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ON THE SEISMIC DESIGN SPECTRA FOR HEAVY COMPONENTS AND COMPARISONS WITH THE USUAL FRS TECHNIQUES

S. CECCONI, V. GIULIANO, L. LAZZERI
AMN S.p.A., Via G. d'Annunzio 113, I-16121 Genova, Italy

SUMMARY

For the analysis of an equipment the floor - response - spectra technique is generally used. However the most common methods to calculate the floor-response-spectra do not take into account the coupling between the equipment and the supporting structure because they always refer to light equipments. Dealing with heavy equipments the mass of the equipment may be included in the structural model, consequently its response is obtained; however this in some cases may be not enough.

Our problem costisted in evaluating the seismic response of a heavy equipment (polar crane) with its natural periods of the same order of magnitude of the periods of the supporting structure (containment).

In this case the usual approach with the floor-response spectra technique was considered not adequate, because of the too large resonance amplification in the equipment response which may produce a lot of difficulties in the design of the equipment.

Then a simplified coupled equipment-supporting structure model has been analyzed under the direct action of the ground motion response spectrum.

For the supporting structure a stick model has been used (the soil-structure interaction was simulated by usual springs) while for the equipment an equivalent lumped mass and springs model has been chosen.

Moreover a parametric analysis (for various fundamental periods and for various dampings of the equipment) has been carried out in order to determine an acceleration-period function to be subsequently used for the appraisal of the maximum seismic response of the equipment.

Computed results are presented and compared with the usual floor-response-spectra. As it is shown, a big reduction is obtained just corresponding to the resonance periods of the supporting structure, while a good agreement still exist for low and high periods, i.e. when the equipment presents a stiff connection to the supporting structure (complete coupling) and when the equipment is very flexible (complete decoupling). Moreover, the response-spectra of the joint point, between the equipment and the supporting structure, are presented; it is interesting to notice how such spectra are not constant, but are largely decreasing near resonance periods of the supporting structure. The main conclusions of the paper may be summarized as follows: when dealing with the appraisal of the seismic response of heavy equipments it is always convenient to analyze the couple structure-equipment system, as it is however required by the usual Regulatory positions. The use of the simplified FRS techniques greatly overestimates the response of the equipment at least around resonance even if this practice is less expensive. However, in view of large advantages in terms of actual accelerations and consequent structural design, the first more sophisticated procedure should be encouraged for many heavy equipment even if of not primary importance such as polar cranes.

1. Introduction

The problem of the seismic design of the polar crane inside a containment is a typical one for Nuclear Power reactors and some problems have been discussed in the open letterature /5/. In this particular case the supporting structure of the crane is very rigid,so that peaks in the FRS accelerations are to be found at frequencies typical of cranes, so that resonance condition may be expected particularly if the broadening of the peaks as requesteed by regulatory agency positions is performed.

Then a different approach taking advantage of the feed-back action of the equipment on the structure /4/ has to be used. The relevant analyses are presented in this paper.

2. Polar crane dynamic analysis

A sophisticated model has been made to evaluate with sufficient accuracy the foundamental periods and the partecipation factors of the polar crane (fig.1). Various types of geometric sections for the bridge girders (with different inertial characteristics) have been analyzed.

The hoisted load has been added only for the vertical excitation model, the hypothesis has been made that this mass is complitely uncoupled from the crane horizontal motions.

A modal analysis has been carried out for different positions of the trolleyon the bridge girders.

As a result of this parametric analysis it is found that the range of the foundamental vibration periods of the crane (from 0.1 to 0.2 secs) includes the resonance period of the containment.

Hence the responses obtained with the FRS approach present a very large amplification, and it was impossible a reasonable design of the crane and containment.
Consequently a new approach was resorted to.

3. Polar crane model

Different methods are available for the reduction of the equipment model for inclusion in the overall structural model; as an example static condensation as described by Gujan /6/ or component mode synthesis as suggested by Hurty /7/ could be used.

However a very simple but effective procedure was resorted to in this case.

The hypothesis has been made that a single degree of freedom oscillator is an adequate representation of the crane.

As it is known from the modal analysis theory, this hypothesis is correct if a predominant vibration mode exists, i.e.if the mass associated with the first mode is comprehensive of most of the whole mass.

If the mode normalization is such that:

$$\sum_{i} \emptyset_{ik}^{2} \; Mi = 1$$

where

$[\emptyset_{ik}]$ = eigen modes matrix

$[Mi]$ = diagonal mass matrix

then the modal mass defined as the ratio between base shear equivalent acceleration (i.e. the response value corresponding to the modal frequencies and damping) is given by:

$$MK = \Gamma_{K}^{2}$$

where

MK = is the modal mass of the K_{th} mode

Γ_K = modal partecipation factor for the K_{th} mode.

In the present case it is:

$$\Gamma^{2}_{1,\,hor}/M_{tot} = 0.85$$

$$\Gamma^{2}_{1,\,vert}/M_{tot} = 0.85$$

Hence a reasonable representation is achieved by means of a 1 dof system.

4 Coupled dynamic analysis

The equivalent dynamic models of the crane have been introduced into the dynamic stick model and the analysis has been carried out by means of SAP 4/1 Code. The fondamental period of the crane has been varied (by a fictitious change of the equivalent stiffness) in order to cover the whole spectrum. The results are shown in figs. 2a,b,c,d; the comparison with the conventional FRS are shown in fig. 3. It is evident that a huge reduction of the crane response takes place when resonance conditions exist between the crane and the building, this is mainly due to the reduction in response at the support location. It should be mentioned that simplified procedures /2,3/ have been used to compute the original FRS, however possible inaccuracies are not such as to invalidate the general pattern of the results.

