Selection of Thrust Restraints for Above Ground Pressure Pipes With Expansion Joints

** Paulraj. S.*

Abstract

Pressure pipes used in various industrial applications are subjected to internal pressures of a high order by the fluids carried by them. Though such pipes of various materials of construction are designed to withstand these pressures, strength and stability of pipes at bends either below or above ground require careful examination to achieve external equilibrium specifically when diameters are large. The following discussion is intended to bring forth the different industrial practices in addressing the question of external stability of pipes at bends above ground under various operating conditions. It presents an analysis on the right selection of thrust restraints for such applications.

Keywords: Axial tension, equilibrium, expansion joint, saddle, shut-off pressure, thrust restraint.

I. INTRODUCTION

Supporting arrangement for large diameter pipes at bends above ground level is generally decided by designers from both piping and structural engineering fields. While the focus of piping and process engineers is more on stress analysis to determine the optimal shell thickness for critical pressures with necessary boundary conditions, identification of the right support location for pipes considering the overall economics involved in structural design rests with structural engineers.

Selection of the most appropriate structural system gains importance in getting optimal results due to the high magnitude of forces exerted by these pipes at bends of varying degrees.

Let us take the case of carbon steel piping meant for suction and discharge of circulating water (CW) from underground sumps using high capacity vertical turbine pumps in coal based thermal power plants.

II. COMPARATIVE ANALYSIS

Fig. 1 shows sectional elevation of a pump house with a vertical turbine pump, suction and delivery pipes of carbon steel, rubber expansion joint, shut-off valve, and connection to a main header pipe below ground level. A comparative analysis is done for various flow conditions on the sample considered with possible options for providing structural supports.

A. Critical Cases of Flow

Two cases of flow parameters are considered to assess the forces induced in the system when the pump is in operation.

Case-1 : With the valve closed, i.e., shut-off pressure
Case-2 : When the valve is open, i.e., operating pressure

B. Joint Types

Joints are detailed as "tied or untied joints" to suit the specific purpose they are intended to. Tied joints are those where flanged ends of steel pipes are jointed with necessary seals or bellows and bolted all round for safe transfer of longitudinal forces induced.

Untied joints are used for expansion joints normally without these bolts or tie rods with necessary expansion bellows to allow for axial movement. Provision of an expansion joint with tie rods between the suction pipe and shut-off valve often raises the question of applicability of load transfer at this joint.

C. Assessment of Forces and Structural Behavior

Following design parameters are considered for details shown in fig. 1:

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*Paulraj S. is Vice President - Civil Design, BGR Energy Systems Limited, 443, Anna Salai, Teynampet, Chennai, Tamilnadu, India - 600018. (email: paulraj2k4@gmail.com)

