})$

Strength Design - AISC, for Steel Structures

LOAD CONDITION	LOAD COMBINATION
1. Empty Condition	$0.9 (D + F^{(2)}) + (1.3 W \text{ or } 1.4 E^{(5)})$
2. Test Condition	$0.83 (1.4 D + 1.4 F^{(1)})$
3. Test Condition with Wind	$1.2 D + 1.2 F^{(1)} + 1.3 W_T^{(3)}$
4. Normal Operating Conditions	$1.4 D + 1.4 F^{(2)} + 1.4 A + 1.4 T$
5. Normal Operating Condition with Wind or Seismic	$1.2 D + 1.2 F^{(2)} + 1.2 A^{(4)} + (1.3 W_T \text{ or } 1.4 E^{(5)})$

Notes:

- (1) The weight of water should be used as the fluid load.
- (2) The quantity and weight of material most likely to be contained in the pipes..
- (3) For test conditions, the wind load should be 1/3 the normal wind load or the load from a 45 mph (20 m/s) 3-second gust wind speed.
- (4) Anchor loads need not be considered to occur with extreme wind for plants with operating policy to shutdown prior to the extreme wind events such as hurricanes and typhoons.
- (5) Seismic loads are based on allowable stress design per the UBC.