Practical applications of dynamic feedback between primary and secondary systems

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ABSTRACT

This paper investigates the extent of dynamic feedback resulting from coupling of primary and secondary systems. A series of one and two lumped mass models representing decoupled and coupled primary and secondary systems are studied. Various analyses cases representing different frequency and mass ratios of the secondary to primary systems are carried out. The extent of the interaction effects between the two systems is presented in plots of normalized response of the secondary system versus its frequency ratio to that of the primary structure. A family of such curves is produced for different mass ratios. These curves may be used as guidelines for predicting the extent of dynamic feedback to be expected between primary and secondary systems.

The practical application of using these results to predict the extent of dynamic feedback between primary-secondary systems is discussed in relation to design of a nuclear waste storage facility.

1.0 INTRODUCTION

In seismic analysis of nuclear facilities, it is common practice to decouple secondary systems from the mathematical model of the primary structure. This decoupled model is then used to generate floor response spectra which in turn are used for subsequent analysis of the secondary system. Dynamic design of the secondary system is then carried-out, preferably in a manner to avoid the dominant spectral peak of the floor spectra. In this practice, the analyst should take special notice of the decoupling criteria. Various decoupling guidelines (1,2,3) have been developed over the years, of which almost all are dependent on "mass" and "frequency" ratios of the secondary to primary system. Although at the time of the analysis of the primary structure, the mass of the secondary systems are usually accurately available, their detailed design and hence accurate knowledge of their frequencies is generally unknown or subject to change.

Almost all designers have faced the problem of having to design their secondary systems (whether it is a piece of equipment, piping, tank, pump, vessel, etc) to the peak of the input spectra. In effect this means that the fundamental frequency of the secondary system is in resonance with that of the primary structure. At this point, very few designers/analysts pay attention to the possible coupling between the two systems which might change the dynamic characteristics of the input spectra.

It is desirable to be able to predict the change in response of the primary system resulting from variation in design of the secondary system. This paper investigates this phenomenon through studying two simplified "one" and "two" lumped mass models. Results are presented in terms of dynamic feedback charts.

2.0 ANALYSIS APPROACH

2.1 ANALYSIS MODELS- Two simplified "one" and "two" lumped mass and spring models are used for the purposes of this study. The "one" degree of freedom model represents the decoupled model of the primary system which includes only mass representation of the secondary system. The "two" degrees of freedom model represents the coupled system with appropriate representation of dynamic characteristics of both the primary and secondary systems. Both these models are shown in figure 1. Mp, Ms, Kp and Ks denote mass and stiffness of primary and secondary systems respectively.

2.2 ANALYSIS SEQUENCE- Figure 1 shows the analysis sequence diagramatically. In Case 1, the decoupled model of the primary structure is first analysed. The response of this model is then used as input to excite the decoupled model of the secondary system which in turn results to response of the secondary system. In Case 2, the response of the secondary system is obtained directly from the analysis of the coupled model.

The response of both primary and secondary systems from these models are studied and compared with each other for a variety of mass and frequency ratios.The analysis cases studied cover a frequency ratio (FR) range of 0.1 to 4.0 and a mass ratio (MR) range of 0.001 to 0.4. For all cases, Mp and Kp are chosen such that the primary system is always at 5 Hz. Ms and Ks are varied to achieve the required range of mass and frequency ratios. All analyses are performed using the time-history method, with a synthetic input time-history scaled to a ZPA of 0.25g and a duration of 6 seconds. The input time-history has a broad-band energy content similar to the ones generated to envelop Regulatory Guide 1.60 (4) type spectrum. All spectra are plotted at 5 percent of critical damping.

3.0 DISCUSSION OF RESULTS

3.1 RESPONSE SPECTRA COMPARISONS- All response spectra comparisons are made at the primary/secondary interface, representing the floor spectra. Figure 2 shows the comparison of spectra from coupled versus decoupled models for a constant mass ratio of 0.2 and varying frequency ratios of 0.1 and 0.5. Figure 3 compares the same spectra at the same mass ratio of 0.2, but for frequency ratios of 0.8, 1.0 and 1.2. These comparisons and indeed other comparisons from all analysis cases, collectively support and confirm the decoupling guidelines recommended in (1). However, studying different comparisons as indicated in figure 2 versus figure 3, indicate that the change in response is far more sensitive to frequency ratios than it is to mass ratios. Further more, this degree of sensitivity is much more pronounced at frequency ratios close to unity.

