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General 3D-analysis of asymmetric multistorey R.C. structures

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ABSTRACT: A realistic Model for the 3D-Analysis of Highrise Structures stiffened by Reinforced Concrete Walls is presented, taking into account the nonlinear Constitutive Laws of Concrete and Steel, the Behavior of Concrete after cracking and the Tension Stiffening Effect. The inplane Rigidity of the Reinforced Concrete Floor Slabs is also taken into account. A numerical Example shows the Application of this Model by a Structure under Earthquake Excitation.

1. INTRODUCTION

The Security of High-Rise Structures under Strong Motion Earthquake Excitation is essentially influenced by the Resistance of the bearing Construction against lateral Forces. A careful modelling is required in order to cover important Mechanisms of Force Transmission to the Foundations. The modelling Cost depends on the Quantity of available Data. In the preliminary Design, few Data are sufficient for approximating the overall Behavior of the Structure. In this Design Phase, the use of Continuum Models is advantageous. The final Design can be carried out generally by using Computer supported discrete Models. In this Design Phase, the Calculations will be based upon planar or three dimensional Models of the Structure.

Sometimes it is necessary to investigate the realistic nonlinear Behavior of a Structure under a possible Earthquake Excitation. This Behavior can be described only by a nonlinear Analysis in which material and geometric nonlinearities are taken into Consideration. This nonlinear Analysis is very complex and requires great numerical Effort. Therefore, the numerical Analysis is often restricted to Models which take into account only these nonlinear Mechanisms which exhibit great Influence on the Behavior of the System.

Different Continuum Models for the preliminary Design are introduced by Schäfer, Glück/Gellert, Biswas/Tso, Liang and Anastasiadis. Among the different Methods of modelling the inplane Rigidity of Slabs in Discrete Models, the "Master Joint/Dependent Joint" Concept is quite advantageous (Elenas 1990). In a nonlinear Finite Element Analysis (material Nonlinearity) a realistic Constitutive Law for Steel and Concrete is required.

2. FINITE ELEMENT FORMULATION

The mathematical Formulation of the Model presented here is based on Continuum-Mechanics Formulas (Elenas 1990). The incremental-iterative Representation of the general Equilibrium Equations is derived, beginning from the Principle of Virtual Displacements, without an a priori Reduction to linear Material Behavior (Material Linearity) and Limitations to small Strains (Geometrical Linearity). No Change of boundary Conditions is allowed during the Excitation. For not very slender multistorey Structures which are stiffened by Reinforced Concrete Walls, the geometric nonlinearity can be neglecting for Simplification of the Analysis. The above Considerations leads to the well known Equation

$$\underline{M}\,{}^{t}\ddot{\underline{U}}^{(k)}+\underline{C}\,{}^{t}\dot{\underline{U}}^{(k)}+{}^{t-\Delta t}\underline{K}\,\Delta\underline{U}^{(k)}={}^{t}\underline{R}-{}^{t}\underline{F}^{(k-1)} \quad (1)$$

where $\underline{M}$ is the Time independent Mass Matrix, $\underline{C}$ the Damping Matrix, $\underline{K}$ the Stiffness Matrix, $\underline{U}$ the Nodal Point Displacement Vector, $\underline{R}$ is the externally applied Nodal Point Force Vector and $\underline{F}$ is the Nodal Point Force Vector that is equivalent to the Element Stress. The Index over left declares the Time each Matrix is referred and the Index over right declares the actual

Iteration Number. To solve this nonlinear Equilibrium Equation, incremental iterative Solutions are applied. In this Work the implicit direct Integration Newmark-β Method combined with the Newton/Raphson Iteration Method is used.

The Stiffness Matrix of a Finite Element at Time t can be written

$$ {}^{t}\underline{K} = \int_{V} {}^{t}\underline{B}^{T}\, {}^{t}\underline{C}\, {}^{t}\underline{B}\, dV \qquad (2) $$

where $\underline{B}$ the Strain-Displacement Matrix, $\underline{C}$ the Material Property Matrix and V the Volume of the Finite Element.