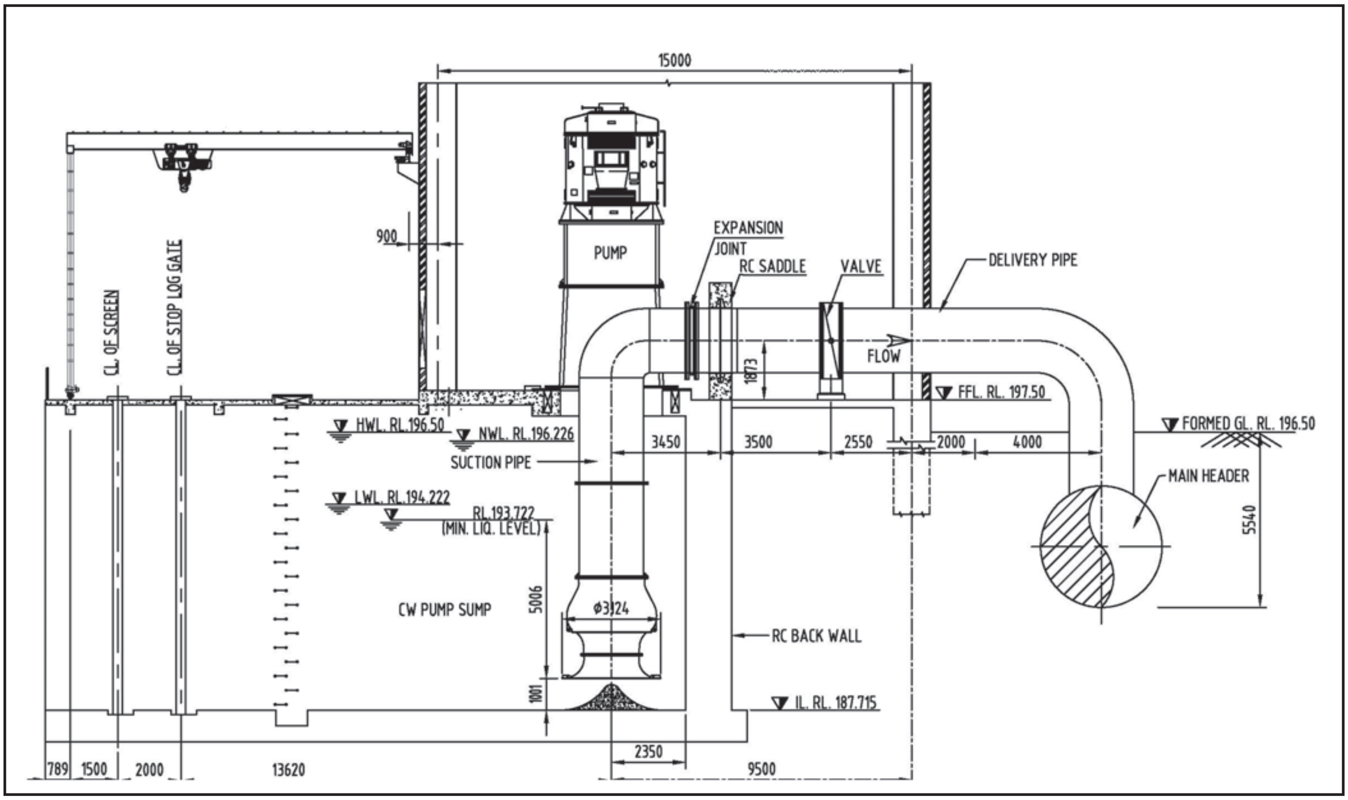

Fig. 1. Sectional Elevation of CW Pump House

Suction and delivery pipe diameter : 2.0 m
Pressure in pipe due to shut-off head : 390 KN/m^2
Pressure due to duty point head : 240 KN/m^2
Angle of deviation of pipe bends, α : 90 deg
Diameter of main header : 3.74 m
Thrust (T) at valve due to shut-off pressure :
=Area of pipe*shut-off pressure
= (3.14*2^2/4)*390 : 1224.6 KN
Resultant thrust (R) in pipe bends due to operating pressure :
=2*Area of pipe* duty pressure*sin (*α*/2)
=2*(3.14*2^2/4)*240*sin (45) : 1065.8 KN

Please refer to fig. 2 and 3 which capture the free body diagrams for cases 1 and 2 respectively.

With untied expansion joints, case 1 calls for an external restraint to counterbalance the thrust force (T) induced in the delivery pipe at valve location due to shut-off pressure. This could be provided in the form of a reinforced concrete (RC) saddle anchored into the RC back wall of sump between expansion joint and shut-off valve given the present layout. Horizontal component (Hf_s) and vertical component (Vf_s) of resultant thrust force at bend in suction pipe are resisted by the pump base plate bolted onto pump floor. Horizontal forces Hf_s and T acting in opposite direction in this case translate to axial tensile forces on the pump floor with residual unbalanced horizontal force on the structure as a whole.

In case 2, while the behavior is same at the suction end, horizontal force (Hf_d) is induced at the bend of discharge pipe which is again restrained by the saddle provided at the back wall. In this case, there would be no resultant unbalanced horizontal force on the structure since the pump floor acts as a balancing diaphragm. Vertical component (Vf_d) of bend thrust at delivery pipe is often countered by the combined weight of header pipe and soil overburden. Adequacy of vertical reaction however, needs to be verified on a case-to-case basis with calculations.

D. Possible Solutions

Thrust restraint provided with a RC saddle anchored into sump RC back wall serves as an ideal solution in handing the thrust (T) due to shut-off pressure or Hf_d with minimal increase in the overall cost of structure. This is owing to the fact that walls of sumps of this size when designed either by limiting crack width or uncracked design method have a thickness of not less than 1.0 m. Incremental cost increase of providing a saddle from back wall invariably turns out to be much less when

