

Seismic Analysis of Sliding Structure

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1 INTRODUCTION

Some components of industrial plants are just sitting on their support, then during a seism, sliding may occur between the structure and its support, inducing a nonlinear behaviour. After having briefly recalled the method to integrate the motion equations of a sliding structure, this paper will be devoted to a numerical approach of the seismic behaviour of the polar crane of a Nuclear Power Plant. The crane is represented by its first eigenmodes and the sliding is modeled by nonlinear links. The influence on the response of various hypothesis like identical motion of the contact points and the number of modes contained in the modal base, are investigated.

2 METHOD TO CALCULATE THE STRUCTURAL RESPONSE

The numerical method is presented in details in Antunes 1988 and Brochard 1989 and only the main aspects will be recalled in this paper. The numerical method used to integrate the motion equations, allows to calculate the relative motion of the structure to its support (this displacement includes the sliding of the structure with respect to the support). This relative motion is expanded on the base of the eigenmodes of the structure free at its contact point with the support. The sliding phenomenon, assumed to be modelled through the Coulomb friction model (Mostaghel 1983 and Constantinou 1984), is taken into account by nonlinear links located at the contact points between the structure and its support. During the motion, link forces act on the structure to simulate either the sliding or the grip between the structure and the support. The modal coefficients are governed by harmonic oscillators equations, coupled through the projection of the link forces on each eigenmode. As for seismic analysis we are mainly interested by the low frequency behaviour of the structure, we keep only in the base the first few eigenmodes. The neglected high order modes are supposed to have a static response.

3 DESCRIPTION OF THE STRUCTURE

The above mentioned method has been used to calculate the seismic response of a polar crane located in the reactor building of a PWR Power Plant. This crane is composed by 2 main beams (length 40,6 m) supported at each extremity by a cross beam (length 9,4 m). About the middle of the beam is located the central crossbar. The operation and service carriages rest on the main beams. The total mass of the crane is equal to 328T. The crane is sitting on its support through the contact rollers located under the cross beams. During the motion, sliding may occur between the rollers and the support. The analysis is performed with the following conditions : no mass is hanged on the carriages and standby situation (the carriages are parked at each extremity of the crane). Using the Computer Code CASTEM 2000 developed by CEA, a beam model has been developed and is presented on Figure 1. It is worth noticing that due to differences between the carriages, the crane is not symmetric with respect to the Y axis.

4 EXCITATION

The support motions at both extremities of the crane are supposed to be identical and directed along the Y direction. The support acceleration response spectrum is presented on Figure 2. This spectrum presents a peak at 3 Hz and the maximal acceleration of the support is equal to 0.8 g.

5 SCOPE OF THE ANALYSIS

As above mentioned, the structure is not symmetric and due to its stiffness, in spite of a 1D excitation, the sliding of the rollers of both extremities will not be identical. Moreover, the gravity center of the crane is located above the sliding surface ; during the motion, the normal reaction to the support will vary from a roller to another, allowing that the sliding may be different for each roller.

The aim of this analysis is to study the influence of different hypothesis in the calculation.

In the first calculation (called CALC 1), we assume first that during the motion, the normal force at each contact with support is constant and equal to the static reaction due to the gravity and secondly that the motions of the rollers are identical. The modal base used in this case contains 2 rigid body modes (translation along X and Y). The frequency of the first bending mode is equal to 4.4 Hz and the corresponding mode shape concerns an horizontal bending in the same direction for the main beams. To study the influence of the number of modes in the base, 2 cut-off frequencies have been considered :

- 20 Hz : In that case, the base contains 15 modes just covering the frequency range of the excitation.

- 35 Hz : The base contains 23 modes and covers widely the frequency range of the excitation.

In the second calculation (called CALC 2), as in the first one, we suppose that the normal reactions remain constant during the motion, but the horizontal motion of each roller is independent. The modal base contains then 3 rigid body modes (2 translation modes and 1 rotation mode) in the horizontal plane and 17 modes which frequencies are smaller than 20 Hz.

