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A PROPOSAL TO REDUCE THE CONSERVATISM OF GENERATED FLOOR RESPONSE SPECTRA USING THE EFFECT OF THE INTERACTION

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1.0 ABSTRACT

This paper offers an alternative method to ASCE STANDARD No. 4-86 for consideration of the effect of the interaction between a primary and secondary system by modifying the floor response spectra (FRS) using the mass characteristic of the secondary system only. Although the standard recommends that where coupling is required, the use of a simplified model is sufficient, some relatively detailed information is still required in order to generate a simplified model of the secondary system. This information may not be readily available at an early stage in a project.

The concept is established by using a two degrees of freedom (DOF) system and further confirmatory work is performed using a six DOF system.

The results of this study also indicate that, firstly, considerable interaction may still occur between secondary and primary systems where the mass ratio is below 1% and, secondly, addition of any further secondary system in the vicinity of the secondary system under consideration induces further reduction of the response of the latter.

Finally, the application of the method is illustrated via an example using the Hinkley Point 'C' Reactor Building Polar Crane floor response spectra.

2.0 KEYWORDS

Factor β, conventional FRS, inherent conservatism, primary system, secondary system, equipment mass, artificial time history, FRS generation, ASCE STANDARD.

3.0 INTRODUCTION

The inherent conservatism in the generation of the floor response spectra using conventional methods is well known and has been the subject of many studies during the last decade. Tuning between the major modes of vibration of the primary and secondary systems, and the feed back of energy from the secondary system to the primary system are two major influences, of which only the first is normally addressed in the generation of the floor response spectra.

a) Generate the initial floor response spectra in the conventional way, i.e., the secondary system is only represented by its mass.

b) Assess the effective mass of the secondary system and attach it to the primary structure via an elastic spring with a stiffness to provide a natural frequency, for the secondary system, equal to the peak generated FRS frequency obtained from a) above.

c) Carry out a time history analysis in order to obtain the maximum response of the secondary system corresponding to the FRS frequency at peak.

d) The maximum response of the secondary system is then multiplied by a factor β as the peak response of the secondary system does not necessarily occur at the frequency corresponding to the maximum FRS amplitude. This factor may be taken as β=1.05.

e) The peak response of the secondary system, obtained from d) above, is then broadened parallel to the frequency axis until it intersects the initial FRS curve described in a) above.

In order to demonstrate the validity of this method further work using a six DOF system is carried out, and also the method is applied for the generation of floor response spectra of the Reactor Building Polar Crane for the Hinkley Point 'C' site conditions. The results of both studies are then compared with the actual response, the ASCE method and the conventional method. These studies are described in section 6.

6.0 CONFIRMATORY WORK

The two DOF system study provides the concept and on this basis a simplified method is developed. However, the main structure generally is complex and therefore one mode of vibration may not be sufficient for a realistic representation of its behaviour. In order to overcome this problem two further models are examined for the purpose of this work:

- A simply supported beam with six degrees of freedom.
- The Reactor Building stick model with Polar Crane.

6.1 Six DOF System

Figure 4 shows a simply supported beam, with six DOF, in which the equipment is represented as an oscillator comprising a single mass and spring. The initial model comprises of five equal lumped masses, each of which is 1000Kg. However, for the purpose of the parametric studies the central mass of 1000Kg is divided proportionally between the secondary mass (equipment) and beam mass connected via a spring, which is representative of the equipment spring.

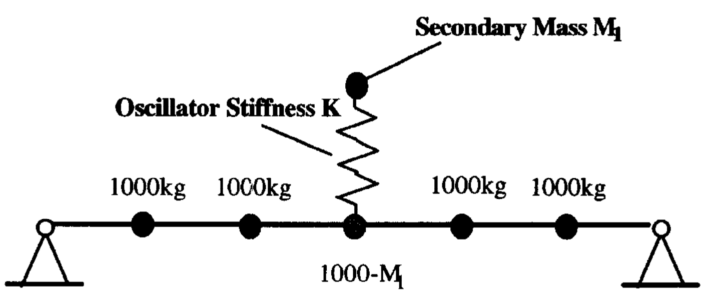

Figure 4

The input motion is in the form of an artificial time history compatible with the UK soft site spectra (Principia Mechanica Ltd., 1981). The actual responses of the equipment corresponding to the frequency range of 1Hz to 30Hz are calculated for the equipment mass/total mass ratios of 0.4%, 1%, 1.5%, 2% and 2.5% respectively and the results compared with the conventional floorresponse spectra obtained from the initial model.