In the present Work an isoparametric, plain Stress, rectangular, only physically nonlinear Finite Element of Reinforced Concrete is derived. Appropriate coupling of the Degrees of Freedom is used to take into account the inplane Rigidity of Reinforced Concrete Floor Slabs in multistorey Structures. This is done advantageously at Element Level using the "Master Joint/Dependent Joint" Concept. This can be expressed mathematically by a Change of the Finite Element Basis.

3. CONSTITUTIVE RELATIONS

The Material Property Matrix of Reinforced Concrete can be analyzed

$$ {}^{t}\underline{C} = {}^{t}\underline{C}^{c} + \sum_{i=1}^{n} {}^{t}\underline{C}^{s(i)} \qquad (3) $$

where the Index over right declares the Material, c states for Concrete and s for Steel respectively and n is the number of thee Steel Layers (Elenas 1990).

The biaxial Stress-Strain Relationship for Concrete is based on an orthotropic hypoelastic Formulation of the equivalent uniaxial Strain developed by Darwin/Pecknold (Darwin, Pecknold 1977. Elenas 1990). To model the Failure Criterion of the Material the Model of Kupfer/Gerstle is used (Elenas 1990). The Cracks are modeled by a fixed smeared Model controlled by a Tensile Crack Criterion (Elenas 1990). The Reinforcing Bars are modeled by smeared Steel Layers having uniaxial Stress-Strain Behavior using the Steel Model developed by Kent/Park and taking into account the Strain Hardening as well as the Bauschinger Effect (CEB 1983, Elenas 1990). The Tension Stiffening Effect is also taken into account by Increase the Steel Stiffness using the Gilbert/Warner Concept (Elenas 1990). The Summary of the presented Model is given in Fig. 1.

4. NUMERICAL EXAMPLE

A 16-Storey High-Rise Building stiffened by six Reinforced Concrete Walls, as shown in Fig. 2, is examined. The Wall Thickness is 20 cm and the Storey Hight is 3 m. The Concrete Strength is 30 MPa and the Steel Quality is BSt 500/550. The Reinforcing Grade is 2% for the vertical Direction up to the 8th storey and 1.5% above it. The Reinforcing Grade for the horizontal Reinforcement is 50% of the vertical one. The Building is loaded by an Earthquake Excitation as shown in Fig. 3 in Y-Direction. The Damping Ratio is assumed 5%. Figure 4 and 5 shows the linear and the nonlinear Response of the Rotation of the 16th Storey respectively. It is recognized a 15% Underestimation of the above Storey Rotation by using a linear Analysis as well as a permanent Rotation after Excitation in the nonlinear Analysis.

5. CONCLUSIONS

This Contribution shows clearly that the realistic Behavior of a Structure can be calculated only by a nonlinear Analysis, taking into Consideration the essential Nonlinearities of the Structure. An applicable physically nonlinear Model for the Analysis of three dimensional asymmetric Reinforced Concrete Structures is presented and its Application is shown by an numerical Example. Further Investigations taking into account other Constitutive Relations as well as additional nonlinearities as geometrically or Changes in the Boundary Conditions during the Excitation, can improve the above described Model.

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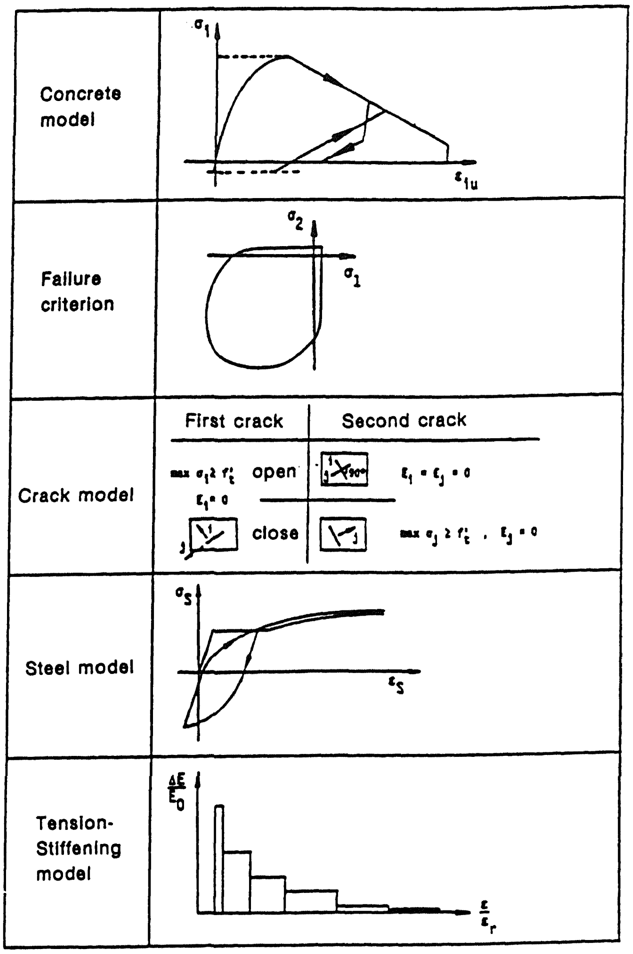

