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COMPONENT-STRUCTURE-INTERACTION DURING STRONG DYNAMIC EXCITATIONS

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SUMMARY

Presented in this paper are methods and results concerning the interaction between equipments and the supporting structure. In case of linear behaviour a frequency-domain analysis leads to results efficiently. If considerable nonlinear effects occur in the support a time-domain calculation taking into account the nonlinear effects becomes necessary. Both methods are verified by shaking table experiments. Within limited parametric studies the effect of important parameters is shown for simple examples.

INTRODUCTION

In most cases equipments or vessels are mounted on floors made of steel or reinforced concrete. In the normal design procedure the floor response is usually taken as the input motion for the component which is assumed to be rigidly fixed at its bottom. In fact a heavy component may induce bending vibrations in the supporting structure as it is shown in figure 1 in principle.

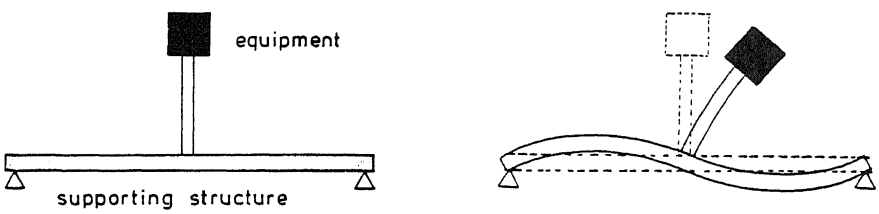


Fig. 1: Example component-structure-interaction

These induced vibrations lead to a behaviour of the component which is different to that one gets for a rigidly mounted structure. The objective of this paper is to show the influence of the component-structure-interaction for some examples. The investigations considered two stress levels: At first linear behaviour of the supporting structure was assumed. In that case a frequency domain analysis is possible. In the second stage nonlinear behaviour in the support was considered which demands a time domain analysis.

LINEAR BEHAVIOUR OF THE SUPPORTING STRUCTURE

As for the case assuming a linear behaviour of the supporting beam a method in the frequency domain was formulated. The used method resembles to methods used for soil structure interaction problems (Ref. 1). The whole system is divided in two parts, the component and the supporting beam. Using the parameters stiffness, mass, damping and length of the beam the reaction under a harmonic moment at midspan can be evaluated (Ref. 2,3). The frequency dependent complex stiffness of the beam, the impedance function, is then used for the determination of the response of the component. The procedure is given in figure 2.

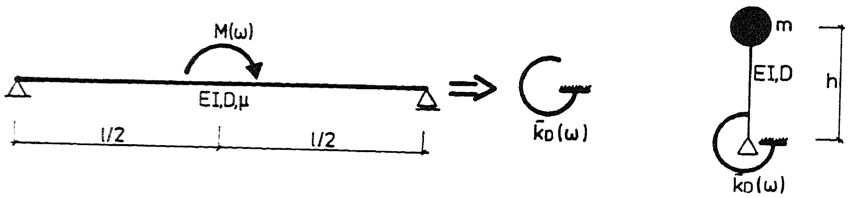


Fig. 2: Determination of the response of the component in the linear region

For this example only the beam-modes with even numbers are of interest:

$$\omega_i = \frac{m^2\pi^2}{l^2}\sqrt{\frac{EI}{\mu}} \qquad \Phi_i(x) = \sin\frac{m\cdot\pi\cdot x}{l} \;;m = 2,4,6\ldots$$

The generalized mass, stiffness and damping are:

$$M_i = \int_0^l \Phi_i^2(x)\cdot\mu\cdot dx = \mu\int_0^l \sin^2\frac{m\pi x}{l}\,dx = \frac{\mu\cdot l}{2} \qquad K_i = \omega_i^2\cdot M_i \qquad C_i = 2D_i\cdot\omega_i\cdot M_i$$

The first derivation of the deflection of the i th mode leads to the rotation:

$$\varphi_i = \frac{d\Phi_i}{dx} = \frac{m\pi}{l}\cdot\cos\frac{m\pi x}{l}$$

After some intermediate steps one gets the generalized force:

$$P_i = \frac{m\pi}{l}\cos\frac{m\pi}{2}\,e^{i\omega t}$$

Using these equations and the equation of motion the amplitude of the i th mode and the adjacent rotation under harmonic excitation can be written:

$$\hat{y}_i = \frac{P_i}{\omega_i^2 M_i + i\omega C_i - \omega^2 M_i} \qquad \hat{\varphi} = \sum_{i=1}^{n}\hat{y}_i\,\varphi_i\,(x=l/2)$$

Finally one gets the wanted rotational complex stiffness:

$$\bar{k}_D = \frac{1}{\hat{\varphi}}$$

In a further step the component is changed to a system with translatory springs only. For this system the transferfunction can easily be derived (Fig. 3).

