Designing Efficient Piping Systems

Seismic analysis of above ground piping in a process plant

Source: depositphotos.com / maroti

A typical process plant has a large network of pipes and equipment

Engineering design is a very stringent process and it involves various considerations including natural calamities, especially earthquakes. The use of this engineering design even in process plant piping is no exception. This article that gives insight into analyzing the seismic effects on the design of pipes. Using an assortment of analysis techniques, the results are presented herein.

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Rocks, being elastic in nature, store elastic strain energy during the gigantic tectonic plate action that occurs in the earth. However, the material content in rocks is small. Hence, when the rocks along a weak region on the surface of the earth reach their strength, a sudden movement takes place causing release of shock waves.

These waves are mainly classified as 'Body waves' and 'Surface waves'. Body waves comprise primary waves (P-waves) and secondary waves (S-waves) whereas surface waves comprise 'Love waves' and 'Rayleigh waves'. P-waves produce tension or compression strain along the direction of energy transmission whereas S-waves oscillate at right angle to it (refer Figure 1). Love waves are similar to S-waves but without a vertical component. A combined effect of the S-wave and Love wave cause maximum damage to a structure due to their racking motion in both the vertical and horizontal directions.

TABLE 1: RESPONSE SPECTRUM WITH 5 PER CENT DAMPING:

TIME PERIOD, SECONDS	SPECTRAL ACCELERATION IN 'G'S (5 PER CENT DAMPED)
0.01	0.5074
0.05	0.5845
0.075	0.7032
0.1	0.8287
0.15	1.0213
0.2	1.1060
0.3	1.1886
0.5	1.1006
1	0.8071
2	0.4506
4	0.1870
10	0.0683

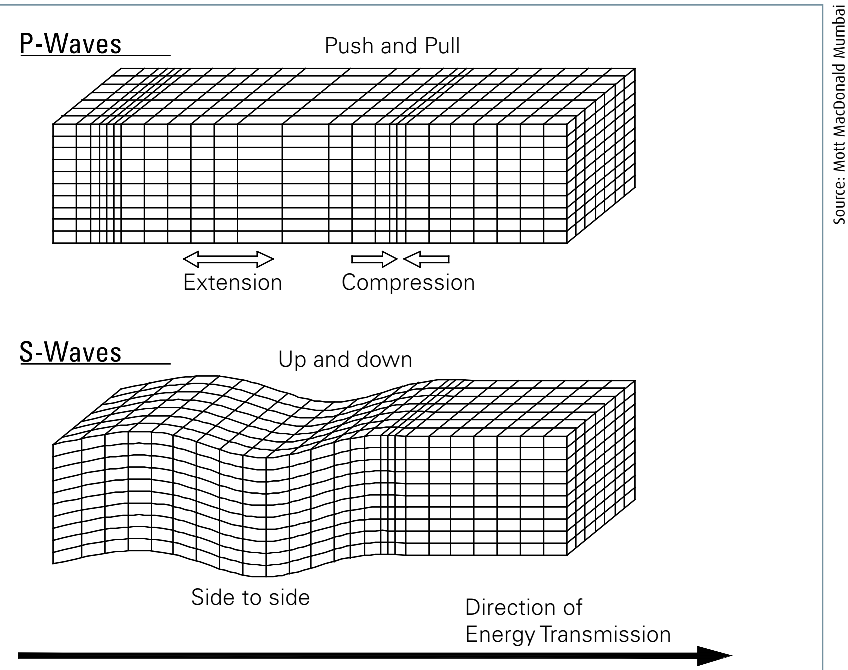

Figure 1: Shock waves occurring on the Earth's surface

Effect of earthquake on pipes

In a typical process plant, a pipe either rests on a steel structure or on a concrete support. The pipe can be fixed to the structure either through supports like U-bolts or can slide freely. However, for this seismic analysis, an assumption that no relative movement occurs between the pipe and the support has been made.

Consider a pipe attached to a support. Under the action of seismic event on the system (pipe + structure), the pipe experiences an excitation force due to seismic acceleration which is based on the properties of the support structure. Each structure has its own response to seismic excitation based on material, mass, geometry, stiffness etc. Accordingly, the response spectrum needs to be modified before applying to any system.

As per Newton's first law, the inertia of the pipe resists its movement due to seismic acceleration and results into a force, called 'inertia force', which acts against the direction of earth motion. This force changes magnitude as well as direction based on seismic motion creating unbalanced forces and vibrations in the pipe. If frequency of pipe reaches in the close vicinity of the natural frequency of the support then it can produce higher amplitude movements and even cause resonance.

Methods of seismic analysis

The earthquake characteristics are described by ground acceleration, the time of shaking and its response spectrum. The 'design earthquake' is generally defined by either of the magnitude of the largest earthquake that probably could occur or the magnitude corresponding to large return period e.g. 500 years, 1000 years, etc.

The return period can be calculated as follows:

$T = -t / \ln(1 - p)$

Where,

p is the probability of exceedance in t years, generally 10 per cent in 50 years and T is the return period, in years.

Example 1: t = 100 years, p = 10, then $T = -100 / \ln(1 - 0.1)$.

Therefore, T = 949 years ~ 1000 years

Earthquake analyses

The effect of an earthquake on a pipe can be analyzed by the following methods:

- Quasi-static or static equivalent method
- Response spectrum method (RSM)
- Time history analysis method

Quasi-static or static equivalent method (SEM)

SEM, which has been followed by most of the codes, assumes that the mass distribution throughout the height of the structure is uniform, with the centroid of mass and rigidity coinciding at each level. In most of the cases, this assumption holds well except for the structures of highly irregular shapes. In this method, a horizontal force in proportion to the ratio of seismic acceleration to gravitational acceleration is applied, as base shear, to get horizontal forces acting on the system.