Fig. 1 Reinforced Concrete Model

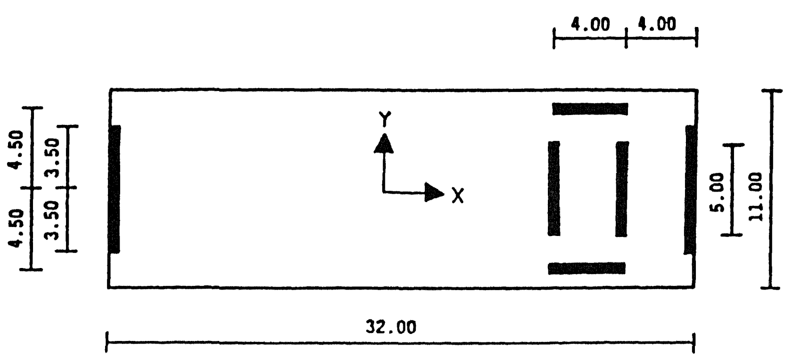

Fig. 2 Plan of the Stiffening System

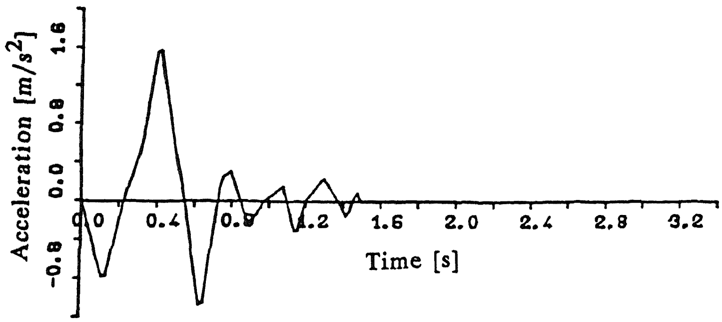

Fig. 3 Accelerogram of Earthquake Excitation

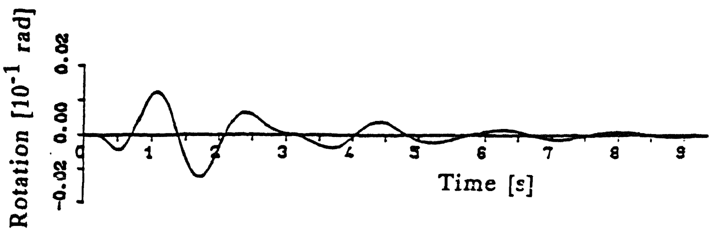

Fig. 4 Time History of the Rotation of the 16th Floor Slab after linear Analysis

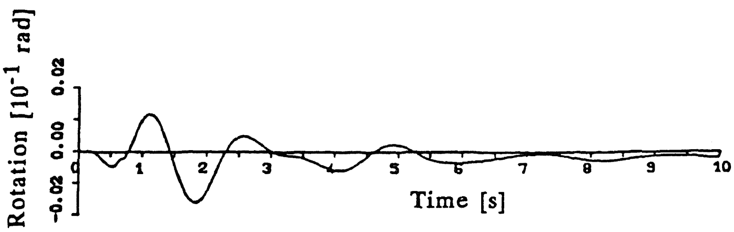

Fig. 5 Time History of the Rotation of the 16th Floor Slab after nonlinear Analysis