In the last calculation (called CALC3), we suppose that the motion of each roller is independent and that the normal reaction may vary during the motion. The modal base contains then 21 modes (frequencies smaller than 20 Hz) including 6 rigid body modes. The non linear links represent both the sliding and the contact between the roller and the support. In addition with the seismic load, the crane is submitted to static forces representing the gravity effect. The instantaneous reaction on the support is the sum of these static forces and of a fluctuation due to a small rocking motion related with the seismic excitation.

In all calculations, the friction coefficient is equal to 0.2 and the modes "free at the link-points" are damped at 4 %.

6 RESULTS

In this paragraph, we analyse the following results :

- the maximal absolute acceleration of the rollers and of the middle of the main beams (i.e. a point near the non linearity and a point far from this non linearity),
- the maximal bending moment around the Y and Z axis, at the middle and at the extremity of the main beams,
- the frequency content (through the response spectrum) of the absolute acceleration of the rollers and of the middle of the main beams.

The maxima of the crane response are presented in Table 1.

We observe that :

- in the first calculation to extend the modal base up to 36 Hz does not modify significantly the bending moments but increases about 15 % the accelerations,
- in the second and third calculations, to allow differential motions between the rollers modifies strongly the results obtained in the first case for both accelerations and bending moments. But to consider that the normal reactions on the support may vary during the motion (CALC 3) does not modify the response. Moreover, in these calculations, we have verified that the motion of rollers located at the same extremities of the main beams are identical (this last point is related with the great stiffness of the cross beams) and that the maximal differential displacement between rollers located at different extremities of the main beams is equal to 2 cm. In the CALC 3 calculation, it has been also observed that all rollers remain in contact with the support during the excitation.

The response spectra of the motions of the rollers and of the middle of the beams are presented on Figure 3 and 4. We

can observe in both cases that the results, got from the 2 last calculations, are rather identical but are different from the results obtained with the hypothesis of a simultaneous motion of all rollers. During the motion, sliding phases are frequent and during these phases the structure vibrate on modes which mode shapes correspond to free boundary conditions at the rollers. The peaks observed on the response spectra correspond to the values of the eigenfrequencies of the crane with these boundary conditions :

- 4 Hz, 5.3 Hz (which are the main peaks), and 10 Hz for the middle of the beams,
- 4 Hz, 5.3 Hz, 10 Hz and 15.6 Hz for the rollers (the peaks corresponding to the 2 last frequencies being the most important).

It is important to notice that the response spectrum of the roller motion is smaller than the excitation spectrum in the neighbourhood of the eigenfrequency of the crane clamped on its support (2.7 Hz), which illustrates the decrease of the response due to the sliding. Nevertheless, the response spectrum of the rollers motion is higher than the excitation one, for frequencies greater than 6 Hz, in a frequency range where there is only few energy in the excitation signal. Similar frequency content has been observed and analysed in details for simple sliding systems (Brochard and al. 1989).

Finally, in the first calculation, to extend the modal base up to 36 Hz, does not modify the roller response spectrum, and the middle beam spectrum, for frequencies smaller than 20 Hz. Nevertheless, a peak at 27 Hz appears in the middle beams response spectrum.

7 CONCLUSION

The seismic response of a polar crane has been performed in using a non linear modal synthesis method, and a Coulomb friction model for the sliding phenomenon.

Due to the lack of symmetry of the crane, sliding at both extremities is different. This aspect must be taken into account in the calculation. On the contrary, modelling the variation of normal reactions on the support is not necessary, the load decrease of one roller being balanced by a load increase of the other roller located on the same extremity of the beam, the displacement (sliding) of these rollers are equal as they are linked by a very stiff cross beam.

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Table 1. Seismic response of the crane

	Direction	CALC 1		CALC 2	CALC 3
		Cut off freq. 20 Hz	Cut off freq. 35 Hz	Cut off frequency 20 Hz	Cut off frequency 20 Hz
Max Acc. at midspan (m/s ²)	Y	6,4	7,8	5,7	6,0
Max Acc. at roller (m/s ²)	Y	11,1	13,0	11,7	11,8
Max Bending moment at midspan (10 ⁶ N.m)	Y	1,17	1,13	1,63	1,90
	Z	1,67	1,69	1,44	1,44
Max bending moment at the extremity of the beams (10 ⁶ N.m)	Y	0,49	0,50	0,56	0,6
	Z	0,33	0,33	0,19	0,19

