System Level Dynamic Analysis using Abaqus CAE/Standard for Piping Vibration Problems

Amol S. Kulkarni, Pradeep Singh Chauhan, and Purushottam Sawant

Executive Engineers, Larsen & Toubro Hydrocarbon Engineering Ltd. Mumbai

Abstract: Industry Standard Piping Software's are extensively used for piping stress and flexibility analysis in Oil and Gas sector. Piping design for dynamic loads calls for a system level analysis for predicting the natural frequencies of piping and ensuring that they are in the desired range. The traditional piping software's, have difficulty in incorporating the flexibility of piping support structure members, which can influence the overall dynamic behavior of the piping system. Hence modeling the flexibility of the piping support structure is of utmost importance to perform the modal analysis and predict the exact frequencies and mode shapes of the system. L&T has recently executed a Ammonia Feedstock Conversion project, where, high vibrations were observed in the piping system of a flash drum. Abaqus CAE/Standard was used to perform complete system level analysis of piping, flash drum and piping support structure. Analysis results were used to arrest critical vibration modes of the system by modifying the piping support structure, originally installed. These modifications contributed towards substantial reduction of vibration levels in the piping and flash drum assembly.

Keywords: Modal, Frequency, Flash Drum, Vibration, Abaqus CAE

1. Introduction

As per the GOI directive, many of the Ammonia production plants in India are now switching from the conventional fuel oil feedstock to natural gas feedstock for Ammonia Synthesis process. L&T has recently executed three such feedstock conversion projects.

The CO2 generated in the Ammonia Synthesis process is recovered in the CO2 removal section of the plant using the activated amine solution. The process involves absorption of CO2 in the absorber column using an aqueous amine solution. The amine solution is then regenerated by depressurization in two stages viz. HP flash drum and LP flash drum, followed by heating in a stripper. The recovered CO2 is sent to the urea plant as process feed.

A schematic of HP/LP flash drum used for the flashing process is shown in Figure. The HP & LP flash drums are stacked over one another and a transfer line is used used to transfer the two phase mixture of activated amine solution and CO2 gas from the HP to LP flash drum. This transfer line or piping has a typical layout or configuration which is commonly referred as necklace piping. The piping and the control valve assembly is usually supported on an independent structure. But the portion of the piping, which rises up the LP flash drum in most cases needs to be supported from the drum. This piping is prone to flow induced vibrations during operation due to the tendency of liquid slug formation in a two phase flow, which exerts dynamic loads on to the piping system.

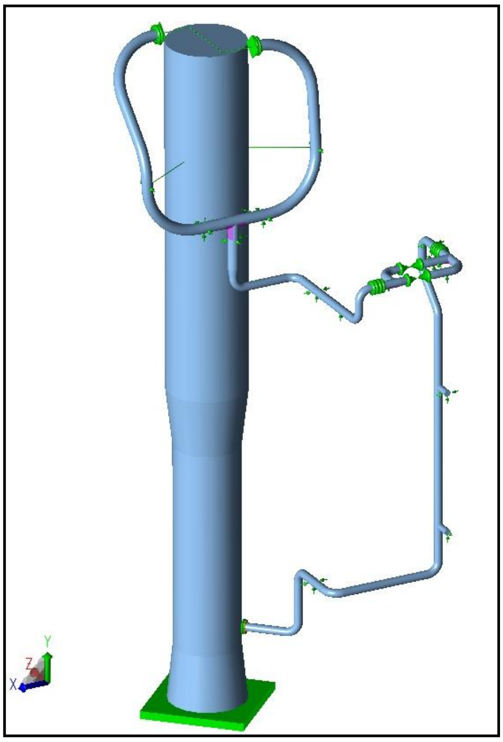

Figure 1: Flash Drum and Piping Arrangement

Erosion and slug formation are the governing phenomenon in deciding the flow velocity of fluid. Slug formation occurs in a two phase flow and when the velocity is lower than permissible value. Due to slug formation there is a fluctuation in pressure and flow velocity that causes vibration in pipes.

