Impact of Support Gaps on the Dynamic Response of Components

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Abstract

Piping and other component supports usually have some gaps that are introduced due to construction tolerance and also by design in guide type and other supports with gap to accommodate thermal expansion. The gaps introduce non-linearity and to accurately account for the impact of these gaps a non-linear analysis is required, however in most linear analyses small gaps are generally ignored.

This paper first briefly summarizes available relevant work in the literature on the impact of gaps on the dynamic response of piping and components and then provides results from an example analysis performed to assess the gap impact. From these, conclusions are drawn and recommendations are made regarding the impact of the gaps on the dynamic response of support gaps and when it is conservative to ignore the gaps in the analyses and when the impact of gaps should not be ignored.

1. Introduction

The subject of piping and equipment supports gaps due to construction tolerance or designed in, whether to include in the analysis models or not and their impact on the dynamic response continues to be of much debate. The key effects of a support gap are 1) frequency reduction 2) increased damping due to energy dissipation due to impact 3) potential reduction in dynamic response depending on the frequency shift in relation to forcing function and 4) local impact force.

This paper first briefly summarizes available relevant work in the literature on the impact of gaps on the dynamic response of piping and components and then provides results from an example analysis performed to assess the gap impact. From these, conclusions are drawn and recommendations are made regarding the impact of the gaps on the dynamic response of the support gaps and when it is conservative to ignore the gaps in the analyses and when the impact of gaps should not be ignored.

2. Literature Review

Number of experimental and analytical studies are available in literature that address the impact of gaps and support non-linearity. Summary of the key relevant literature review is provided below.

Barta [1] describes some of the piping models and the analysis techniques used to study the effects of support flexibility, free play, and impact and energy dissipation resulting in increased damping using both the time history and response spectrum analyses. The paper concludes that the effect of gaps on magnification of seismic support loads due to impact is minimal at support frequencies lower than five Hz. Load magnification increases rapidly with increases in support stiffness and also with increases in gap size at higher support frequencies. Energy loss due to the impact damping associated with gaps is an important consideration in determining seismic loads throughout the entire range of support frequencies. The effect of gaps on reduction of response frequency could be significant in association with a more cyclic loading condition. Large piping system analysis results suggested that the seismic response spectra method, which ignores the nonlinearities is more conservative than the nonlinear time history method

Sone and Suzuki [2] carried out both the vibration tests with an actual piping-supporting model having gap and friction and numerical simulation with its simplified model. Their paper evaluated the response reduction effect due to these nonlinearities. The main result is that the nonlinearities due only to gap and to both gap and friction result in reduction in the relative displacement responses of piping systems for both multiple excitation case and uniform excitation case

Cloud et.al [3] developed an effective equivalent linearization technique to analyse piping systems with seismic stop supports and implemented in a computer program. Comparisons of analyses and shake table tests demonstrated good correlation between analytical and experimental results. During contact the dominant response frequency was observed to increase as the gap size was decreased. The impact forces generally increased with higher excitation and larger gaps.

Blakely and Williams [4] used the pseudo-force method in MSC/ NASTRAN to model piping system nonlinearities including support gap. They showed in the piping example, accurate representation of system nonlinearities better matches reality than does an equivalent linear model.

Alkmyr in his Master's dissertation [5] studied the influence of modelling of nonlinear pipe supports in calculation of maximum reaction forces and moments in the piping system. The parametric study was carried out on two test models and showed in general that there were significant differences between the results from the analyses with linear and nonlinear modelling. The analyses of a typical piping system with real time history loading showed that it is quite difficult to propose an equation or method that compensates for nonlinear effects which have been neglected in the linear time history analysis of a nonlinear piping system. For this reason, the author recommended that nonlinear supports are modelled as nonlinear when performing time history analysis if more accurate results are required

Axelsson and Viktorsson [6] studied two piping systems, one simple geometry with two supports that resembles a main steam system and one typical main steam system with a more complex geometry containing more supports. Both systems ware modelled with supports that contain gaps using specialized finite element code Pipestress and the general purpose code ANSYS. In the time step analysis it was very difficult to resolve the short duration reaction force that frequently appeared at first contact between the pipe and its supports. The analyses done on the model representing a typical steam system indicate that it is not conservative to neglect gaps, with respect to reaction force, if the spikes were taken into account. If the reaction force spikes are neglected, the results indicate that it is realistic assumption to neglect gap up to 5mm, both considering the pipe stresses and support reaction forces. With gaps larger than five millimeter, the simplified model showed results similar to that for small gaps; if the spikes due to impact are neglected, one can neglect a support gap. In terms of stresses in the pipe system, it is slightly conservative to neglect gaps. On the other hand if the spikes are considered, the maximum stress levels increases with a gap size equal to 20-40 millimeter and the reaction forces including the spikes increases significantly

