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Seismic Re-evaluation of Piping for an Old Operating Process Plant

R. K. Mishra, R. S. Soni, H. S. Kushwaha and V. Venkat Raj

Bhabha Atomic Research Centre, India

ABSTRACT

In the context of studies related to life extension of an old operating process plant, seismic re-evaluation for the as-built condition of the plant, using the current state of knowledge about the seismic characteristics of the site, assumes great importance. The aim of such an exercise is to assess the vulnerability of various systems and components of the plant for the maximum potential earthquake at the plant site. In this paper, methodology for the seismic re-evaluation of piping and connected equipment of an old operating process plant is presented. A few sample piping system analyses, their results and the conclusions arrived at, are also discussed in this paper.

INTRODUCTION

Seismic re-evaluation of existing facilities is an area of interest to many industrial plants, chemical plants and power plants of various categories. Existing facilities usually require seismic re-evaluation under two circumstances, viz. when the design level earthquake differs from the present seismicity of the site or when it is required to assess the remaining life of an existing plant in its as-built condition as a part of its life extension. The aim of this exercise is to assess the effects of the maximum potential earthquake at the plant site on the various systems and components of the plant. The potential options for the re-evaluation of existing facilities include a rigorous analytical study to reduce the conservatism and strengthening of the facilities as required so as to enhance the resistance to seismic hazard.

Seismic re-evaluation requires a realistic determination of ground motion without unnecessary conservatism. It also requires defining various parameters used in the analysis, such as damping values, more realistically. The exercises can be performed permitting the induced stresses to be as close as the allowable limits while considering seismic loading.

Presented herein is a methodology for the seismic re-evaluation of piping of an old operating process plant alongwith the connected equipment, as a part of its life extension program. This is a chemical plant which handles hazardous and toxic gas / liquid. Seismic re-evaluation of the facility is done to asses its seismic resistance in as-built condition. The piping system was originally designed using the ANSI B31.3 (Ref.1) standard which specifies an increase of 33% on allowable stresses for occasional loads such as the seismic loading. This results in a conservative design for seismic loading.

Seismic re-evaluation involves a re-assessment of the structural integrity of various structures and components of the existing plant for the review basis ground motion. If the reassessment indicates that structural integrity is not satisfied, suitable retrofitting measures may be suggested. Keeping these objectives in mind, various parameters such as seismic ground motion, damping values of various structures, analysis procedure, stress limits to be considered are discussed in this paper. A few exercises carried out for the plant piping and equipment are discussed in detail in this paper.

SEISMIC MOTION USED FOR THE RE-EVALUATION

The old operating process plant is a chemical plant and, therefore, all the equipment and piping of this plant were originally designed using ASME code, Section VIII, Div.2 (Ref.2) and ANSI B31.3 standard (Ref.1), which are meant for the design of conventional pressure vessels and chemical piping respectively. Both of these codes identify seismic loading as one of the design loadings.

Since the plant happens to be in close proximity to a populated area, it is all the more essential to ensure that any mishap may not lead to serious consequences to the public. With this objective in mind, the seismic risk at the plant site was examined in great detail. Based on this study, it was observed that the site had experienced an earthquake having maximum felt acceleration of 0.028g within an epicentral distance of 300 km. Moreover, the mean recurrence interval has been estimated to be around 475 years for an earthquake with Peak Ground Acceleration (PGA) of 0.02g.

Based on the above studies a peak ground acceleration of 0.03g alongwith the site specific ground motion spectra is considered as the review basis ground motion. The proposed ground motion has about 95% probability of non-exceedence in a span of 50 years. This is generally an acceptable level of acceleration for re-evaluation.

DAMPING

Damping plays a major role in deciding the seismic response of a component. Damping in various structures, systems/component is usually attributed to various phenomenon such as friction, gaps, hysteresis, non-linear behaviour etc. A realistic assessment of damping is, therefore, very essential for the evaluation of seismic response of existing facilities. In general, for the seismic re-assessment of existing components, use of mean damping values is appropriate. Proposed values of damping which are required to be used in seismic re-evaluation of an old process plant are taken from the report NUREG / CR-0098 (Ref.3) and from ASME boiler and pressure vessel code (Ref.4). Based on this, a damping value of 5% has been used for the analysis of piping connected with equipment.