Figure 2. Slug Formation in Two Phase Flow

The piping hence needs to be designed taking into account the probability of dynamic loads that may come as a result of two phase slug flow. The piping is susceptible to vibrations due to these dynamic loads predominantly in the 0 to 5 Hz frequency range. The general engineering practice is to design the piping and its supports such that the fundamental frequency of the piping system is above 6 Hz. The analysis of piping for natural frequencies is usually carried out in standard piping analysis software's and the natural frequencies are ensured above the desired norm by adequately supporting the pipe.

2. Problem Definition

The traditional piping software's have difficulty in incorporating the flexibility of piping support structure members, which can influence the overall dynamic behaviour of the piping system. Moreover, the piping software's are used to estimate piping behaviour assuming connecting equipment as rigid body. Therefore, the effect of equipment behaviour is not concomitant with that of piping. Hence modelling the flexibility of the piping support structure is of utmost importance to capture overall system behaviour under operating conditions. Abaqus CAE/Standard was used to perform the complete system level analysis of piping, flash drum and piping support structure. Modal analysis was required to estimate critical mode shapes.

3. System Level Finite Element Analysis of Flash Drum and Piping Support

3.1 Finite Element Modelling

The system to be analyzed consisted of HP and LP flash drum, piping, piping support structure and main structure. The drums and the piping were modelled using shell elements (S4R). Some of the pipe supports had physical gaps to allow for free thermal expansions. Gaps in piping supports are taken into account by keeping supports unrestrained in respective directions. The fluid weight inside the drum is incorporated by considering equivalent density of equipment, gas and liquid put together.

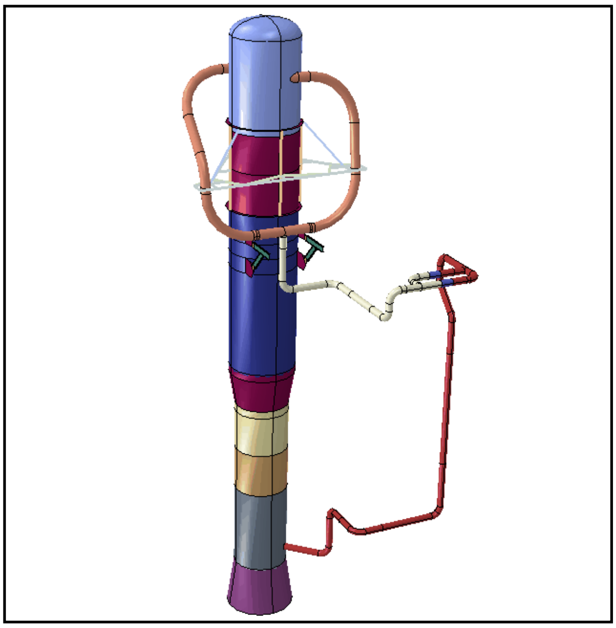

Figure 3: Finite Element Model

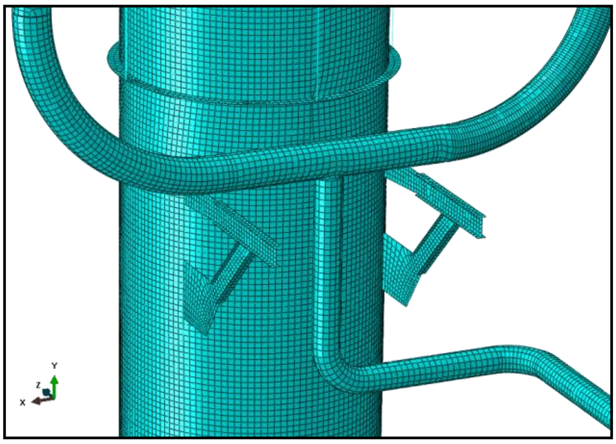

Figure 4: Meshed Model

3.2 Interactions between Support and Pipe

Tie constraints are applied as interaction between supports and pipe to simulate the condition of pipe resting on the support structure. These constraints transfer the effect of flash drum on piping and vice-versa.

