

Verification of the Local Structural Response of Building Structures in the Anchorage Areas of Heavy Components

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1 Introduction

In conventional dynamic structural analyses for determining dynamic system response for various locations at which components are installed inside the structures it is common practise (in order to simplify analytical effort) to assume that the anchorage (anchor plate, anchor bolts or throughbolts, concrete and reinforcement in the area of bound) has rigid body characteristics and that the building structure itself does not display any local response of its own. The influence of the stiffness of the anchor plate as well anchor bolts and its stress level on the dynamic response is also neglected. For a large number of anchoring systems, especially for all those components and systems having only a small mass, this assumption is certainly appropriate. At some locations, particularly at points where heavy components are anchored or when loading input has been increased, this can lead to local loading of the anchor system as well as of the building structure well into the nonlinear range. Often, verification of capability to accommodate these loads is not possible without changing the wall thicknesses or increasing the percentage of reinforcement. Since the presence of linear or nonlinear effects can be expected to result in energy dissipation (increase in damping capacity and also a change in the stiffness of the coupled system) it must be assumed that the dynamic response between the "theoretical coupling point" A and the real connection point B of the component on the anchor plate (Fig. 1) can be considerably altered. Some changes of the dynamic response in the connection point B have to be expected generally even in cases of linear-elastic loading of the anchorage. Using typical anchoring systems as an example, the influence of consideration of nonlinear effects in the anchorage area of a typical anchor plate on the dynamic response as well as the conservatism of conventional analytical approaches (in which these effects are neglected) were investigated and quantified.

2 Anchorage and Input Parameters

The analyses were based on an anchor plate with two 20-mm-diameter anchor bolts (Fig. 2). The design loads specified for this anchor plate were about 15 kN (tensile) 20 kN (shear) and 2.0 kNm (moment). The load functions assumed for this component took the form of real acceleration time histories (Fig. 3) expected for a typical area of a reactor building of standard design when subjected to earthquake loading. The peak accelerations of these time histories were about 0.7 g in the horizontal direction (direction of shear in the anchor plate) and 0.9 g in the vertical direction (direction of tension in the anchor plate). The characteristics of the component were chosen such that nonlinear behavior on the part of the anchor plate described above could be obtained with the selected excitation input. The mass of this "hypothetical" component was therefore increased to about 160 kN.

On the basis of this mass the stiffness of the component also had to be adapted so that representative eigenvalues for the first horizontal natural frequency as well as the first vertical natural frequency (approximately 5 Hz and 15 Hz, respectively) could be obtained.

3 METHOD OF ANALYSIS

Due to the complexity of the behavior of the coupled system of the component and the anchorage the investigations were carried out in two stages. In step 1 a detailed nonlinear analysis was performed using a structural model of the anchor plate with anchor bolts and the (reinforced) concrete floor. The plate was represented by means of three-dimensional elements. The nonlinear behavior of the steel components (anchor plate and bolts) was described by an isotropic plastic material model incorporating strain hardening. An anisotropic material model was used for the concrete. The loads, comprising horizontal and vertical forces as well as moments, were applied at the center of the plate (Fig. 1). The results obtained from this analysis took the form of stiffness matrices and characteristics (nonlinear force-displacement diagrams) for the various directions of the anchoring system. In a second, separate step a detailed mathematical model was used to perform a nonlinear dynamic analysis of the global system (component and anchoring elements plus local building structure). The characteristics of the anchor system were represented in this analysis by the nonlinear equivalent anchor stiffnesses derived in step 1. The time-dependent dynamic response of the coupled system (realistic acceleration time histories and the corresponding acceleration response spectra of the building structure) at the location at which the component was installed (location of anchorage) were represented in graphical form and compared with the results of an analysis in which nonlinear effects had been neglected.