METHOD OF RE-ASSESSMENT

The finite element model of the pipe layout has been analysed for pressure and dead weight load including insulation weight using CAESAR-II (Ref.5). Subsequently, the layout has been analysed to evaluate the dynamic response for the seismic loading as described above. For seismic re-assessment of the system, response spectrum analysis has been carried out. Number of modes included in the analysis was kept sufficient to ensure that inclusion of all the remaining modes does not result in more than 10% increase in total response of the system. ASCE standard (Ref.6) permits to include all the modes in the analysis having frequencies less than the ZPA frequency or cut-off frequency, provided that the residual rigid response due to missing mass calculated from the following equation is added :

$$[K]\{x_{mm}\} = [M]\{ 1-\sum_{i=1}^{n}\Gamma_i \{\Phi_i\}\} a_r$$

where a_r is the highest spectral acceleration in the interval between the cut-off frequency and ZPA and x_{mm} is the residual rigid response displacement due to the missing mass.

For the modal combination purpose the above response was considered as an additional mode having frequency equal to ZPA or cut-off frequency and combined using the SRSS or 10% SRSS method as mentioned above. In the present work, all the modes up to 33 Hz (ZPA frequency) have been considered for the dynamic analysis. The missing mass response has been evaluated using above equation. Finally, the two responses have been combined using the SRSS method.

BASIS FOR THE RE-EVALUATION

The plant was originally designed using ANSI B-31.3 (Ref.1) code which is meant for chemical plant and petroleum refinery piping. This code specifies an increase of 33% on allowable stress for occasional loads such as the earthquake load. However, it is difficult to qualify the system with this low value of allowable stress for seismic loading.

The basis adopted for seismic re-evaluation of the piping and equipment of this plant in the present study is to make use of the latest provisions of ASME Sec-III, Subsection-ND (Ref.4) wherein earthquake loading has been classified as a reversing type of load. For such reversing type of loads, the recent revision to ASME code has permitted the use of higher damping values (5% of critical damping) while performing response spectrum analysis using the 15% peak broadened spectra. In addition, it permits the induced stress due to seismic (inertial), pressure and dead weight to be allowed to go as high as $4.5S_m$ during service level D. In order to take advantages of the recent changes in the ASME design philosophy which are supposed to be consistent with the observed behavior of the system during earthquake, analysis of the plant piping alongwith the equipment has been performed using the current revisions of ASME Sec-III, Subsection-ND. The design, fabrication and NDE of the old process plant equipment and piping are consistent with the provisions of ASME Section III, Subsection-ND.

Finally, the resultant stress due to static loading and dynamic loading has been calculated as per the following equation (Ref.4):

$$(B_1 . P.D/ 2.t) + (B_2 .M/Z) < 4.5.S_m$$

where,

P = The pressure occurring coincident with the reversing dynamic load.

M = The amplitude of the resultant moment due to the inertial loading from the earthquake.

B_1 , B_2 = Primary stress indices for the specific product under investigation.

S_m = Allowable design stress intensity value

D = Outside diameter of pipe

t = Nominal wall thickness of the piping component

TYPICAL LAYOUTS

Taking into consideration the plant performance history as well as the past experiences, a few critical process piping and equipment have been chosen for seismic re-evaluation of the plant. The purpose of this identification is to perform seismic analysis and check the structural integrity of these lines alongwith the connected equipment. Three typical layouts containing major gas and liquid lines alongwith the major equipment, which are discussed in this paper, are as follows:

(a) **Layout-1:** The first layout consists of gas lines, one stripper and three towers (Fig.1). Pipeline size varies from 6"NB to 16"NB. The gas pressure varies from 20.5 to 17.5 Kgf/cm^2. Temperature on this line varies from 100^0C to 209^0C.

(b) **Layout-2:** This pipe line starts from the top of one hot tower and ends at the bottom of a cold tower (Fig.3). The diameter of this pipe is 18"NB. This pipeline handles gas at the design pressure of 20.4 Kgf/cm^2 and temperature of 130^0C.

(c) **Layout-3:** This layout starts from the top of one of the hot towers and ends at one of the cold towers at one end and at another stage hot tower on the other end (Fig.5). The diameter of the pipeline varies from 16"NB to 36"NB. This pipeline handles gas at the design pressure of 20.4 Kgf/cm^2 and temperature of 130^0C.

