SEISMIC RESISTANT ANALYSIS OF HEAVY EQUIPMENT OF PWR PLANTS

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SUMMARY

At present time, the elastic analysis of heavy equipment of PWR plants, e.g. primary coolant loops, ice condenser, etc., is based on floor response spectra coupled with parametric study. If the floor response spectra are derived by the time history method, the equipment response will be overestimated due to the feedback from equipment to structures. Another difficulty is to choose the proper input elevation because the equipment are supported at several locations.

The desirable method is to combine structures and heavy equipment in one model. This is a relatively easy task for BWR plants because the motion in the two horizontal principal directions can be assumed decoupled. For a PWR plant, due to the layout of the primary coolant loops and the ice condenser, the responses in two principal directions are coupled.

The most straight-forward method for combined model is using the commercially available finite element programs. Axially symmetrical solid elements can be used to model the containment vessel, foundation and soil. However, they cannot properly represent the coolant loops and equipment support structure. Then the next improved model will consist of plate elements, shell elements, beam elements and even the 3-D elements. This model, with so many degrees of freedom, may have the problem of high computer cost and numerical instability.

The new method to be recommended here is simple and reliable. The structures are represented by composite cantilever beams overlaid one another. The soil is represented by swaying and rocking springs. The lumped mass method is used and each mass point is assigned with two horizontal degrees of freedom. The heavy equipment are also represented by lumped mass models. Instead of combining the structure model with equipment models, the stiffness matrices are combined. The stiffness of the equipment supports can also be represented by the support stiffness matrices. The different damping values of structure, equipment and soil are combined by the weighted damping method. Variation of soil, concrete properties and support conditions are covered by the parametric study. An example with four primary coolant loops and ice condenser is presented herewith.

1. Introduction

For seismic resistant design of the safety class equipment, piping, etc., the floor response spectrum is the most popular and convenient way of specifying input information. However, most floor response spectra are generated with the assumption that there is no feedback from equipment to supporting structures. This is a good assumption for light equipment. For heavy equipment, i.e. primary coolant loops of a PWR plant, this assumption will overestimate the equipment response. Another source of conservatism, in applying floor response spectrum to a large piece of equipment supported at several elevations, is built in when the most critical spectrum among all applicable ones is applied. The conservatism thus induced may cause a design problem for both the equipment and the supporting structure of a plant in high seismic zone.

The effect of mass ratio, of equipment to the supporting structure, was investigated in the past by several authors. Crandall and Mark (Fig. 2-13 of Reference 1) showed the equipment mean square response as a function of mass ratio based on a two mass model subjected to white noise input. Penzien and Chopra (Fig. 8 through 16 of Reference 2) showed the two degree response spectra of N-S component, 1940 EL Centro earthquake as a function of mass ratio. Amin et. al. (Fig. 3 through 5 of Reference 3) showed the distortion ratio as a function of mass ratio based on the model of a SDF-system attached to a 3DF-system, subjected to the N-S component of 1940 EL Centro earthquake.

A commonly asked question is that at what mass ratio the feedback effect can be ignored. This ratio depends on the degree of conservatism one can afford. Generally speaking, the feedback effect is proportional to the mass ratio. Amin et. al. (Reference 3) showed that the response is overestimated by less than 30% for a small mass ratio of 0.01. For most safety class equipment, the mass ratio is always less than 0.01; hence, the floor response spectrum can be applied. For heavy equipment like primary coolant loops of a four loop PWR plant, the masses are more than one tenth of that of the supporting structure, and the feedback effect can no longer be ignored.

2. Combined Analysis

In order to reduce the unnecessary conservatism, the combined analysis of heavy equipment and the supporting structure is highly recommended here. This is a relatively simple task for BWR plants, because the reactor vessel is at the center of the containment building and the lumped mass model can be applied as usual. However, for a four loop PWR plant, the four coolant loops are off center and the two horizontal degrees of freedom are coupled. This causes some difficulty in proper lumped mass modelling.

The commercially available finite element programs offer another alternative for combined analysis. Axially symmetrical solid elements can be used to properly and efficiently model the biological shield building, the containment vessel, the foundation mat and the soil. However, they cannot properly model the coolant loops and the supporting structure. Then the next improved model will consist of plate, shell, beam and even 3D elements. This model, with so many degrees of freedom, may have the problems of high computer cost and numerical instability.

To circumvent the foregoing difficulty, a simple and reliable lumped mass method is recommended here. Instead of combining equipment and the supporting structure models, the proper stiffness matrices are combined. The degrees of freedom assigned at points of attachment are consistent with the degree of fixity. For example, translational degrees of freedom for force connection and rotational degrees of freedom for moment connection, etc.

Usually the degrees of freedom of the equipment stiffness matrix are more than we desire in the combined analysis. Hence, they are condensed to a smaller size. The condensation scheme requires some physical insight of the equipment behavior. The general mathematical and physical consideration of condensation can be found in the literatures (References 4, 5, and Appendix 6 of Reference 6). Of course, the same purpose can be achieved by performing component mode synthesis technique (References 7, 8, and 9).

3. Example and Parametric Study

A PWR plant with four primary coolant loops and the ice condenser as shown in Figure 1 is used as an example of the combined analysis. The shield building, containment vessel, crane wall and interior concrete support structure are modelled as four centilever beams overlaid one another and set on the same foundation mat. The loops and ice condenser are also represented by lumped mass system. The flexibility of the equipment supports and the local deflection of concrete supporting structure are also represented by proper stiffness matrices. The soil is represented by the rocking and swaying springs (10). Parametric study can be applied to cover the uncertain range of input values. The different damping values of equipment, structures and the soil are combined by the weighted damping technique (11). Since the intention of this combined analysis was to determine the effects of the equipment on the seismic resistant design of the supporting structure, each loop was represented by three mass points. Two at the steam generator and one at the pump. Each mass point was assigned with two translational degrees of freedom in the horizontal plane. The ground response spectrum was used as input.

The effect of equipment stiffness on the response of supporting structure was also investigated by varying the stiffness matrix of the ice condenser. The supporting structure experienced lower response, when ice condenser was tuned in to the structure, than for any other case. This vibration absorbing effect was also studied by previous authors (Reference 12 and Fig. 2 - 12 of Reference 1).

4. Conclusions

A simplified procedure was developed to take advantage of the reduced responses of heavy equipment. The displacement stiffness matrix approach, which underlies this proposed method, has been available for more than a decade. However, the nuclear power industry is still using the floor response spectrum for seismic resistant design of heavy equipment. The possible reasons are that it is on the conservative side for equipment design and that it did not cause design problem yet. As to the supporting structure design, it is conservative only when the heavy equipment reactions from the steam supplier are considered in the local and overall design. Anyhow, as the SSE (Safe Shutdown Earthquake) value keeps on increasing, it is about time to adopt the combined analysis now.

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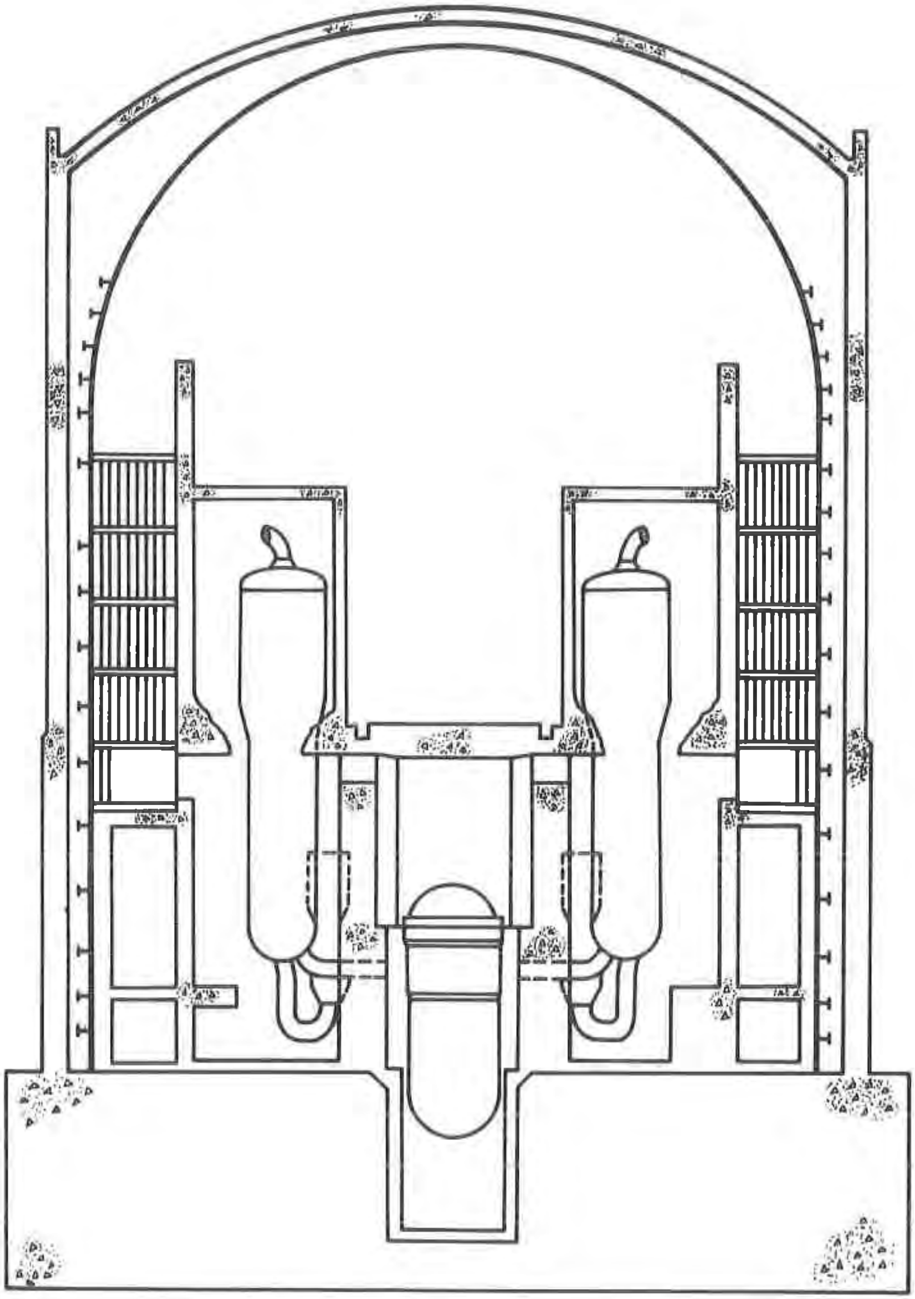

FIG. 1 A FOUR LOOP PWR PLANT WITH THE ICE CONDENSER