Figure 2 indicates that, although the mass ratio is outside of decoupling recommendations, coupled response is not markedly different than decoupled response. Figure 3 on the other hand, indicates clearly large differences in response, both in terms of amplitude and frequency content of the floor spectra. Where, the decoupled model predicts a spectral amplitude of 3.3g's at frequency of 4.5 Hz, the coupled model for a frequency ratio of 1.0, shows a spectral amplitude of 1.4g at the same frequency; a reduction in response of more than half.

Also, of interest is the comparison shown in figure 4. This figure compares the floor spectra obtained from the coupled model for a frequency ratio of 0.1, at two mass ratios of 0.001 and 0.2. This comparison indicates that at low frequency ratios, the floor spectra is not sensitive to the mass ratio of the secondary system. That is, if secondary systems are designed extremely flexible or rigid, their masses do not have a significant effect on floor spectra characteristics. Figure 5 shows the same comparison, but at a frequency ratio of 1.0. This comparison indicates the extent of change in floor spectra generated from a coupled model, when the mass ratio changes from 0.001 to 0.2. This change is due to dynamic feedback resulting from tuning of the secondary system to the primary structure, becoming more pronounced at higher mass ratios.

3.2 COMPARISON OF THE PEAK REPONSE OF THE SECONDARY SYSTEMS- The peak response of the secondary system calculated via the decoupled route is compared with that of the direct (coupled) route. The variation in response is presented in plots of normalised response of secondary system (coupled response divided by decoupled response) versus its frequency ratio to that of primary system. A family of such curves corresponding to different mass ratios are plotted and presented in figure 6. This figure shows that through interaction effects (dynamic feedback) between the two systems, the response of the secondary system reduces for the coupled case. The extent of this reduction in response increases with increasing mass ratios and for frequency ratios approaching unity.

4.0 PRACTICAL APPLICATION

4.1 BUILDING MODEL- The effects of primary-secondary interaction and the extent of dynamic feedback between the two systems was an important consideration in the design of a nuclear waste storage facility in UK. The primary structure, an open concrete box, houses and supports the secondary stainless steel structure. Figure 7 shows a schematic representation of the structures.

4.2 ANALYSES CASES- The preliminary seismic design used a decoupled model of the concrete structure representing the secondary steel structure by its mass only. The response of this decoupled model was in turn used for preliminary design of the secondary steel structure. This preliminary design was such that the fundamental frequency of the steel structure matched that of the primary concrete structure. The mass ratio of the secondary to primary structure was approximately 0.4. With this high mass ratio and the frequency ratio of 1.0, designing the secondary structure to the spectra generated from the decoupled model, would have resulted in an overdesign of the steel structure. Recognizing this conservatism, the dynamic feedback chart (figure 6) indicated reductions of as much as 50 percent in response of the secondary structure. A coupled model later developed and used for final analysis and design of both the primary concrete and secondary steel structures, confirmed this reduction in response. After design iterations, the final design of the steel structure resulted in a frequency ratio of 1.4 to that of concrete structure. Figure 8 shows comparison of response spectra generated from the decoupled model versus the coupled model for both preliminary and final frequency ratios of 1.0 and 1.4. The reduction in response for both cases compares favourably to the predictions from the dynamic feedback chart.

5.0 CONCLUSION

Dynamic interaction between primary and secondary systems is an important consideration in design of secondary systems. The results of this study further support and confirm the decoupling guidelines as recommended by the NRC (1) . For economical design of important secondary systems, special attention should be given to the possibility of change in the input motion (floor spectra) if the frequency of the secondary system matches that of the peak of the input spectra. Extensive reduction in response of the secondary system may result from tuning and hence dynamic feedback between the two systems. This could possibly be overlooked in design of the secondary system.

To assist the analyst to quantify these feedback effects, normalised plots of dynamic feedback charts are produced and presented (figure 6). These plots may be used as guidelines only as they are based on single degree of freedom oscillators. Real structures are more complex and hence variation in the extend of feedback may be different.