4 NONLINEAR ANALYSES OF ANCHORING SYSTEM

The mathematical model used in the investigations of step 1 is shown in Figures 4 and 5. On account of the existing symmetry, only half of the anchor plate and the concrete floor was represented in the model. The dimensions of the local structural model of the 50-cm-thick concrete floor were 1.50 m x 0.30 m. The bending reinforcement (minimum reinforcement = $7.5 \text{ cm}^2/\text{m}$) was distributed over the upper and the lower layer of elements. The shear reinforcement was distributed over appropriate vertical rows of elements. The dimensions of the 20-mm-thick anchor plate were 600 x 12.5 mm (half of the width). The cylindrical, 180-cm-long threaded anchor bolts were modeled using square equivalent anchor bolts having the same cross-sectional area. The connection between the anchor bolts and the concrete was modeled by slide lines. Nonlinear material properties of the concrete, reinforcement and steel were taken into consideration. In order to obtain a better understanding of the nonlinear processes taking place in the anchoring system during loading, the investigations were performed for different directions of loading. Separate analyses were thus conducted for the force (FX,FZ) and moment (M) loading (Fig.1). The nonlinear analyses of the local structural model were conducted using a three-dimensional finite element program for elasto-plastic analyses of structures subjected to transient and impulse type loads (Tropp, 1984). In order to obtain better insight into the nonlinear processes occurring in the region of anchorage, a number of characteristic parameters of deformation and state were derived.

Figures 6 to 8 show the degree of deformation that can be expected at the anchor node when a constant vertical, horizontal or moment loading is applied to the anchor plate. The stresses that are to be expected from the normal load and the associated crack propagation patterns are shown in Fig. 9. On the basis of the total deformation of the system comprising the anchor plate, the anchor bolts and the concrete which was expected to arise at the various levels of loading, the corresponding force-displacement diagrams were generated for the individual

types of loads (Figs. 10 to 12). It can therefore be said that in the case of the anchoring system investigated here nonlinearity can generally be expected with tensile forces of 250 kN, shear forces of 220 kN and upwards, and moments starting at about 30 kNm.

5 DYNAMIC ANALYSIS OF GLOBAL SYSTEM

The mathematical model used for the investigations comprising step 2 is shown in Figure 13. It represents a support structure of which the total mass is idealized as a concentrated load. Each base point is allocated three elasto-plastic spring elements which represent the behavior of the anchoring system in the horizontal, vertical and rotational directions and have properties based on the force-displacement diagrams described under 4 above (Fig. 14).

Linear and nonlinear analyses were performed using the mathematical model described above. In the linear analyses (independent from the local level) linear elastic anchor springs (K_E) were assumed. The global model was excited at nodes 1 and 2 simultaneously in the vertical and horizontal directions using the assumed time histories (Fig. 3). For the purpose of quantifying the influence of the nonlinear effects at the anchorage location on the real response of the structure in the area of load application (connection point B), a number of parametric studies were performed (Krutzik 1984) with the above-mentioned model in which the corresponding nonlinear springs were used. In order to determine the influence of the nonlinearities on the response in the normal direction, only the vertical and the rotational springs of the model were assigned nonlinear properties (Model V). The properties of the horizontal springs remained unaltered (elastic). The influence of the nonlinearities on the horizontal direction of vibration was correspondingly established by assuming nonlinear springs for the horizontal direction and keeping the linear elastic springs in the vertical direction (Model H). Analyses were also performed using the nonlinear springs for all three directions; see Model HV. The response spectra were generated for the coupling points (1 and 2) as well as the component (node 7) on the basis of 2% damping. Representative acceleration response spectra for Model HV are shown in Figures 15 and 16. The reduction in the peak accelerations corresponds to the combined effects of the models V and H.

6 CONCLUSION

The investigations that were carried out demonstrated that the nonlinear response of an anchoring system can be realistically determined using the method applied in this study. If consideration is given in the analyses to the influence of the characteristics of the anchorage (anchoring elements and local building structure) the dynamic response at the anchorage location (the real connection point B) as well the coupling point of the component (7) is found to be considerably less. In order to establish definitely the effects of the model input parameters (particularly the geometry of the corresponding anchor plate and of the anchor bolts as well as their material properties), further investigations should be conducted with the aim of determining the characteristics of typical anchor systems.

7 REFERENCES

- /1/ Tropp R., NONDYN, Computer code for Nonlinear Calculation of Concrete and Elastoplastic Materials, Siemens Report R621/84/039
- /2/ Krutzik N., Vinker D., Verification of the Dynamic Response of Structures in Anchorage Areas of Components and Systems Considering Nonlinear Effects, Internal Report Siemens R621/84/96