Response spectrum method

It is a plot of maximum steady state response (displacement, velocity or acceleration) of a series of oscillators with different natural frequencies to a given shock. In this analysis the maximum response developed by a system to the transient load is analyzed. Response spectrum can be modified based on damping. The acceleration is in inverse proportion to the damping. RSM is the most common method in dynamic analysis of earthquake.

Time history analysis

It provides instrumental measurement of duration, frequencies or accelerations and can be used to understand linear or nonlinear response of a structure for a specific excitation. This method is generally not used to analyze seismic effect as each earthquake is different and the source could be away from the structure under design. However, this method can be used for forensic analysis of a seismic event.

Static equivalent method as per ASCE 7

A few mathematical calculations need to be performed in order to obtain seismic response co-efficient Cs. These co-efficient Cs will be used to generate seismic load acting on the system. All calculations and assumptions are done in accordance to the book of standards issued by the American Society of Civil Engineers (ASCE) 7.

The stepwise solution to obtain the static seismic co-efficient's:

Step 1: Identify site class based on type of soil from ASCE 7• (Table 20.3-1). Assuming soil type as dense soil let soil class be 'C'.

Step 2: Identify short period acceleration, i.e., the acceleration corresponding to 0.2s and spectral response acceleration corresponding to 1s from the response spectrum.

$(Ss)_{0.2s}$ = 1.1060 and S_1 = 0.8071.

Step 3: Get short period site coefficient from ASCE 7, (Table 11.4-1).

In this case, for $(Ss)_{0.2s}$ =1.1060 and Fa=1 for class C.

Step 4: Calculate spectral response acceleration at a short period adjusted to site class as:

S_{MS} = Fa*Ss = 1*1.1060 = 1.106.

Step 5: Get long period site coefficient from ASCE 7, (Table 11.4-2) and in this case, for S_1 = 0.8071 and Fv = 1.3 for class C.

Step 6: Calculate spectral response acceleration at period of 1s adjusted to site class as

S_{MS} = Fv*S1 = 1.3*0.807 = 1.0491.

Step 7: Calculate spectral response acceleration parameter at short period of 0.2s defined as:

S_{DS} = 2/3* SMS = 2/3*1.106= 0.74

Step 8: Calculate spectral response acceleration parameter at period of 1s defined as:

S_{D1} = 2/3*SM1 = 2/3*1.0491= 0.7

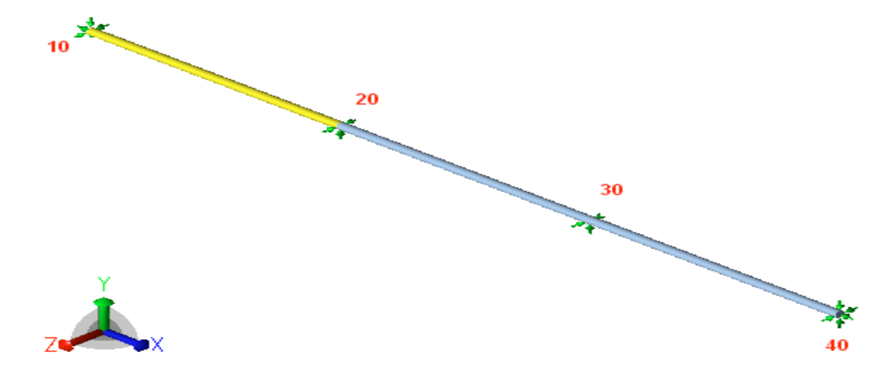

Figure 2: Calculation of stress due to seismic load on the pipe

Source: Mott MacDonald Mumbai

Step 9: With S_{DS} and S_{D1} values response spectrum can be built as follows:

- Period Sa less than T_0, straight line Sa
- Flat S_a between S_a between T_0 and T_s.
- S_a curve about T_s.

Sa = S_{DS} [0.4+0.6 T / T_0] ...... for period < T_0

Sa = S_{DS} .... for T_0 <=T<=T_s

Sa = S_{D1} / T .... for T> T_s

Step 10: Calculate seismic response co-efficient Cs as Cs = S_{DS} / (R/I).

Where, R is the response modification co-efficient and can be obtained as minimum value (conservative approach) from the ASCE 7 (Table 12.2-1 or Table 13.6-1). The typical value for structural support, R = 3. (Note: More accurate values can be selected on the basis of structural properties). I is the occupancy importance factor which can be obtained from ASCE 7 (Table 11.5-1).

I will vary from 1 to 1.5. Selecting I = 1.5, Cs can be calculated as Cs = 0.74 / (3/ 1.5).

Therefore, Cs = 0.37.

Example for designing a pipe

Consider a straight pipe subjected to spectral acceleration as per Table 1. The pipe data given is as follows. The outer diameter of the pipe is 8.625 inches, its thickness is 0.322 inches, with a corrosion allowance of 0.125 inches, and the material used is A106 B.

The weight of the pipe is 28.5lb/ft. Simple beam calculation provides the vertical dead weight on support number 20 = 228 lb (refer Figure 2).

The seismic force acting at each support location can be calculated as:

$(F_{seismic})$ 20 = 0.37 * 627 = 232 lb acting in the lateral direction.

The support and foundation shall be designed for this obtained value.

The stress due to seismic load on the pipe can be calculated using bending equation σ = M/Z. $(\sigma_b)_{midspan}$ =PL/4Z =232 * 20/4 * 16.7 = 70 PSI.

Conclusion

Designing a piping system for seismic event is largely dependent upon data availability and its proper interpretation. Even though static analysis is the most popular and proven method in pipe stress analysis, the response spectrum analysis provides additional and useful information like modes of vibrations and frequencies.

•Please refer to the ASCE 7 for all tables and annexures given herein