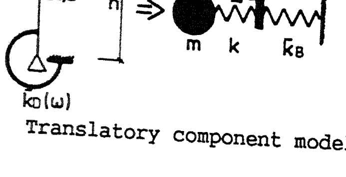


Fig. 3 Translatory component model

Using the above shown relations, systems were investigated which were tested on the shaking table (Fig. 4). Figures 5 and 6 show the gained results of the calculation and the experiments.

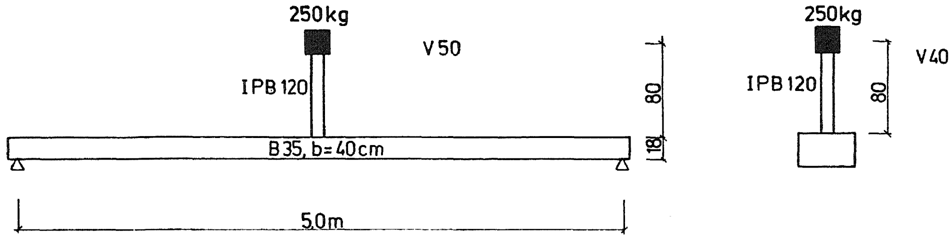


Fig. 4 Investigated model

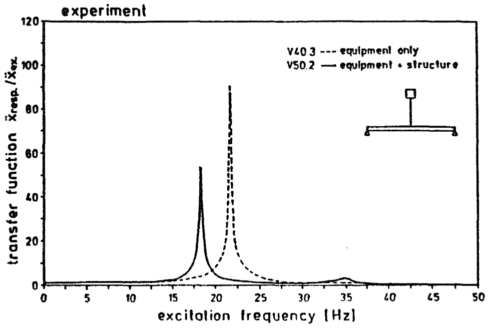


Fig. 5 Experimental results

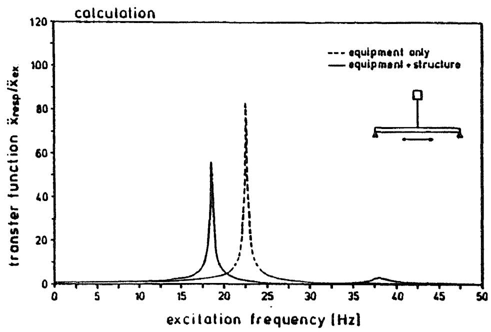


Fig. 6 Analytical results

From these results the general findings

* interaction reduces the resonant frequency
* additional peaks at higher frequency

could be formulated.

Within a parametric study which was conducted by considering for simplicity only the second mode of the beam, the influence of the parameters damping, stiffness and mass could be analyzed. Figures 7, 8, 9 give the results of a variation of the mass ratio, the damping ratio and the ratio between the eigenfrequencies of the beam and the component. Drawn in these figures is the tranfer function related to the peak response of the SDOF-representation of the equipment.

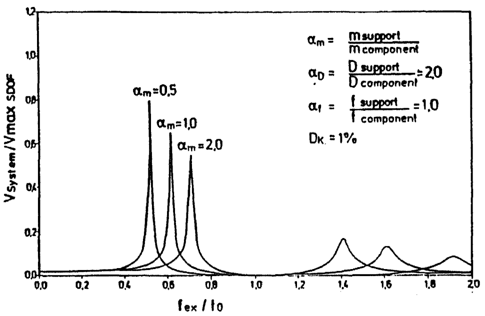


Fig. 7 Variation of mass ratio

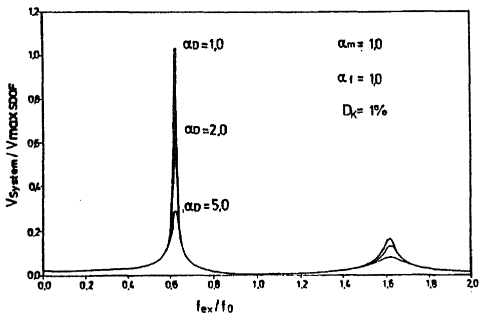


Fig. 8 Variation of damping distribution

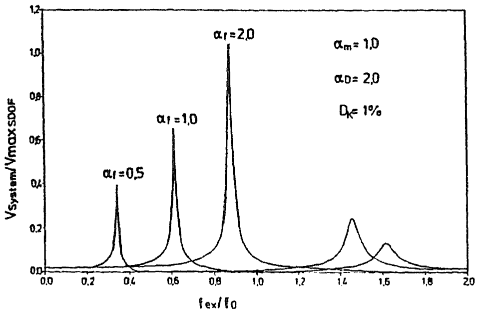


Fig. 9 Variation of eigenfrequency ratio

The above stated general findings could be verified from these results. In addition one can see that a heavy component (small mass ratio) and components with a high eigenfrequency get higher response than others. However the energy dissipation of the concrete beam leads to a reduction of the response of the equipment in most cases.

NONLINEAR BEHAVIOUR OF THE SUPPORTING STRUCTURE

In case of highly stressed reinforced cracking and further nonlinear behaviour as for instance yielding of the reinforcement may occur (Fig. 10).