In the initial model, the equipment is assumed to be rigid. This comparison is shown in Fig. 5.

The results of the six DOF system indicate that for a mass ratio of 2% and above no clear peak exists and the responses are approximately constant within the frequency range of 7 Hz to 9 Hz while the response of the two DOF system results in a clear peak at tuning level Fig. 2.

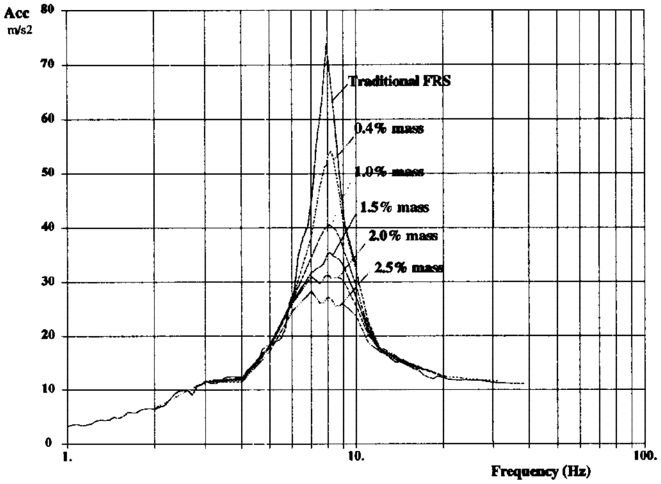

Figure 5

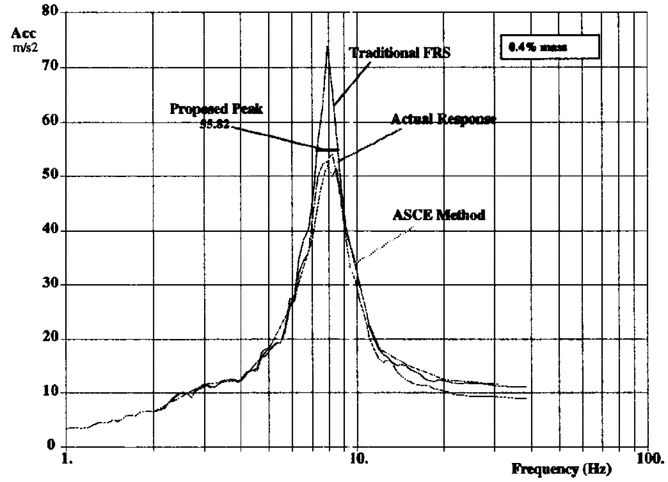

Figure 6

Similar exercises are carried out using the ASCE method for the generation of floor response spectra for corresponding mass ratios. The results of the 0.4%, 1% and 2% ratios and their comparison with time history results and the proposed method are shown in Figs. 6 to 8.