Antaki [7] summarized the several issues related to piping analysis including support gaps. The WRC 353 bulletin, Section 2.3.3 provides guidelines for the treatment of pipe-to-support gaps/clearances. ASME Section III NB, NC and ND do not address modelling details, such as gaps between pipe and restraint to be considered in determining the stresses for comparison against the Code limits. In various places, the ASME NF Code requires the pipe support to provide for movement of the piping or component. The industry practice for the analysis of piping with small gaps (usually 1/16" per side or 1/8" total clearance) is to ignore the pipe support gaps. The EPRI Project 2967-2 identified several studies of the effects of support gaps. In almost all cases, when a non-linear analysis was performed considering small gaps, it was found that the restraint loads and pipe stresses were enveloped by the linear analysis methods.

The Standard Review Plan (NUREG-0800, 3.7.2-5 Rev.2) [8] states that the review plan criteria generally deal with linear elastic analysis coupled with allowable stresses near elastic limits of the structures. However, for certain special cases such as evaluation of as-built Systems, Structures and Components, the concept of limited inelastic/nonlinear behaviour when appropriate can be acceptable.

3 Analytical Simulation

In the following subsection an example of a typical vertical heat exchanger is used to study the impact of varying gap sizes on the dynamic behaviour and response to a typical seismic time history using ANSYS software.

3.1 Heat Exchanger with a Varying Gap Lateral Support

As shown in Figure 1, a simplified model of a typical heat exchanger (diameter 2.7 m and height 20 m with average thickness 80mm) and supports is created using ANSYS version 14.5. BEAM188 element has been used to build the heat exchanger and support bars. The component model is anchored at the bottom of the pedestal support (length 3.3m and support diameter 0.56 m) and includes two sets of lateral supports for each of the lateral directions.

The objective of this analysis is to only study the influence of support gaps on seismic response of the heat exchanger structure. The El Centro horizontal time history signal input [9] has been used here. For simplification, seismic input has been applied only in the (Z) direction of lateral support where a gap is incorporated. No other loads are considered. The bottom (Z) support has been modelled as a non-linear support with ANSYS gap element CONTA178. The top lateral support is modelled using ANSYS linear spring-damper element COMBIN14. As a separate case for comparison, the model was also run with both the top and bottom (Z) support modelled using linear spring-damper element COMBIN14. As shown in Table 1, the maximum support loads are calculated for different lower (Z) support gap sizes of 0, 2, 5, 10, 15 and 20 mm.