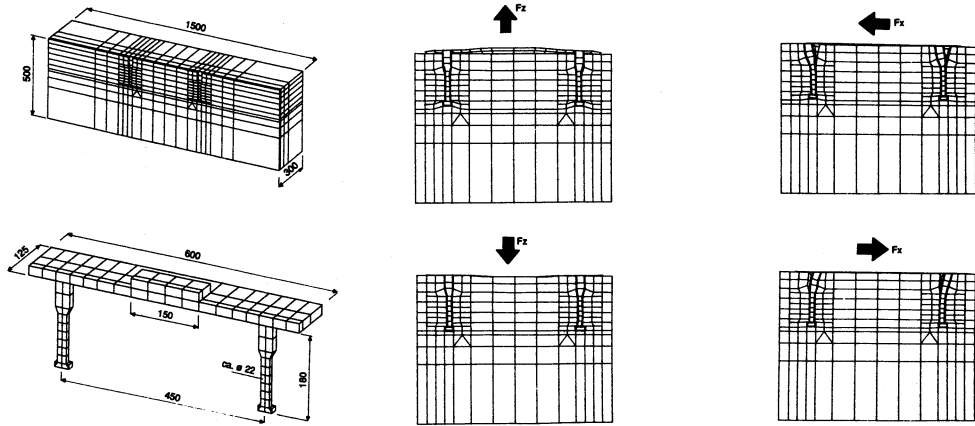


Fig.5 Mathematical Models for the Concrete Structure and the Anchor Plate Fig.6 Deformation of the Anchorage Subjected to Normal Force Loading Fig.7 Deformation of the Anchorage Subjected to Shear Force Loading

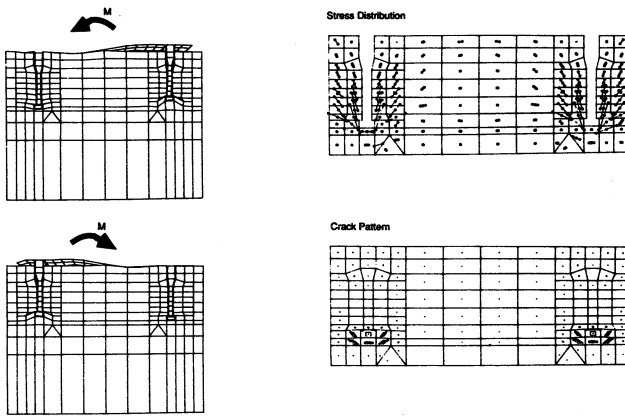


Fig.8 Deformation of the Anchorage due to Moment Loading Fig.9 Stress Distribution and Crack Propagation due to Normal Force Loading

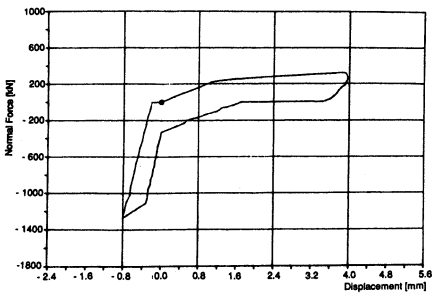


Fig.10 Characteristic of the Anchorage due to Normal Force Loading

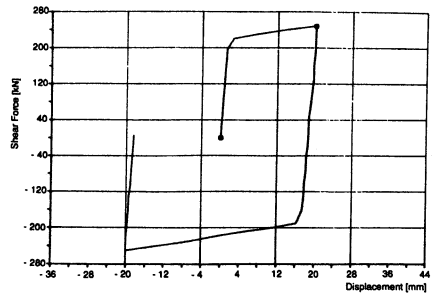
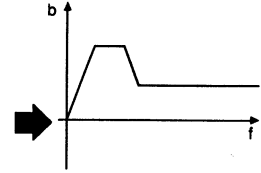
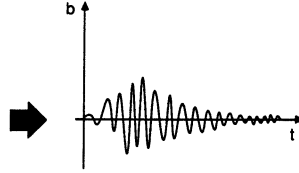
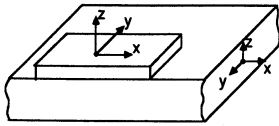
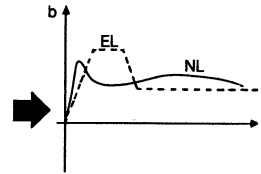
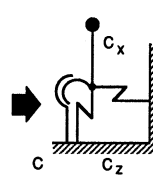
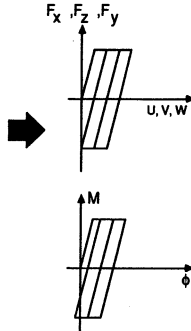
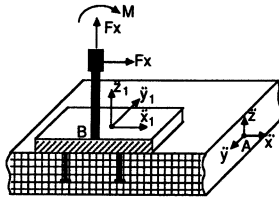