RESULTS

Modelling for the above three layouts have been carried out using the elements of straight pipe, bends, tees, with incorporation of various types of supports e.g. directional restraints, hangers etc. at various nodes as per the respective locations at the site. Analyses have been carried out for various loadings. Dynamic analyses for earthquake loading, have been carried out using response spectrum method. Observed dynamic behaviour for the three layouts are as per the description below :

(i) **Layout-1**: The first natural frequency of this layout is 0.282 Hz. Upto cut-off frequency of 33 Hz for this layout, 143 modes are excited (Table 1). Total mass participation in various directions i.e. x, y & z are 98.34%, 95.16% & 98.33% respectively (Table 2). A typical mode shape at the fourth mode (frequency 0.3214 Hz), where mass participation is maximum among various modes, is shown in Fig.2.

(ii) **Layout-2**: The first natural frequency of this layout is 0.181 Hz. Upto cut-off frequency of 33 Hz for this layout, 88 modes are excited (Table 1). Total mass participation in various directions i.e. x, y & z are 97.33%, 86.86% & 97.31% respectively (Table 2). A typical mode shape at the first mode (frequency 0.1806 Hz), where mass participation is maximum among various modes, is shown in Fig.4.

(iii) **Layout-3**: The first natural frequency of this layout is 0.536 Hz. Upto cut-off frequency of 33 Hz for this layout, 54 modes are excited (Table 1). Total mass participation in various directions i.e. x, y & z are 91.47%, 85.02% & 91.47% respectively (Table 2). A typical mode shape at the third mode (frequency 0.6410 Hz), where mass participation is maximum among various modes, is shown in Fig.6.

Results obtained utilizing design codes ANSI B31.3 as well as ASME Boiler and Pressure Vessel Code, Section-III, subsection-ND are described below :

(a) **Analyses as per Code ANSI B31.3:** The ANSI B31.3 code, which is basiclly design code applicable for Petroleum Refinery and Chemical Plants, considers earthquake as occassional load and permits 33% increase in allowable values for carrying out analysis. Since this code is applicable design code for the process plant, the above systems were analysed utilising this codal provision. The three layouts described above were analysed and the results obtained are as shown in Table 3, where typical stress values are shown. It is quite clear from the results that two out of the three layouts are not able to fulfill the criteria of the code. Only layout-2 is qualifying (Table-3). Thus, it looks evident that with the permissible limit given in this code, it is difficult to qualify the plant for seismic re-evaluation.

(b) **Analyses as per Code ASME Section-III ,ND :** It was decided to take advantage of the higher allowable stress limit permitted in the recent ASME, Section-III, subsection ND. As per the new criteria the permissible limit is 4.5 Sm (Ref.4). Analyses carried out using this code showed that all the three layouts are qualifying without any problem (Table-4).

CONCLUSIONS

Following conclusions can be inferred from the above exercises:

(1) It was found from the above exercises that for seismic loading, the equipment are throwing significant amount of load on the piping.

(2) It was found that with 33% increase in allowable stress value, as per ANSI B31.3 code to take care of occasional loads such as earthquake, it was not possible to qualify the layouts.

(3) Results of analyses carried out as per ASME Section-III, ND showed that the system is qualifying without any problem. Moreover, the design, fabrication and NDE of the old process plant equipment and piping are consistent with the provisions of ASME Section III, Subsection-ND.

REFERENCES

1. ANSI B31.3, Standard for Chemical Plant and Petroleum Refinery Piping

2. ASME Boiler and Pressure Vessel Code, Section VIII, Div.2 - Rules for the Construction of Pressure Vessels- Alternative Rules, 1995

3. Newmark, N.M. and Hall, W.J., "Development of criteria for seismic review of selected nuclear power plants", NUREG / CR-0098, 1978

4. ASME Boiler and Pressure Vessel Code, Section-III, Subsection-ND, 1992

5. Piping analysis software CAESAR-II, ver. 3.23, COADE Inc., Houston, USA

6. ASCE standard 4-86, Seismic analysis of safety related nuclear structures.

Table 1: Frequencies for the Three Layouts

Layout-1		Layout-2		Layout-3	
Mode	Frequency (Hz)	Mode	Frequency (Hz)	Mode	Frequency (Hz)
1	0.282	1	0.181	1	0.536
2	0.287	2	0.361	2	0.538
3	0.318	3	0.364	3	0.641
4	0.321	4	0.427	4	0.642
5	0.403	5	0.482	5	1.080
6	0.664	6	0.509	6	1.167
7	0.759	7	0.552	7	1.252
15	1.293	12	1.127	15	4.086
50	7.175	44	9.027	45	24.723
143	32.973	88	32.678	54	32.989