It should be mentioned that a similar pattern of the results has been obtained by Castellani /4/, considering two one degree of freedom oscillators in series.

5 Conclusion

The problem of the seismic design of a polar crane has been discussed; it is shown that the use of the conventional FRS tecnique leads to unrealistic and overconservative results. The inclusion of even a simplified model of the polar crane (one degree of freedom system) into the overall model of the structure has considerable advantages in terms of peak accelerations and this practice should be encouraged.

Typical data are presented and discussed.

References

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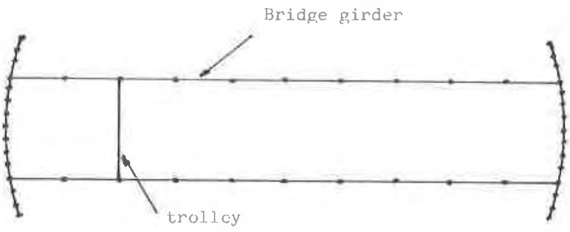

fig.1 - Polar crane model

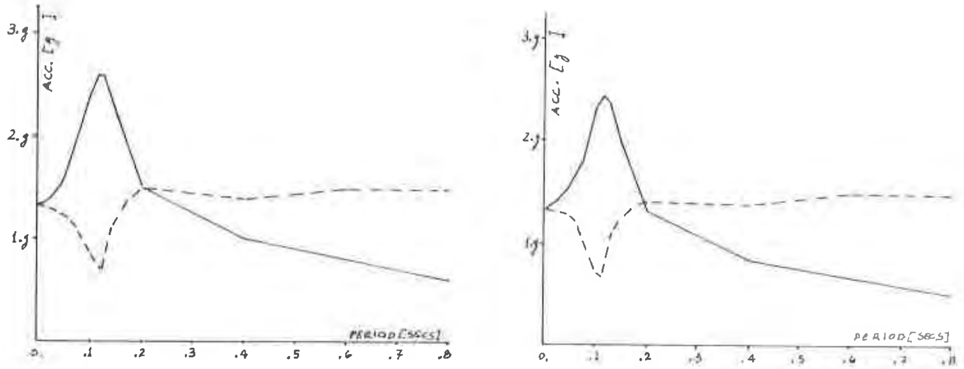

Fig. 2a : horizontal excitation

β_e = 3%

Fig. 2b : horizontal excitation

β_e = 5%

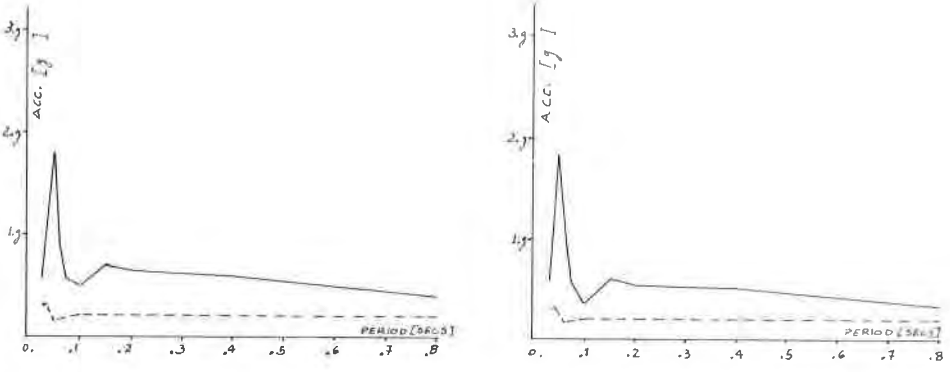

Fig. 2c : vertical excitation

β_e = 3%

fig. 2d : vertical excitation

β_e = [illegible]%

Acc.response spectra of the polar crane (———) and of the support location (- - -) for horizontal (fig. 2a, 2b) and vertical (fig. 2c, 2d) ground motion.

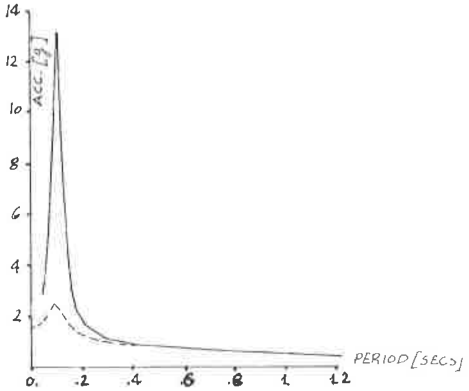

Fig. 3a $\beta_e = 3\ \%$

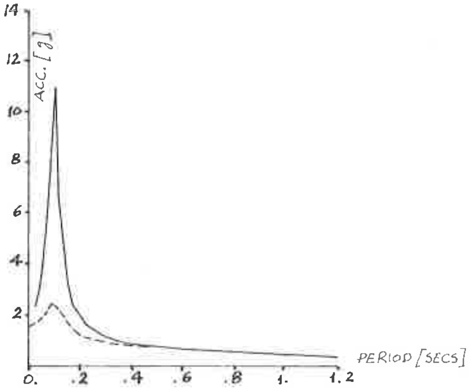

Fig. 3b $\beta_e = 5\%$

Comparison between computed (- - -) and usual (——) horizontal F.R.S. for two different equipment dampings.