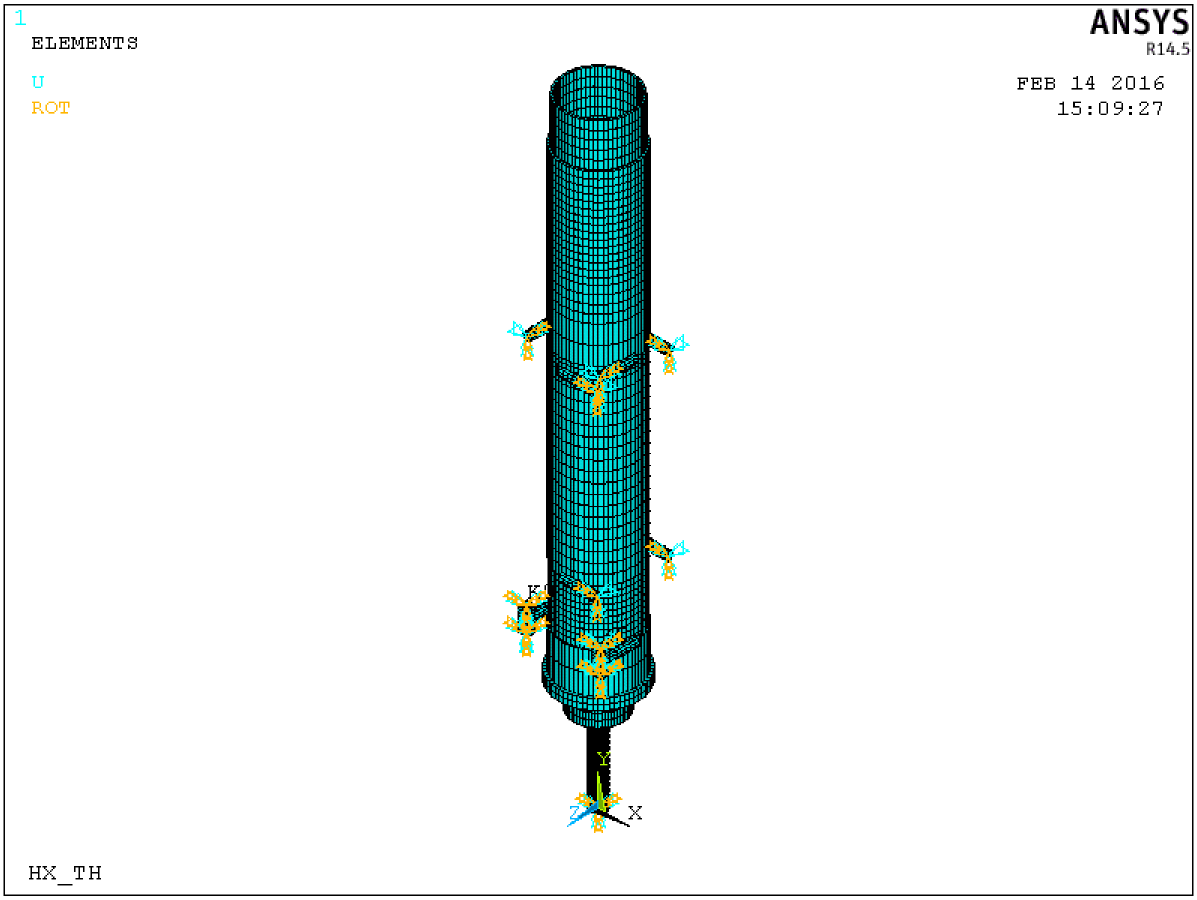

Figure 1: Simplified Model of a typical Heat Exchanger and Supports

3.2 Results

For the heat exchanger model analysed here, Table 1 provides the results of support reaction load and maximum deflection for the seismic time history input for 0, 2, 5, 10, 15 and 20 mm gaps. As seen in Table 1, the support loads are higher for the nonlinear model when compared to linear model. The frequencies as given in Table 2 and are found to be above 5 Hz.

Table 1: Gap Vs Lateral Support Loads

gap size (mm)	Max load (N) at lower (Z) support	Maximum Deflection of model (mm)	Seismic input El Centro (NS direction)
0 (linear model)	1.39E+07	145	Time History
0	2.71E+07	150	Time History
2	2.62E+07	149	Time History
5	2.46E+07	147	Time History
10	2.11E+07	144	Time History
15	2.17E+07	142	Time History
20	2.39E+07	142	Time History

Table 2: Heat Exchanger natural frequencies

mode #	Natural Frequencies (Hz)	
	No gap	with gap
1	6.27	6.26
2	6.60	6.29
3	12.79	10.12
4	13.39	12.47
5	13.66	13.41

3.3 Discussion

The simulation work is currently "work in progress" and does not contain adequate parametric variations at this time. However, general trends similar to what is available in literature are evident in terms of impact of support gap on the frequency, response deflection and support reaction loads.

Natural Frequency

In the simulated case, the software only calculates frequencies with and without gaps irrespective of the gap size. The presence of gap is seen to cause a reduction in the natural frequency.

Support load

The support load in general is seen to decrease with increasing gap size up to around 10-15 mm. Upon further increase in gap size, the support load starts increasing again before it becomes essentially inactive and carries no load.

Maximum deflection

The maximum heat exchanger response deflection is seen to decreases with increasing support gap size.

4 Summary of Findings

Based on the literature review and the example analysis performed, the following can be summarized:

1. The effect of gaps on amplification of seismic support loads due to impact is minimal at support frequencies lower than five Hz as stated in [1].
2. For piping systems, smaller gaps up to 5-6 mm can be neglected and the linear analysis will generally yield conservative pipe moments and stresses.
3. In the case of piping system, analysis results suggest that the seismic response spectra method, which ignores the nonlinearities is more conservative than the nonlinear time history method [1].
4. For the heat exchanger system analysed here, it is observed that with regards to seismic support loads, it is not conservative to neglect the gaps. The support loads are found to be higher for the nonlinear support model when compared to linear support model.
5. The spike in reaction load which occur at contact can be much higher and can only be best estimated by a nonlinear analysis. Therefore for any given system if more accurate support loads are required, it is recommended that non-linear sensitivity analysis should be done to assess the impact of gaps on support loads.
6. The impact forces generally increased with higher excitation. The impact load was also observed to increase with increase in support stiffness.
7. In the case of the heat exchanger model analysed here and also as observed in [2], non-linarites due to increasing gap size resulted in reduction in the model displacement responses.
8. The effect of gaps on reduction of response frequency could be significant in association with a more cyclic loading condition.

5 Conclusion and Recommendation

The above summary discussion is based on literature review and a limited analysis case. The following recommendations can be made:

- For smaller gaps in piping systems, linear analysis neglecting the gap generally yields more conservative results. But the same was not observed for the heat exchanger system analysed here and therefore sensitivity analysis should be performed for any given system to determine the influence of support gap on system characteristics.

- For larger gaps and where impact force spikes are important, the non-linear analysis should be performed to obtain accurate support loads.

6 References

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