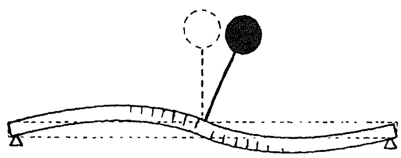


Fig. 10 Nonlinear interaction

As these effects cannot be investigated by the methods shown above a simple nonlinear time domain calculation with a typical floor response as input motion was performed. The nonlinear behaviour of the concrete was considered in the FEM-model by a simplified representation of the cracked section (Fig. 11).

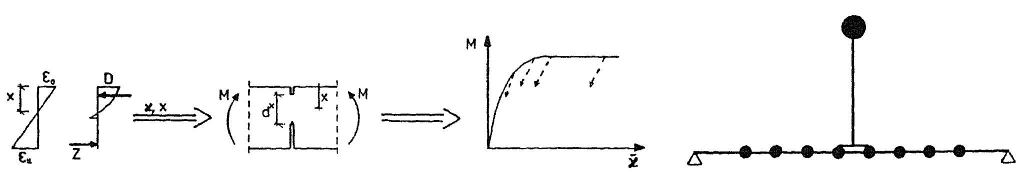


Fig. 11 Representation of cracked section

Fig. 12 show the experimentally investigated specimens the reinforcement of which was varied to give concrete or reinforcment failure. A typical acceleration - displacement relation gained by the experiments is shown in Fig. 13. Fig. 14 gives the function between excitation peak acceleration and the transfer behaviour, expressed as the ratio $\ddot{x}_{component\text{-}response} / \ddot{x}_{excitation}$. The decrease of the transfer with stronger excitation can well be seen.

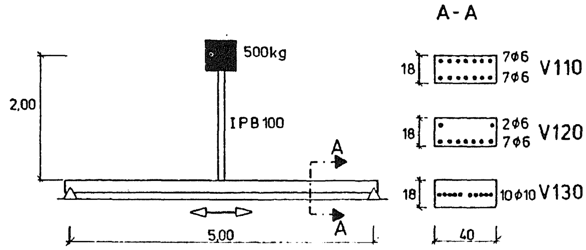
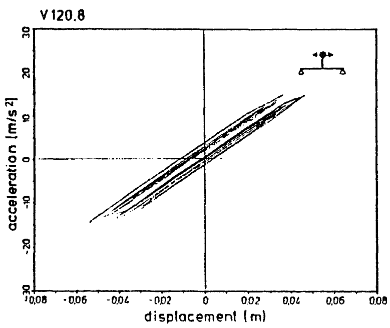


Fig. 12 Investigated systems



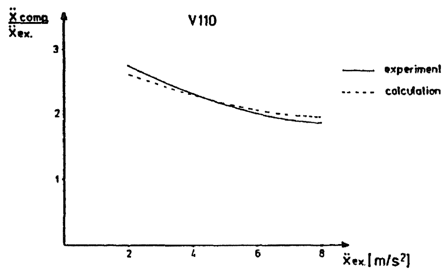
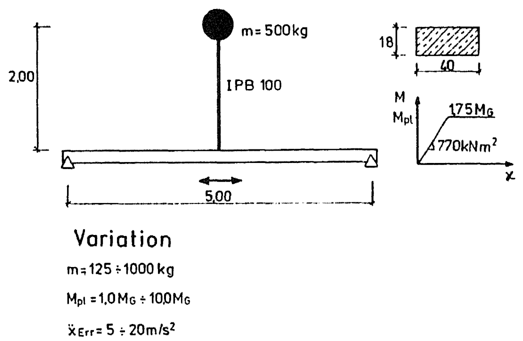


Fig. 13 Observed hysteretic behaviour Fig. 14 Transfer behaviour

In a further step a parametric study was conducted. In this study the parameters a component mass, yielding moment and excitation level were varied (Fig. 15). An example of the results of this study is drawn in figure 16 where the relation between the transfer behaviour and the component mass is given.



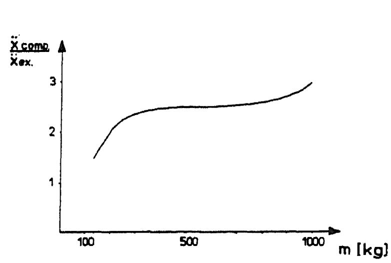


Fig. 15 Parametric study Fig. 16 Component mass - transfer behaviour

CONCLUSIONS

Examples for linear and nonlinear component-structure-interaction were shown. The necessary tools for the evaluation of the effects were presented. From the gained results the following conclusions can be drawn:

* Interaction depends on stress-level

* Effects of linear interaction:

  - shift of resonant frequency
  - variation of peak
  - additional peaks

* Effects of nonlinear interaction:

  - stress reduction in the component due to energy dissipation in the support
  - consideration of operational and earthquake loads necessary

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