Discussion on Structural Design of Steel Pipe Support Structures

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This is the second of a 2 part article on the design of pipe support structures. Part 1 of this article (February 2010 issue) discussed the effects of atmospheric temperature changes, expansion joint requirements and the introduction to design loads. This article concludes with the continuation of design loads, structural instability concepts and detailing for stability requirements. (Equation and figure numbers in this part are a sequential continuation from Part 1.)

Interaction between Pipes and the Support Structure

In practice, pipes are not attached to each and every pipe support in order to restrain the forces caused by thermal expansion or contraction. Under these conditions, at the onset of expansion/contraction, friction forces may develop between the pipes and the structural steel support. This frictional force is applied to the top flange generally creating an eccentric load, or torsion, on the supporting wide-flange shape. The force generated by friction (F) can be expressed as:

$$F = \pm \mu N \qquad \text{Equation 5}$$

where μ is the coefficient of static friction, approximated to be 0.3 for most steel-to-steel contact surfaces, and N the normal force at the contact surface.

If a thermal differential between the pipe and the supporting structure occurs, frictional forces would initially be restrained by the supporting structure. Assuming the flexural stiffness in the longitudinal direction of each bent of pipe rack (ref. *Figure 3*, Part 1), the total force restrained by the pipe rack bents (F_f) is given by:

$$F_f = \sum k\Delta \qquad \text{Equation 6}$$

where, Δ is the horizontal displacement of the pipe support bent and k is the stiffness of the frame about its weak axis. In this case, the pipe anchor force is also equal to the force restrained by the pipe bents prior to slip. Therefore, each pipe support bent restrains a share of the frictional force prior to slip, regardless if the pipe is fastened to the pipe support or is free to move longitudinally. However, at the onset of the frictional slip the force at the pipe anchor point, which is located by the piping engineer, would be equal to force P (as given in *Equation 4*, Part 1) and F_f given in *Equation 6*.

Although friction may develop at the contact surface from the resistance to movement of the pipe under thermal differentials, eventually there becomes no correlation between the maximum friction force (F) and the force exerted by the thermal expansion or contraction (P) of the pipe. The maximum friction force (F) depends upon variables such as temperature differential and contact surface conditions. The magnitude of the thermal expansion force (P) is extremely high compared to the friction force F as assumed. This is demonstrated in the following numerical example:

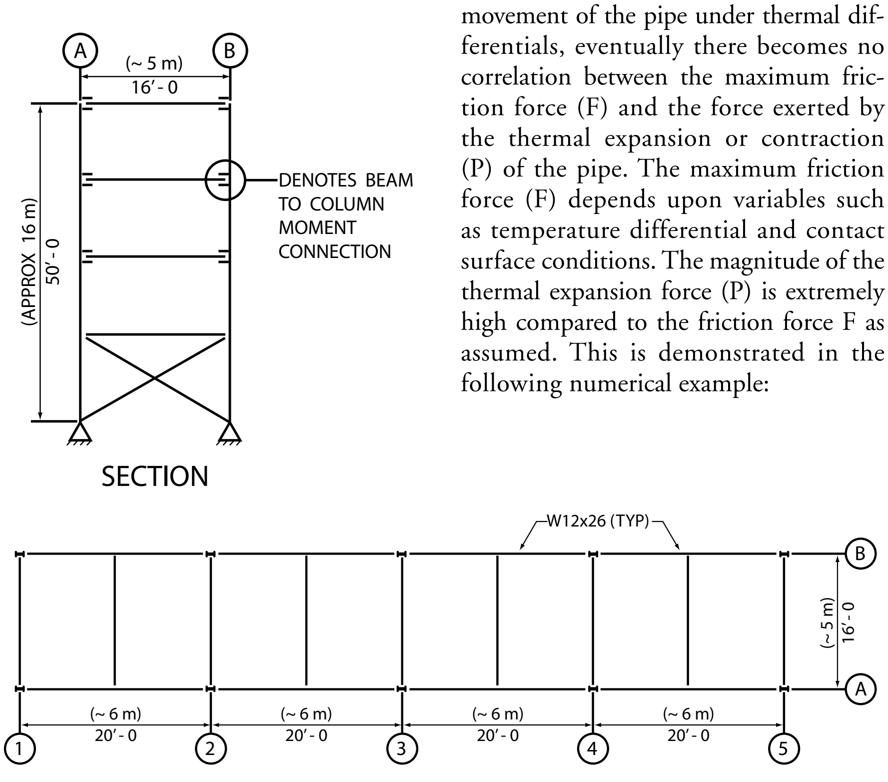

Figure 5.