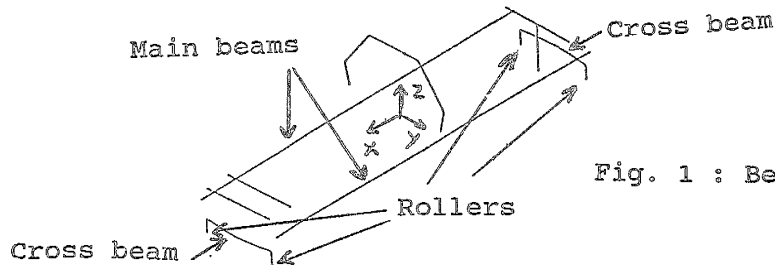


Fig. 1 : Beam model

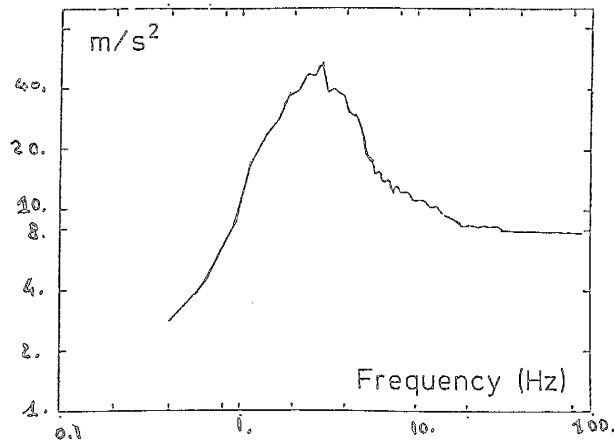


Fig. 2 : Response spectrum of the support acceleration (damping coefficient : 4%)

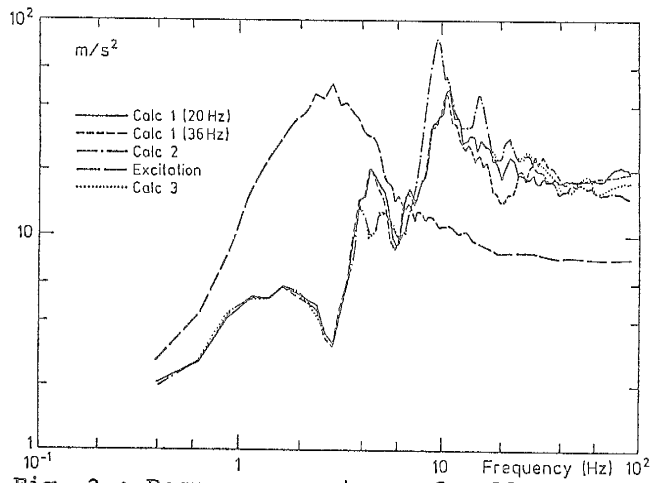


Fig. 3 : Response spectrum of roller motion

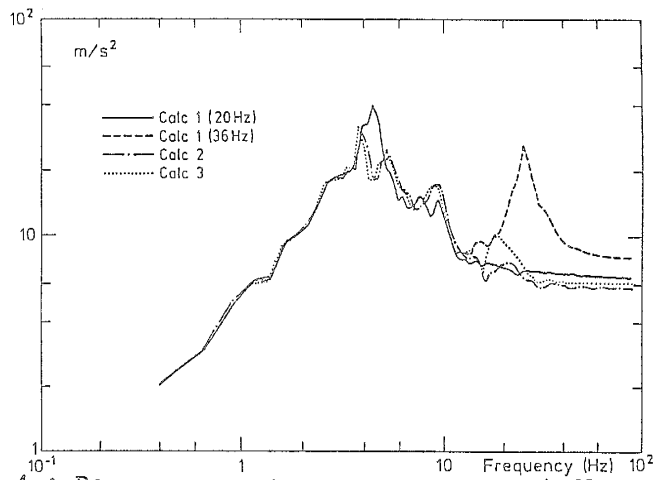


Fig. 4 : Response spectrum of the beam middle motion