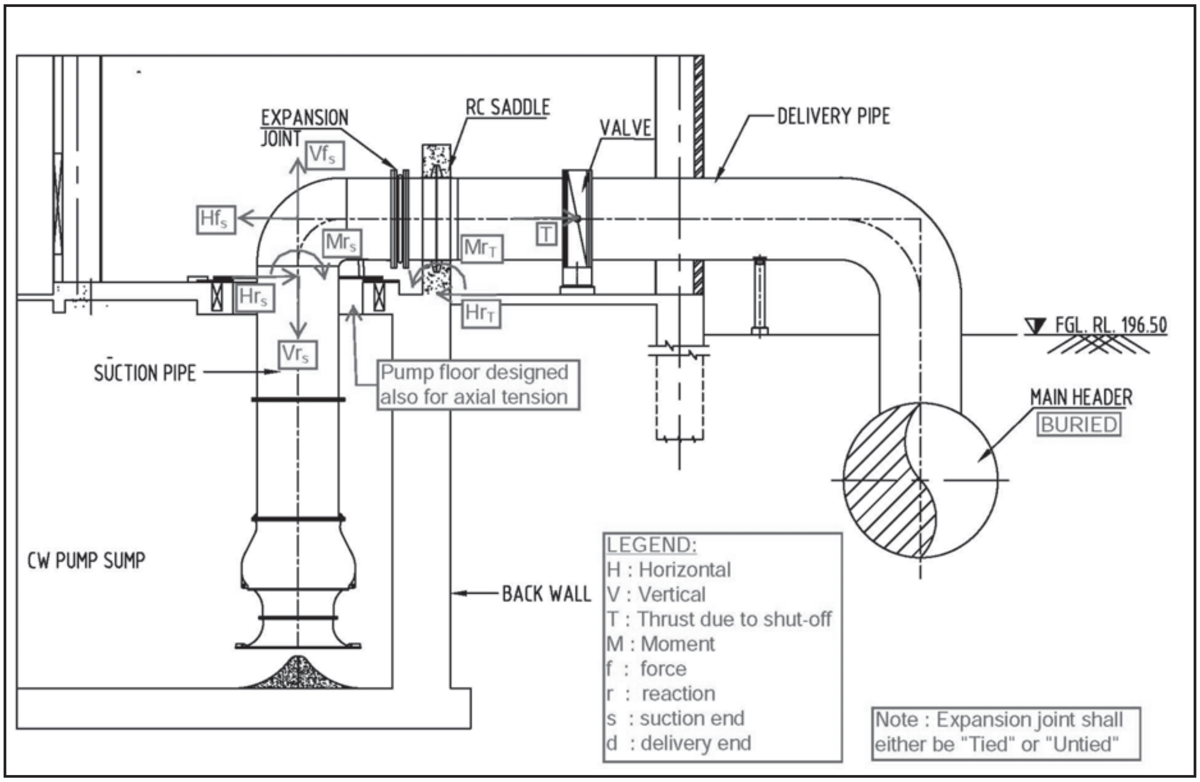

Fig. 2. Free Body Diagram for Case-1

compared to that of an independent thrust block outside the building. This also eliminates the need to design the structure for the unbalanced horizontal force (Hf_s) at suction pipe bend.

Alternatively, a thrust block can be contemplated with a concrete encasement around the buried header pipe outside the pump house but this arrangement would not be an optimum one from stability considerations owing to the large moments induced at header pipe bottom level by the unbalanced horizontal forces induced either by thrust force component of delivery pipe bend (Hf_d) or by the thrust (T) due to shut-off pressure at valve location.

To evaluate this, if bottom of thrust block is at 5.84 m below Formed ground level (FGL), moment induced by the maximum horizontal thrust force at bottom level :
=1224.6*(1.873+1.00+5.84) = 10670 KN-m

For a base width of say 5m, approximate weight of thrust block required would be (10670/2.5) = 4268 KN. With a factor of safety of 1.4 for stability, length required for thrust block :
=(4268*1.4)/((5.84*5) – (3.14*0.25*3.74^2))*25= 13.11 m. Approximate volume of concrete encasement works out to 239 m^3 discounting the effect of passive resistance of soil.

A reinforcement concrete (RC) saddle anchored in the back wall attracts a moment of (1224.6*1.873) = 2293.7 KN-m. RC saddle of size 4 m wide, 3.5 m high and 1 m thickness with reinforcement anchored into RC back wall would be adequate to handle the bending moment and shear force induced. Volume of concrete envisaged in this case is around 11 m^3. Anchoring of saddle onto a rigid back wall which is designed for stresses of a higher order for full and empty conditions of sump generally takes care of the forces transferred from the saddle.

Thus, it is evident that choice of saddle anchored to back wall as a thrust restraint is economical when compared to an independent thrust block outside the pump house.

System design in engineering is greatly dependent on the consistency in representation of design parameters and requirements among various disciplines to bring about optimized results.