Numerical Example:

Assume:

Bay spacing = 20 ft. (~ 6m), Bay width = 16 ft. (~ 5m). See *Figure 3* (Part 1).

Atmospheric temperature variation = 80° F

Elongation per bay ($\Delta\ell$) = E t ℓ = (0.00065 x 80° F x 20 ft. x 12 in.)/100° F = 0.125 in.

Change in unit stress (σ) = E ∈ t = (29,000,000.0 x 0.00065 x 80° F)/100° F = 15.08 ksi.

Force imparted by restraining this expansion/contraction, P = A E ∈ t = A x 15.08 ksi.

(Where, A is the cross sectional area of the pipe.)

Given, a 6 in. (150 mm) diameter Schedule 40 Std. pipe the cross sectional area, A= 5.58 in^2 Weight of the pipe with water = 12.5 lb/ft., for 20 ft. length (tributary length on the pipe rack.) the weight = 230 lb

Friction force between the pipe and the structural steel support, F = μ N

F = 0.3 x 230 lb. = 69 lb.

P is the force imparted by the pipe due to expansion and contraction.

P = 5.58 in^2 x 15.08 ksi. = 84,146 lb.

Consequently, the friction force is extremely small compared to the force imparted by thermal expansion and contraction. Additionally, the increase in magnitude of the assumed friction force is gradual while the occurrence of slip overcoming friction is sudden. Thus, the maximum frictional force and eventual slip occur at or near the onset of expansion and contraction of the pipe. Typically, multiple pipes are supported at any given tier of the pipe rack. If anchor points are staggered for each pipe, it would complicate the estimation of friction forces since these forces oppose each other; however, these would further reduce their impact on the supporting structure. In general, frictional forces on the pipe racks may be neglected, but local affects, if any, due to the friction force (F) on the supporting member, should be considered.

In the event that the pipes are fastened at each pipe support location and restraining forces due to expansion/contraction of the pipes develop, the purpose of providing any pipe anchor would be defeated.

This is primarily due to the fact that each pipe support bent is providing a restraint for the pipe against its expansion/contraction force equal to its tributary length of the pipe support. In addition, pipe restraint against expansion and contraction defeats the purpose of providing the expansion loops, U-shaped attachments intended to flex with pipe expansion/contraction, and the pipe anchorages for thermal affects. Such a system is not only impractical, but is also not economical.

As illustrated in the numerical example, the friction forces are very small in comparison to the forces imparted due to the expansion and contraction of the pipe material. The general practice of not fastening the pipes against the forces of expansion/contraction of the pipes is the most practical approach.

Stability

Stability of the frames is essential in the design of pipe support structures. Frame instability occurs due to initial eccentricities, fabrication and erection tolerances, dead loads, and the elastic deformations. In *addition* to the bracing required for the applied loads, frame stability bracing should be provided as shown:

where:

A_b = Area of brace required for stiffness and frame stability (in^2),

$$A_b = \frac{2\left[1+\left(\frac{L_B}{L_C}\right)^2\right]^{3/2}\sum P}{\left(\frac{L_B}{L_C}\right)^2 E} \qquad \text{Equation 7}$$

P = Actual axial load in column (kips),

$\sum P$ = Axial loads in all columns braced by the brace being designed (kips),

L_B = Bay spacing or the distance between the columns (inches),

L_C = Unbraced length of the column (inches), and

E = Modulus of Elasticity (ksi).

The minimum area of brace, A_b, is required for frame stability without consideration of any applied lateral loads. Structures will be subjected to instability without this minimum brace in addition to the brace required for applied loads. Therefore, the total brace area $A_{b(total)}$ required would be A_b plus the brace area required for the applied lateral loads. This total area of the brace should be provided at or near the center of thermal stiffness as shown in *Figure 3* (Part 1).

The number of braced bays should also be symmetric with respect to the center of thermal stiffness. In any symmetrical and uniform structure, the center of thermal stiffness could be assumed to coincide with the centroid of the structure.

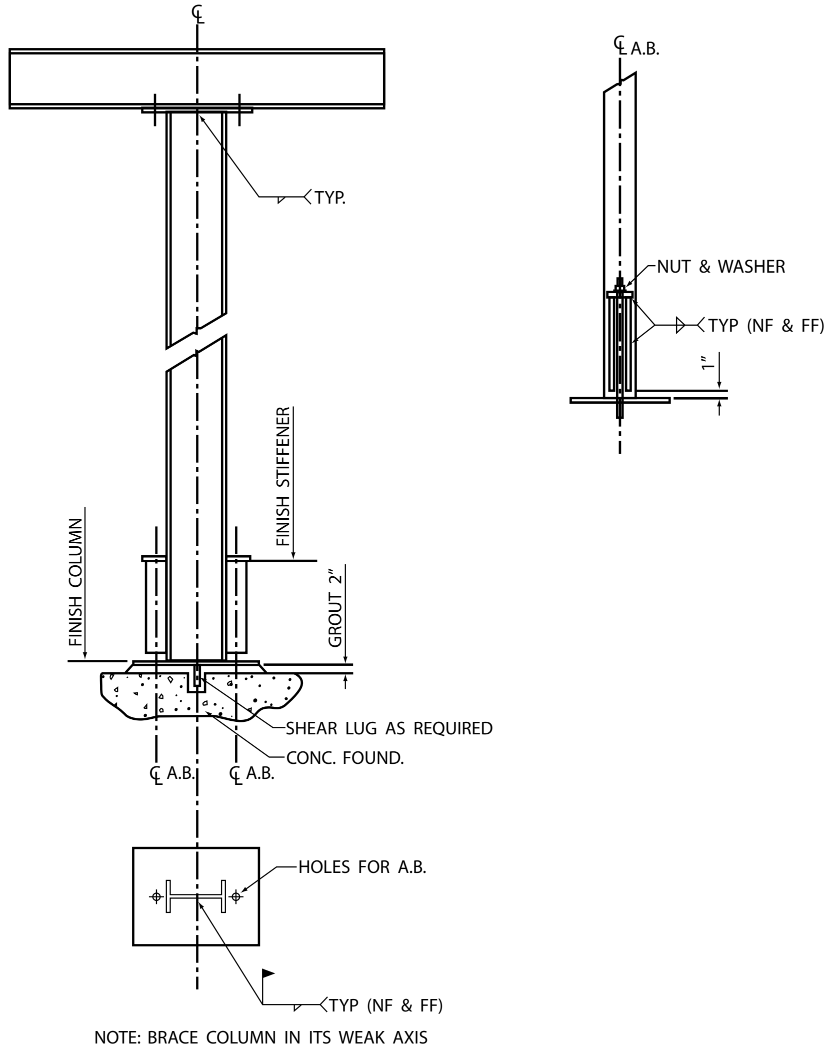

Figure 6: T-Support Column.

Detailing for Stability

Oversized and slotted holes should be avoided. Expansion joints are not required in any pipe rack of less than 500 feet long. However, at intersecting pipe racks an additional frame could be located at the intersection if the intersecting pipe rack is a long stretch (*Figure 4*, Part 1).

The spacing of these adjoining frames at the expansion joint need not be greater than the required spacing for the installation of anchor bolts and the connections of the structural steel. Typically, a two foot gap between the columns/frames is adequate. This would allow both the columns at the expansion joints to be placed on one common foundation. Alternatively, depending upon the length of the intersecting pipe rack, longitudinal beams could be connected directly to the intersecting pipe rack with oversized or slotted holes. For short runs of intersecting pipe racks, no slotted or oversized holes for the bolts would be required. In all cases, only the longitudinal exterior beams of the pipe racks should be connected to the intersecting pipe rack columns. Ideally, if the vertical bracings and the centers of thermal stiffness are in the proximity of the intersecting pipe racks, they could be directly connected with the standard bolted connections.

Columns are generally oriented with their strong axis along the length of the pipe rack without transverse bracing. If transverse bracing is provided, as shown in *Figure 5*, column orientation with its strong axis along the transverse direction provides a more economical design.

Bracing for Stability

Primary bracing systems include:

1) Transverse braces (*Figure 5*) in the plane of the bents,
2) Longitudinal braces (*Figures 3* and *4*; Part 1) along the length of the pipe rack, and
3) Horizontal bracing or plan bracing, as shown in *Figure 4* (Part 1).