Fig.11 Characteristic of the Anchorage due to Shear Force Loading

Conventional procedure



Consideration of elasto-plastic capabilities



1. Nonlinear three-dimensional analysis of anchor node

2. Definition of elasto-plastic stiffness

3. Derivation of modified response spectra

Fig.1 Modification of the Dynamic Response of the Structure at Component Anchorage Points

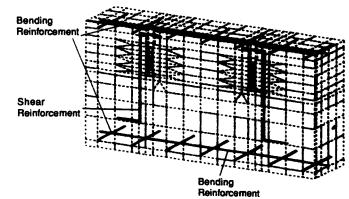
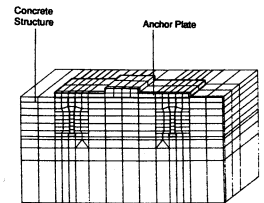
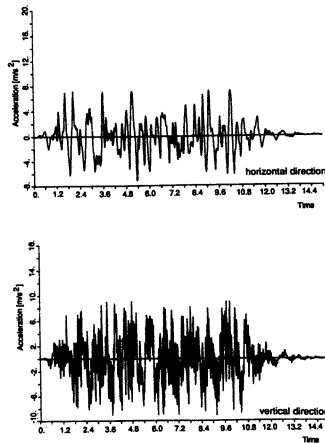
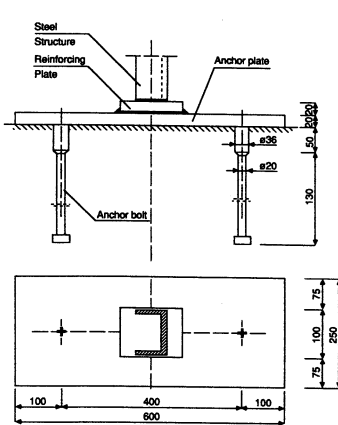


Fig.2 Anchor Plate, Example

Fig.3 Secondary Time Histories of the Anchoring Area

Fig.4 Idealization of a Typical Anchorage

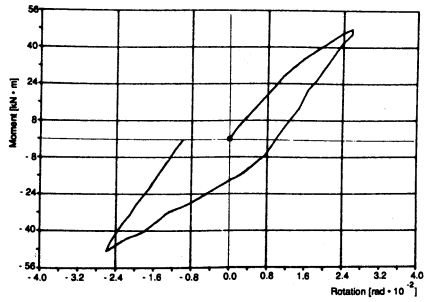


Fig.12 Characteristic of the Anchorage due to Moment Loading

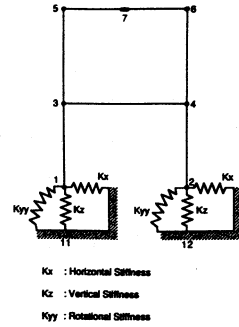


Fig.13 Mathematical Model of the Coupled System

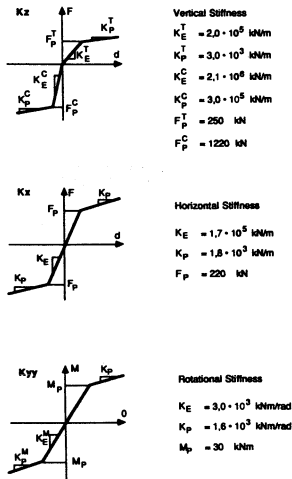


Fig.14 Force-Displacement Diagrams for the Anchorage

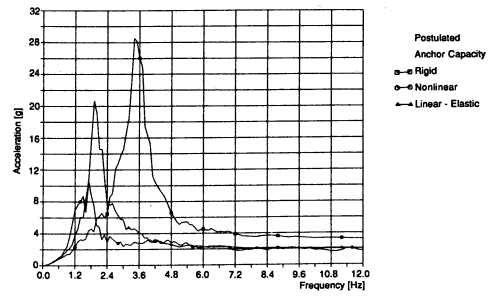


Fig.15 Comparison of the Dynamic Responses in the Connection Point of the Component (Horizontal)

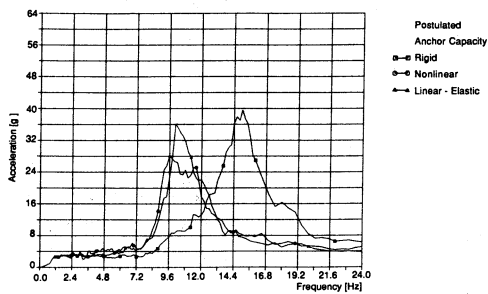


Fig.16 Comparison of the Dynamic Responses in the Connection Point of the Component (Vertical)