6.0 REFERENCES

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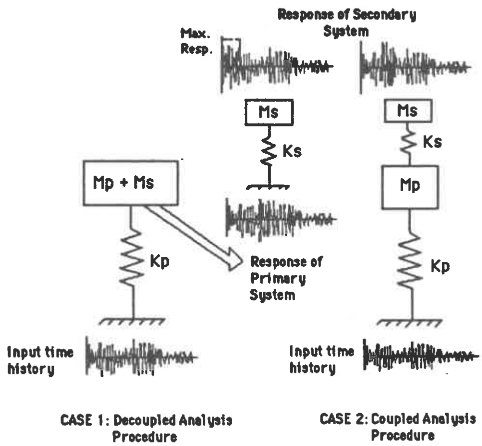


FIGURE 1: Analysis Procedure

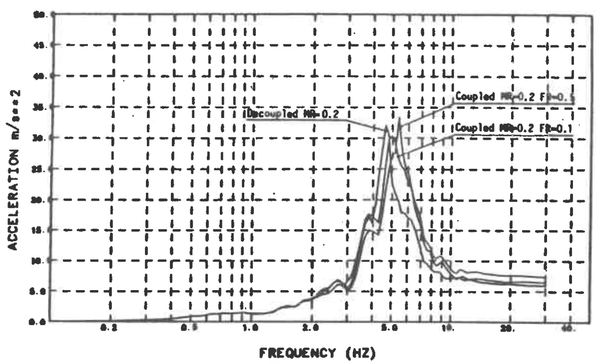


FIGURE 2: Response Spectra at Primary-Secondary Interface; Coupled Vs. Decoupled

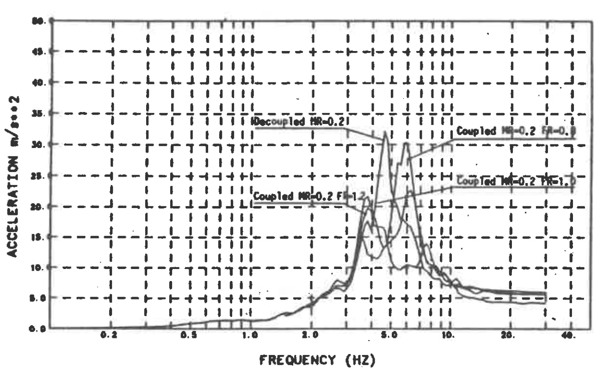


FIGURE 3: Response Spectra at Primary-Secondary Interface; Coupled Vs. Decoupled

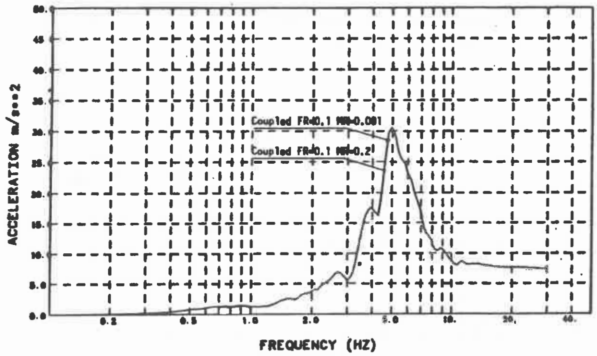


FIGURE 4: "Coupled" Spectra at Primary-Secondary Interface; Low Frequency Ratio

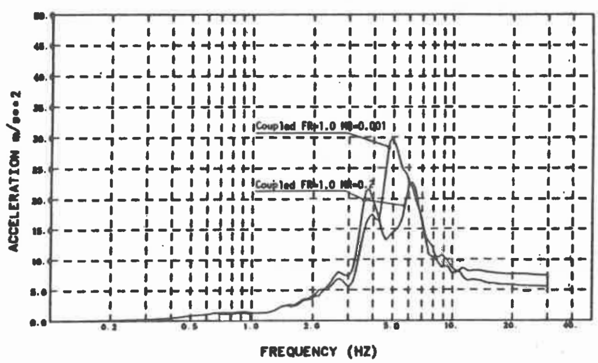
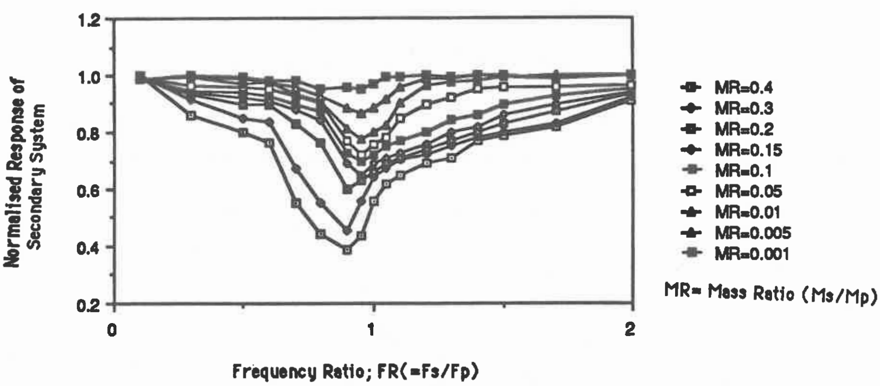