❖ Providing a thrust restraint either within the building or outside becomes mandatory to keep the system in equilibrium when expansion joints cannot be subjected to axial force transfer as per Expansion Joint Manufacturers' Association (EJMA) requirements even if they are tied joints.

❖ This recommendation is also meant to ensure that

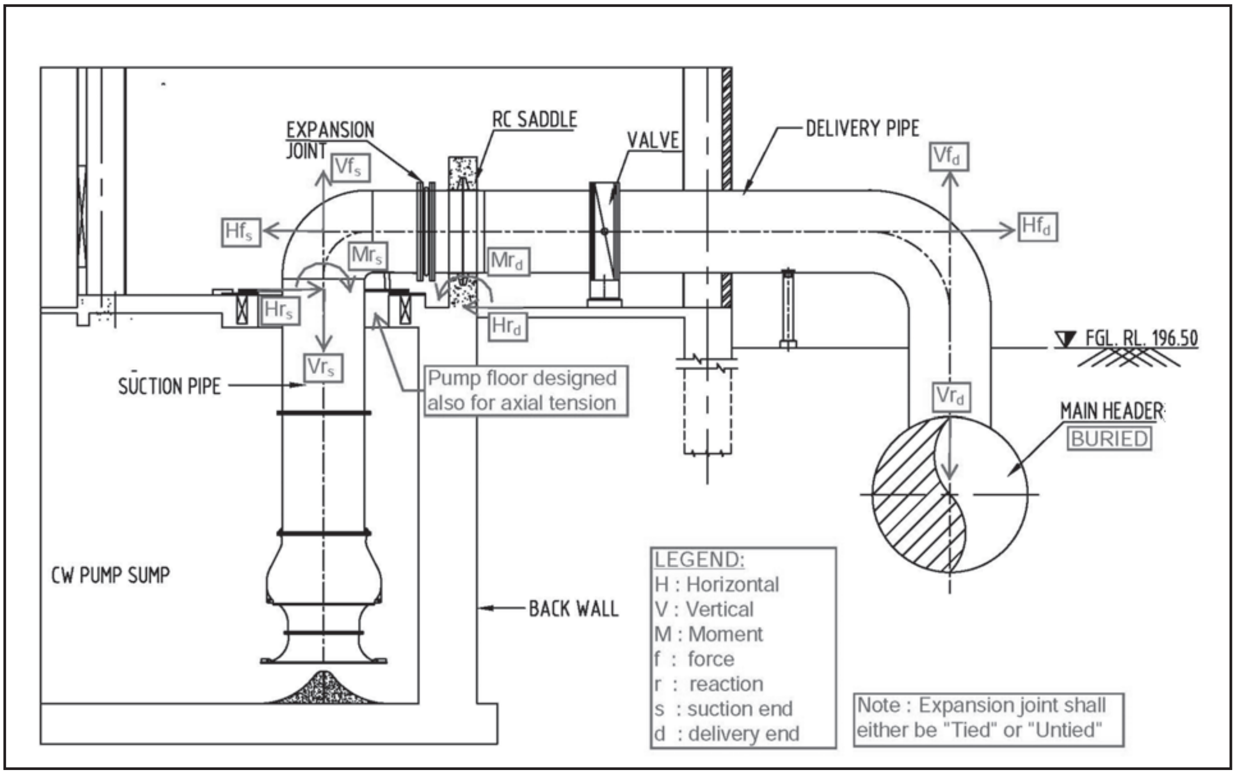

Fig. 3. Free Body Diagram for Case-2

pump vibrations are not transmitted through tie rods of expansion joints though they are provided with prescribed play for axial movement.

❖ Increasing the shell thickness of suction and delivery pipes is no solution to withstand these thrust forces which require external restraints in achieving external equilibrium.

❖ Economy in cost and execution time would be achieved if thrust restraints are in-built in the structure as compared to provision of independent concrete thrust blocks outside.

This analysis, though not exhaustive, is an attempt to bring about a better understanding of the approach in design and review of such systems in industrial applications.

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About the Author

Paulraj S. is a Civil & Structural Engineering professional with more than 30 years of experience in structural design, review, and engineering coordination of industrial projects in thermal power cement, automotives etc. with added experience of direct execution of residential and commercial projects. Projects engineered cover a wide spectrum of structures in in-situ, precast & pre-stressed reinforced concrete and structural steel using Indian, American, DIN, and other international codes.

He has considerable field experience in design supervision at project sites with a sound knowledge of construction practices, construction, and erection methods. He also has working knowledge in proposal engineering, project scheduling, and engineering management.