4 Results and Discussion

4.1 Frequency and Participation factor

The total mass of the system is 320 Tons. The fundamental frequency of the system obtained was 1.18 Hz. Effective mass participation was found to be in X and Z direction. In second mode, the effective mass participation was 80% in X direction and in fourth mode, the effective mass participation was 68% in Z direction.

4.2 Comparison of Results

The traditional piping software's consider vessel to be relatively rigid then what they are in actual as they are modelled using pipe elements which are meant for modelling piping. Hence, the fundamental frequency of any such vessel obtained from piping software's are usually on higher side, as observed from the results tabulated in Table 1.

The piping software's assume the support structure to be completely rigid, whereas in reality the support structure have their own flexibility depending on their geometry and material and if they are not adequately designed, their stiffness can have a large influence on the overall piping frequencies. The results presented in Table 1 show that the piping frequencies predicted from system level analysis, which accounts for the support structure flexibility, are on a lower side.

Table 1: Comparison of Results obtained from Piping Software and those obtained by Abaqus

Location	Frequency obtained from Piping S/W (Hz)	Frequency obtained from Abaqus (Hz)	Frequency Measured at Site (Hz)
1st	1.32	1.18	1.2
2nd	6.07	5.36	5.13

4.3 Result Interpretation

Based on the results predicted from system level analysis carried out in Abaqus CAE and the vibration measurements carried out at site it was evident that the piping natural frequencies were below the desired norm and hence susceptible to flow induced vibration due to two phase slug flow. Suitable modifications were carried out to reinforce the existing support structure for piping and thus obtaining the desired shift in natural frequencies above 6 Hz.

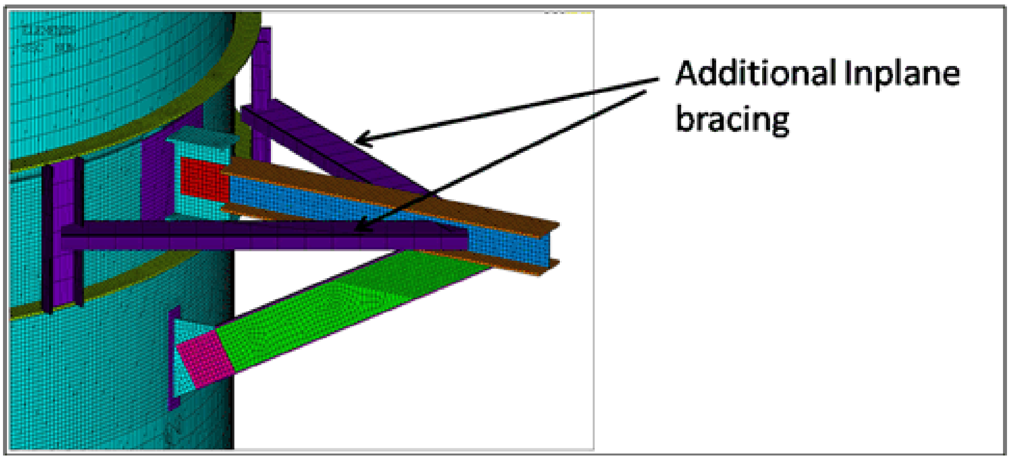

Figure 5: A snapshot of Support Structure Modifications carried out at Site

5 Conclusion

System level analysis carried out using Abaqus CAE standard helped in estimating the natural frequencies precisely and identifying the cause of vibrations observed in the piping handling two phase flow. The frequencies predicted by standard industry piping software's are on a higher side than actual because of rigid support and rigid vessel considerations. Hence, it is recommended that in problems involving dynamic loads a more detailed system level FE analysis should be carried out to estimate the natural frequencies precisely. This approach, which uses Abaqus CAE capabilities, can be extended for carrying out computationally intensive frequency response analysis, which most of standard industry piping software's are not capable of.

6 Acknowledgement

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