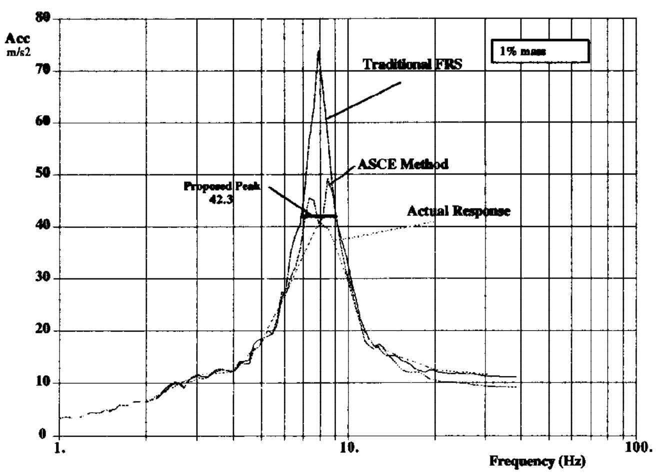

Figure 7

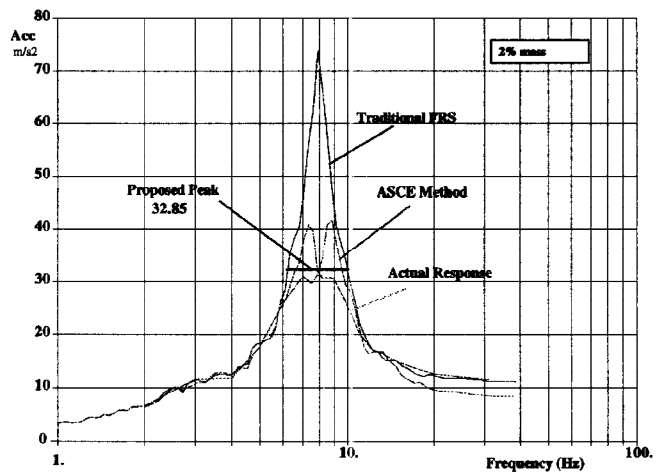

Figure 8

From the results of this study the following observations are made:

1. For a mass ratio of 0.4% considerable interaction exists between equipment and main structure.

2. As the interaction increases in proportion to the mass ratio, the ASCE method tends to be more conservative, e.g., for a mass ratio of 2.5% the ASCE method is more than 30% higher than the actual result.

3. A good correlation exists between the actual response and proposed method for a wide range of mass ratios from 0.4% to 2.5%.

4. The effect of the interaction amongst adjacent equipment is examined and it is concluded that the presence of extra equipment, on the other nodes of the beam shown in Fig. 4, induces a reduction in the response of the existing equipment. The results of this study for two and four extra equipment masses and their comparison with the initial work with a single equipment mass are shown in Fig. 9.

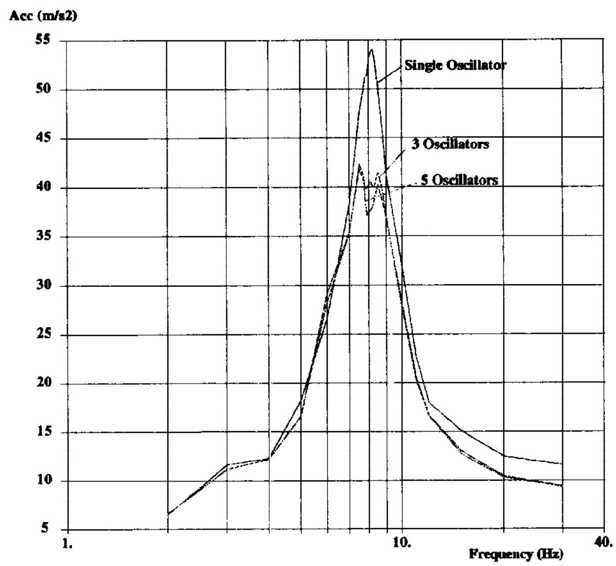

Fig 9

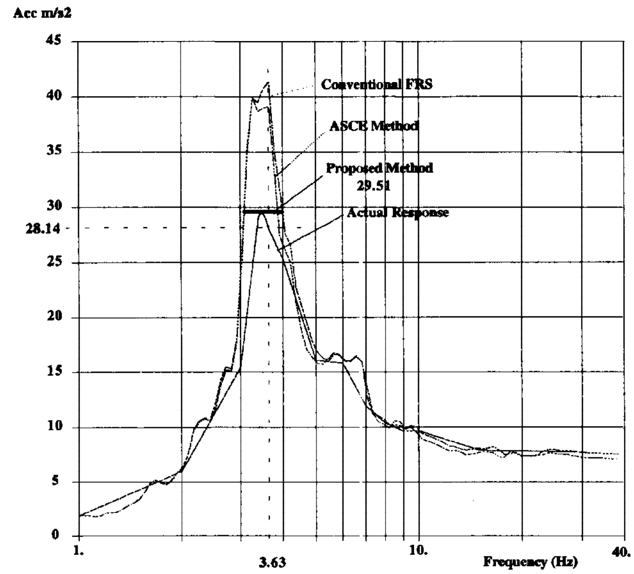

Fig. 10

6.2 Reactor Building Polar Crane

The floor response spectrum at the Polar Crane used for this study is obtained from the stick model of the PWR Reactor Building proposed for the Hinkley Point 'C' site . The ratio of the Polar Crane mass to the total mass of the Reactor Building is taken as 1%.