Plan bracing, as shown in *Figure 4* (Part 1), is not always necessary but should be considered for pipe racks located in regions of high seismic risk with weak or soft story pipe rack frames.

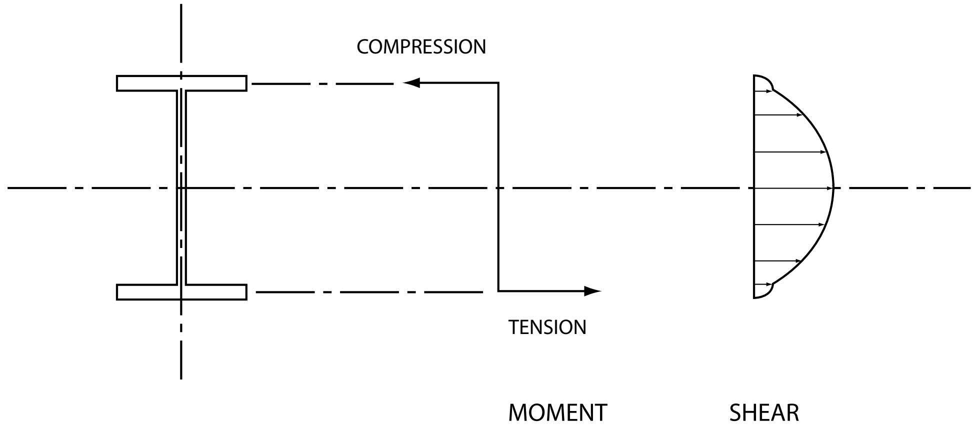

Figure 7: Stress Distribution in Wide Flange Shapes.

The purpose of plan bracing is primarily to transmit horizontal applied loads resulting from pipe anchorages or guides. Guides are restraints attached to the support bents to prevent lateral displacements of the pipes. Plan bracing may be provided in heavy seismic areas if the contents of the pipes carry hazardous material. Plan bracing would also function as a collector element and would provide a horizontal diaphragm to transmit the loads. This would also permit the transverse bents to share the lateral loads as described in Part 1 of this article. For long spans, such as at the roadway crossings of pipe bridges, plan bracing is essential to prevent torsional instability. Transverse frames and the fastening system (attachments) of the pipes should be designed to resist the wind loads without any plan bracing. Therefore, plan bracing is not necessary to resist the wind forces, particularly if the pipe rack heights do not exceed approximately 50 feet (15 meters). All interior hanger or trapeze type pipe supports should be braced in both orthogonal directions for seismic loads.

All T supports, as shown in *Figure 6*, require stability in both the longitudinal and transverse directions. In the longitudinal direction, vertical bracing with struts should be provided. In the lateral or transverse direction of the T support, the stability of the system depends upon the base fixity of the T support; that is, the translation and the rotation of the T support at the connection of its base must be restrained. In structural steel W shapes, the flanges can ideally be assumed to resist the flexural demand of the column and the web may be assumed to resist the shear force. The stress distribution in W shapes is shown in *Figure 7*.

Therefore, in order to provide an elastic, moment resisting connection, the flanges should be fastened as shown in *Figure 6*. The base plate connection with 4 anchor bolts is similar to an end plate connection and there would be a rotational slip depending upon the stiffness of the base plate and the rotational restraint offered by the foundations. T-support bases with two bolts along the strong axis of a column (*Figure 6*) are structurally unstable without the bolt cages connecting to the column flanges in combination with the longitudinal bracing with struts. For W shape T-support columns, the flanges should be restrained in order to provide for a moment-resisting connection. Such non-seismic connections are shown in the suggested details of column base plates in part 4 of the American Institute of Steel Construction's (AISC) *Manual of Steel Construction*. OSHA requirements necessitate a minimum of 4 bolts be placed at all the column bases.

All column bases should be finished and field-welded to restrain the horizontal shear at the column bases. Full penetration welds at the column bases are uneconomical and need not be used just to resist the horizontal shears at the column bases. In practice, two C-shaped fillet welds (between the inside of the column flanges and along the web) would be adequate. The transfer of horizontal shear could be achieved by providing a shear lug at the baseplate. Structural shapes are not economical or practical to be used as shear lugs. Flat plates are very effective as shear lugs and the welds should be balanced to account for reversal of stresses and eccentricities.▪

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