Occasional loads on pipes

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Design of piping structure has been focused in the recent years to fulfill the demand of various sectors. In West Bengal, public sectors like municipal water supply, public health engineering, irrigation, process plant like Haldia Petrochemical, Power Plant like Bakreshwar or Kolaghat thermal power station etc. should take care about the occasional loading on piping structure.

Occasional loading can have a detrimental effect on piping structure. We cannot forget the horribility in boiler accident in Massachusset or gas accident in Bhopal. So, we have to ensure the safety of the designed structure prior to efficiency and economy of the system, in order to get rid from life threatening.

In conventional design practice, there are readily available codes and standards like ASME, ANSI, DIN, AISC, IBR, ASTM etc. But the key area they are dealing with are based on the consideration of static and dynamic loading on the process design day to day climatic conditions and other usual factors like pressure, thermal stress, dead weight etc.

But on the other hand, in actual practice, a piping structure may be subjected to some unpredicted accidental loading. So, the designers in the practical field must consider the effect of occasional loading in piping structure.

In case of rigid design of piping structures if we allow more rigid pipe supports at closer intervals, then there will not have sufficient expansion allowance; that is why the system may fail under thermal loading, although it is prevented from seismic failure.

On the other hand, if we design flexible piping structures, then the system is susceptible to fail under seismic loading. But, the design is not resistant from seismic loading.

So we have to optimize how far we allow the system flexibility or what should be the extent of rigidity of the piping system from the designer's point of view. The simultaneous effects of thermal and seismic loading of the structure must be analyzed in engineer's point of view.

Keywords: piping structure, flexibility, rigidity,occasional

1.0 OCCASIONAL LOAD

Loads which are applied to a system during only a small portion (typically 1 to 10 percent) of the plant's operating life are usually classified as occasional loads. This classification encompasses loads which vary from periodically applied live loads (such as snow), extreme natural phenomena (hurricane, tornado, earthquake), postulated plant accidents like pipe rupture, and usual plant operations like relief valve discharge.

It is quite likely that the optimal support locations required for occasional loads will not coincide with those required for sustained loads. It is recommended that, where possible, a little extra conservatism be introduced into piping design, to permit the use of same support locations for both sustained and occasional loads.

1.1 Seismic Load

Seismic forces on a system result from a sudden erratic vibratory motion of the ground on which the system is supported and the system response to this motion. The principle factors in the damages to structures are the intensity and duration of the earthquake motion. The forces and the stresses in the structures during an earthquake are transient, dynamic in nature, and complex. An accurate analysis is generally beyond the kind of effort that can be afforded in a design office. To simplify the design procedure, the vertical component of the earthquake motion is usually neglected assuming that the ordinary structures possesses enough excess strength in the vertical direction to be earthquake resistance. The horizontal earthquake forces acting on the structure are reduced to the 'equivalent static forces'. Earthquake-resistant design is largely empirical, based on seismic coefficient derived from the performance of structures subjected in the past to severe earthquakes. Among those earthquake damages, it is observed that structural damage can be classified based on the difference of seismic excitation effects and structural failure modes. For example, dynamic loading or impact effect should be serious to fragile structures while relative deformation or liquefaction should be effective to the failure of piping structures.

1.1.1 Time-History Analysis

Time-history analysis is based on a record of postulated earthquake versus time. Data in the form of ground displacement, velocity, acceleration is plotted for the duration of the estimated earthquake record; this information is plotted for three directions (north-south, east-west and vertical, or along the major axes of the structure). This data is then used to simulate the seismic excitation of the piping system in a computerized dynamic model, which monitors the stresses, displacements, and restraint loads for the system at regular intervals throughout the seismic event. The computer analysis is usually performed in the elastic region by numerical integration of a lumped mass mathematical model. The time-history computer analysis, although quite accurate, is generally very expensive, since each time interval requires a new calculation.

1.1.2 Modal Analysis

For most applications time-history analysis is too expensive and time-consuming. Therefore, piping systems are frequently analyzed by modal analysis, using response spectra.

In modal analysis the seismic model of the piping system are breaked into a number of modes of vibration (single-degree of freedom oscillators), the sum of which approximates the seismic characteristics of the total system. Response spectra are the extracted to determine the maximum response (whether acceleration, velocity, or displacement) of the idealized single-degree-of-freedom oscillators of natural frequencies when they are subjected to the specified input vibratory motion. The maximum response during the seismic event is then determined for each mode of vibration. These responses are combined to determine the total response of the system.

The equation of motion for single DOF oscillator when it is subjected to externally imposed acceleration is mathematically described as

$$M\ddot{X}(t) + C\dot{X}(t) + kX(t) = Ma(t) \quad (1)$$

Where,

M=Mass of the system,

C= Coefficient of damping,

k = spring stiffness,

$\ddot{X}(t)$ = Response acceleration of mass,

$\dot{X}(t)$ = Response velocity of mass,

X (t) = Response displacement of mass,

a (t) = Input acceleration

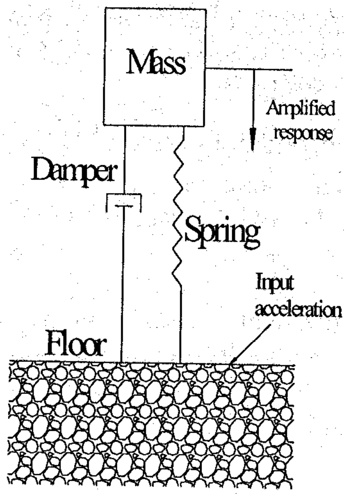
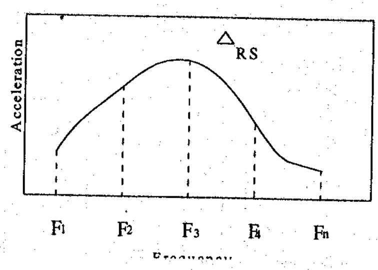


Fig. 1: Response spectrum for single frequency excitation

Table 1: Failure Mode Classification



Relative deformation	Vibration excitation	Liquification
Failure of tie-rod, spring hunger and expansion joint Leakage of gas and liquid from connecting joint	Tumble of connecting meters & pumps	Collaps and inclination of pipe support structure

Examples of Key Items to Advanced Seismic Countermeasure:

- Revision of Seismic Design Code Considering Piping Flexibility
- Optimization of Pipe Supports Arrangement
- Improvement of Seismic Capacity against Pipe Connection and Attachment

1.2 Relief Valve Discharge

Relief valves are used in piping systems to provide an outlet on those occasions when pressure builds up beyond that desired for safe operation. When the pressure setting is reached, the valve opens, allowing sufficient fluid to escape from the piping system to lower the pressure. This permits a controlled discharge of fluid as a means of preventing pressure vessel rupture.

When a relief valve discharges, the fluid initiates a jet force, which is transferred through the piping system. This force must be restricted by pipe supports if the pipe is not capable of resisting the load internally. The magnitude of the jet force is usually provided by the manufacturer. If this value is not known, then it may be calculated fairly easily for those cases where the valve vents to the atmosphere. If the fluid discharged flows through a closed system to a vessel, transient flow conditions may develop which make the valve force difficult to calculate.

For a relief valve venting to the atmosphere, the ANSI B31.1 piping code recommends that the discharge force

$$F = DLF\left(MV + \frac{PA}{1 \times 10^6}\right) \tag{2}$$

Where,

F = discharge force (Newton)

M = mass flow rate from valve (kg/s)

V = fluid exit velocity (m/s)

P = static gauge pressure at discharge (N/m^2)

DLF = dynamic load factor (dimensionless)

DLF is used to account for the increased load caused by the sudden application of the discharge force. This factor will vary between 1.1 to 2.0 depending on the rigidity of the valve installation and the opening time of the valve.

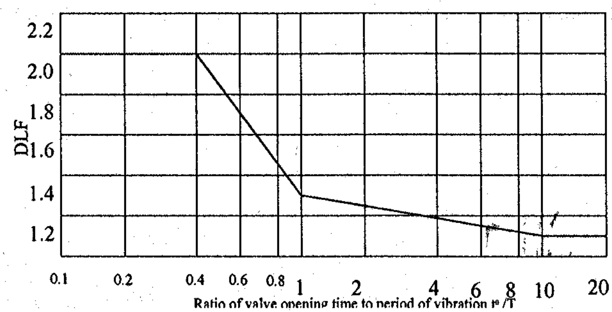


Fig. 2: Hypothetical Dynamic Load Factor

1.3 Wind

Wind loading is a periodic force stemming from aerodynamic iteration of the wind or dynamic pressure effects on the piping system. Piping which is located outdoors and exposed to the wind is normally designed to withstand the maximum wind velocity expected during the operating life of the facility. The magnitude of wind velocity depends on local conditions; an estimate of which can be usually varies with above ground elevation, is statistically estimated from previous observances.

A large part of the wind loading is caused by the loss of momentum of the wind striking the piping system. Despite localized variations, the force usually modeled as uniform load acting over the projected length of the pipe parallel to the direction of the wind. The expression for the wind force can be adopted from Bernoulli's equation fluid flow as follows

$$F = \frac{C_d D q}{100} \tag{3}$$

Where,

F = Applied linear dynamic pressure on projected length (N/m)

C_d = Drag coefficient (dimensionless)

q = Dynamic pressure (N/m^2) = $\frac{1}{2}\rho v^2$

D = pipe diameter, including insulation (mm)

ρ = density of air (kg/m^3)

v = velocity of air (m/s)

The value of drag coefficient is a function of the shape of the structure and a dimensionless flow factor called the Reynolds number. [Wind loading on the support usually need to be considered only in cases, where the support has a large surface area projected into the wind.]

Sometimes an additional factor of safety, called gust factor ranging from 1.0 to 1.3 is used in wind load calculation for a piping system; to account for dynamic effects of non-steady state air flow. The load calculated previously should be multiplied with this factor when necessary.

1.4 Water Hammer

If the velocity of a liquid in a pipeline is rapidly decreased by operating a valve, large increase in pressure is caused which is propagated throughout the fluid as a pressure wave. This phenomenon of abrupt increase of pressure caused by a rapid closure of valve is known as water hammer.

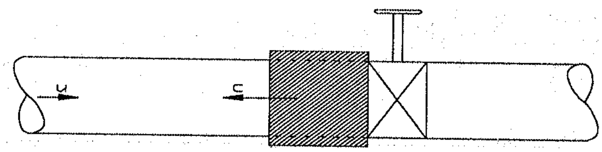


Fig. 3: Water hammer due to valve closure

The flow of a liquid in a pipeline is generally considered as incompressible. But there are situations in which the compressibility (or elasticity) of the liquid as well as the elasticity of the pipe material become important and must therefore be considered.

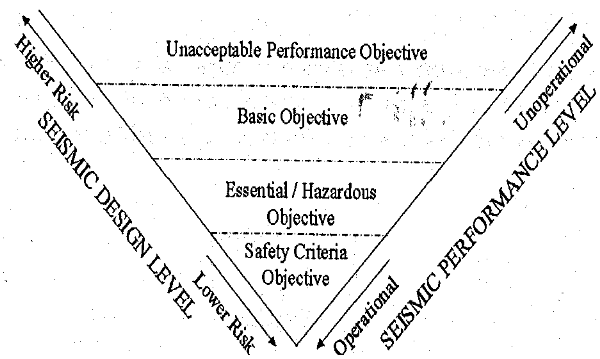


Fig. 4: Seismic Performance Objective

2.0 Service levels for occasional Loads

Service levels for nuclear safety related piping are encoded according to ASME section III. They are, in order of decreasing likelihood and increasing severity of occurrence, levels A, B, C, and D, also known as normal, upset, emergency, and faulted, respectively.

The piping codes regulate the stress levels permitted, but they do not define types of loading to be considered under each service level. Safe shutdown earthquake (SSE) is the maximum earthquake postulated to occur at the plant site at any time. Operating basis earthquake (OBE) is the maximum earthquake postulated to occur within the design lifetime of the plant or one-half of the safe shutdown earthquake, Whichever is greater.

3.0 CONCLUSION

The effects of vibration induced by occasional loads are non-ignorable. A piping system can be vibration excited by a number of sources that are a consequence of the flow of the internal fluid, the pumps, and other ancillary equipment of the system. The vibrational power induced in the pipe structure will be partly radiated as noise and partly transmitted through the isolators attaching the quiet piping system to the supporting structure. For the design calculation, engineers in the practical fields have to be consider the effects of various occasional loading on piping structures; of which seismic loading, wind loading, safety valve blowout, water hammer etc. are the predominantly important loads. They should be taken into paramount focus.

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