The floor response spectrum using the conventional method is generated at the Polar Crane location and a second FRS is generated at the same location using the ASCE recommendation as shown in Fig.10. The peak response using the proposed method is obtained by applying a factor β of 1.05 to the actual time history response of the oscillator at 3.63Hz corresponding to the peak of the conventional FRS. The comparison of results is shown in Fig. 10.

7.0 ACKNOWLEDGEMENT

The authors wish to thank Nuclear Electric for their kind permission to use the Hinkley Point 'C' Reactor Building stick model and UK ground motions for the purpose of this work.

9.0 REFERENCES

ASCE 4-86, ASCE STANDARD, Seismic Analysis of Safety Related Nuclear Structures and Commentary on Standard for Seismic Analysis of Safety Related Nuclear Structures, (1986), American Society of Civil Engineers, pp 15-17

Principia Mechanica Ltd., (1981), Seismic Ground Motions for UK Design, pp 7.1-7.3

ASCE STANDARD No. 4-86 sets de-coupling criteria for secondary systems with single-point attachment to the primary system so as to consider the effect of the interaction where appropriate. The standard recommends that where coupling is anticipated, the use of a simplified model is sufficient, however some relatively detailed information is still required in order to generate a simplified model of the secondary system. This information may not be readily available at an early stage in a project.

The purpose of this paper is to propose an alternative method for consideration of the effect of the interaction between the primary system and the secondary system by modifying the floor response spectra using the mass characteristic of the secondary system only.

The work carried out is broken down as follows:

- Study of the effects of tuning and interaction using a two degrees of freedom (DOF) model.

- Comparison of the conventional floor response spectra versus the ASCE method and method proposed here using a six degrees freedom system

- Finally, an illustration of the developed method within a practical example using Hinkley Point 'C' Reactor Building Polar crane.

4.0 CONCEPT

A two DOF model is used for developing the concept; as in practice, the behaviour of a system may approximately be represented by its major mode of vibration for each direction. Therefore study of the response of a two DOF system can provide a useful indication of real behaviour of the structure assuming each mode of vibration of a two DOF system corresponds to the major modes of vibration of the equipment and main structure. Consider a system consisting of two degrees of freedom as shown in Fig. 1, where:

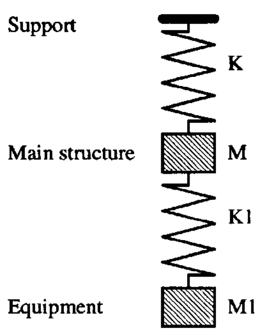

Fig 1

K and M are the stiffness and the mass of the primary system, and K_1 and M_1 are the stiffness and the mass of the secondary system and M_1= aM and K_1= bK where, a and b are arbitrary coefficients.

The response of the equipment using the SRSS method may be written as follows:

$$R_t = S_a\sqrt{(\phi_1^2\Gamma_1)^2 + (\phi_2^2\Gamma_2)^2} \qquad (1)$$

Where, ϕ_1^2, ϕ_2^2 and Γ_1, Γ_2 are eigen vectors and modal participation factors respectively. S_a, the spectral acceleration, is taken as a constant value for the interest range of frequencies in order to eliminate its variation into the response of the system.

The above two DOF system is used in order to investigate:

- Firstly, the variation of the interaction between the equipment and the main structure for different ratios of $a = M_1 / M$. It is expected the response, particularly at tuning level, reduces by increasing the equipment mass because of the increasing interaction effect. The results of this study are shown in Fig. 2 corresponding to the ratio of a equal to 1% , 2.5% and 5%.