Table 2: Mass Participation (%) for the Three Layouts

Layout No.	X-direction	Y-direction	Z-direction
1	98.34	95.16	98.33
2	97.33	86.86	97.31
3	91.47	85.02	91.47

Table 3: Results of Analyses as per ANSI B31.3 Code

Layout No.	Node No.	Calculated Stress (Kgf/mm^2)	Allowable Values (Kgf/mm^2)
1	2280 (Tee) 2310 (Tee)	12 32	15 15
2	45 (Bend) 50 (Bend)	10 10	15 15
3	175 (Tee)	21	15

Table 4: Results of Analyses as per ASME Code, Section-III, ND

Layout No.	Node No.	Calculated Stress (Kgf/mm^2)	Allowable Values (Kgf/mm^2)
1	2280 (Tee) 2310 (Tee)	17 47	54 54
2	45 (Bend) 50 (Bend)	15 14	54 54
3	175 (Tee)	30	54

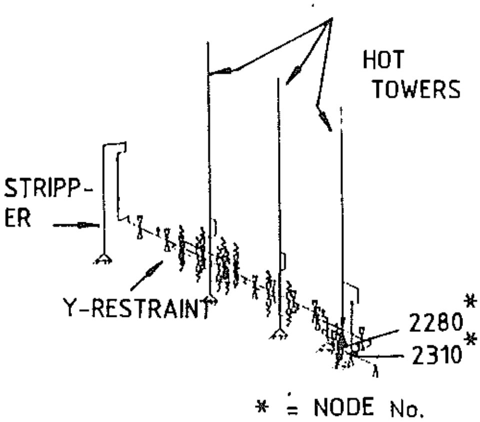

FIG. 1: LAYOUT - 1

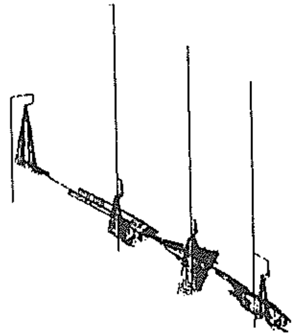

FIG. 2: FOURTH MODE SHAPE OF LAYOUT-1 (0.3214 Hz)

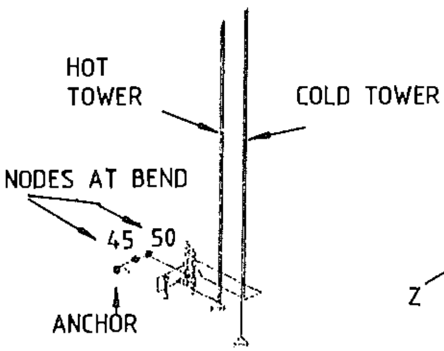

FIG. 3: LAYOUT - 2

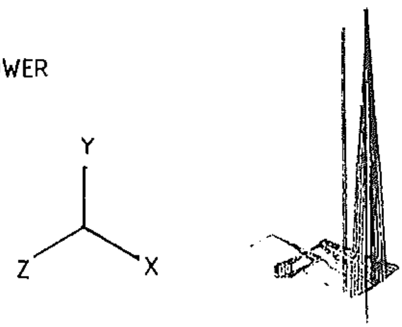

FIG. 4: FIRST MODE SHAPE OF LAYOUT-2 (0.1806 Hz)

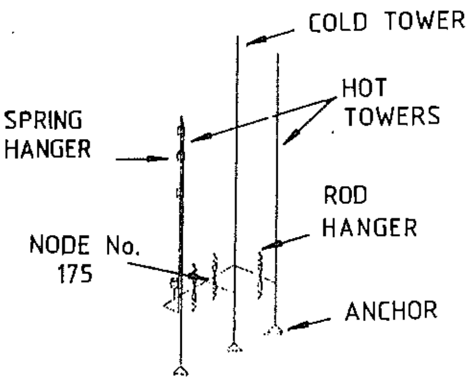

FIG. 5: LAYOUT - 3

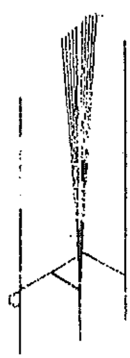

FIG. 6: THIRD MODE SHAPE OF LAYOUT-3 (0.6410 Hz)