FIGURE 5: "Coupled" Spectra at Primary-Secondary Interface; Frequency Ratio=1.0



Fs= Frequency of Secondary System
Fp= Frequency of Primary System

FIGURE 6: Normalized Response of Secondary System Vs. Frequency Ratio; Dynamic Feedback Chart

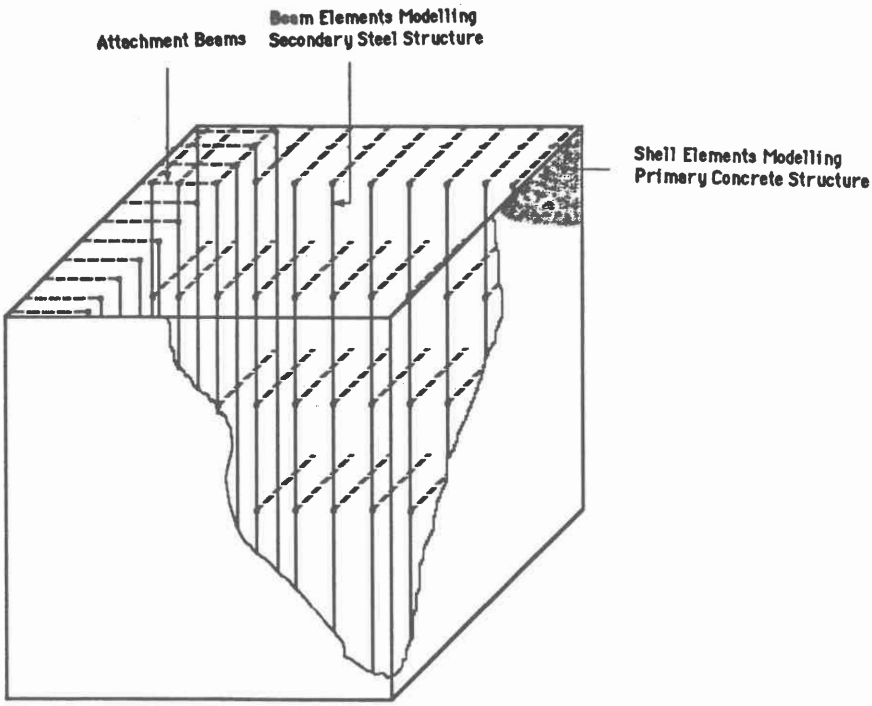


FIGURE 7: Schematic Finite-Element Model of the Waste Storage Facility

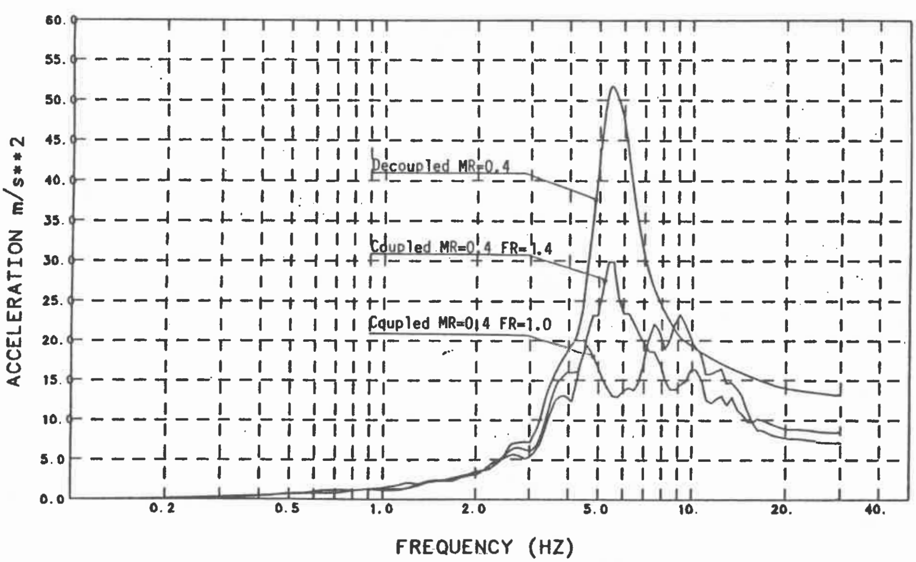


FIGURE 8: Secondary Steel Structure Input Spectra Coupled Vs. Decoupled; FR=1.0 & 1.4