- Secondly, the change of the response of the system due to the small variation of K_1, when it is assumed that the frequency of the of the main structure and the equipment is initially identical, i.e., the following initial conditions exist between M_1, M, K_1 and K:

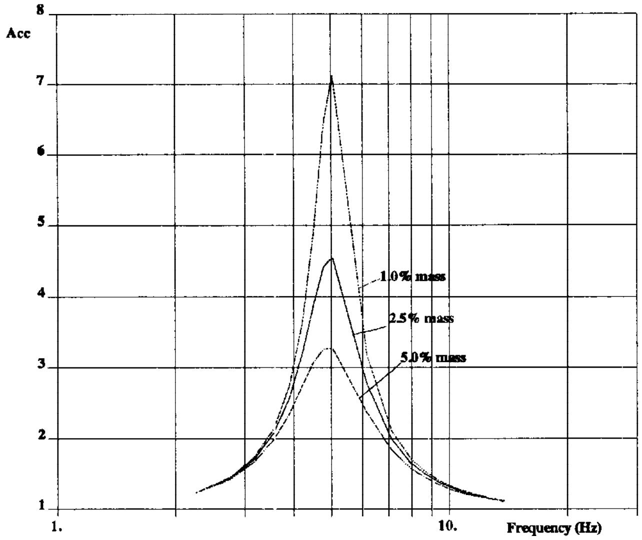

Figure 2

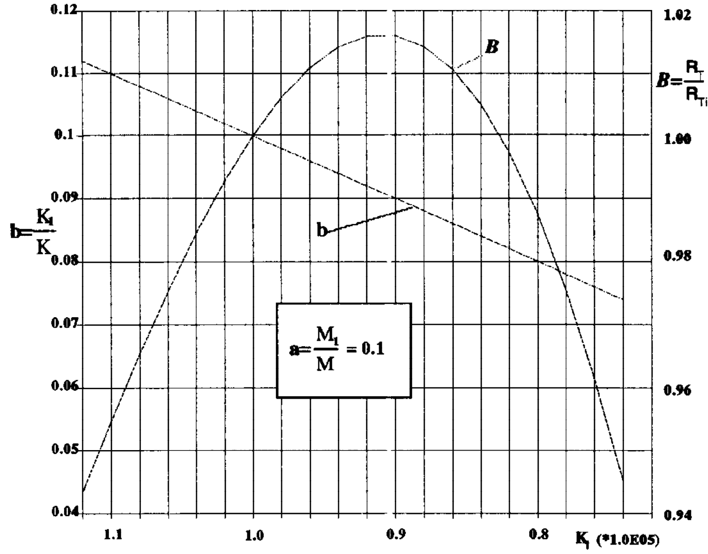

Figure 3

$$M_1 / M = K_1 / K = a \tag{2}$$

and

$$K_1 / M_1 = K / M = (K_1 + K)/(M_1 + M) = \omega_0^2 \tag{3}$$

The natural circular frequencies ω_1 and ω_2 of the system corresponding to the above conditions are:

$$\omega_1 = \omega_0\left(2 + a + \sqrt{a^2 + 4a}\right)^{1/2} \quad \text{and} \quad \omega_2 = \omega_0\left(2 + a - \sqrt{a^2 + 4a}\right)^{1/2} \tag{4}$$

From equations (4), it is evident that both ω_1 and ω_2 are different from ω_0 and therefore it is expected that the maximum response of the equipment occurs when $K_1 / K \neq a$. In order to investigate this matter several analyses are carried out corresponding to the mass ratio 'a' ranging from 0.4% to 10% and the stiffness ratio 'b' ranging from $0.8a$ to $1.2a$.

The results of this study indicate that firstly, the maximum response of the equipment compared with the initial response, corresponding to equations (2) and (3) increases in proportion to the mass ratio 'a' and, secondly, the deviation of the maximum response from the initial response is small. The maximum deviation factor $\beta = R_t / R_{ti}$, which corresponds to a=10%, is less than 2% as shown in figure 3. However, in order to take into account the other influential parameters such as the effects of higher modes, the factor β is taken as 1.05 for the purposes of this study.

5.0 METHOD

The result of the two DOF system studies demonstrated that the response of the equipment is significantly dependent upon the mass ratio of $a = M_1 / M$ and hence, this matter needs to be considered in the FRS generation. ASCE STANDARD No. 4-86 sets de-coupling criteria for secondary systems with single-point attachment to the primary system so as to consider the effect of the interaction where appropriate. Although the standard recommends that where coupling is required, the use of a simplified model of the secondary system is sufficient, some relatively detailed information is still required in order to generate this model . As this information may not be readily available at an early stage in a project, an alternative practical method for the modification of generated floor response spectra using conventional methods is developed. The method comprises the following steps: