Problems and Opportunities of Nonlinear RC Frame Analysis

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Summary

A safe and economic realisation of tall buildings and other slender structures calls for accurate structural analysis. Several current analysis programs allow for a materially and geometrically nonlinear analysis of reinforced concrete frames, either by frame or three-dimensional elements. For the evaluation of these programs the authors suggest a benchmark. The benchmark comprises seven testings and reveals a number of distinct differences between numerical results and experimental data. Most problems arise in the computation of spatial structures. For frame elements, no generally accepted cross-sectional model exists taking into account material nonlinearity for all six internal forces. To overcome these problems a hybrid model for arbitrary cross sections is suggested. The new approach is based on a notional division of the cross section into two areas. The approach allows for a fully nonlinear analysis including interaction between all six internal forces. This provides the opportunity for a unified design procedure. Many current concrete codes already allow a nonlinear determination of the internal forces. However, the limit states are checked separately for biaxial bending and normal force, for transverse forces, and for torsion at cross-sectional level. Interactions are only empirically considered. In contrast, the proposed unified concept is based on the limitation of the principle concrete strains and the reinforcement strain produced by all internal forces. The design procedure is reduced to a single nonlinear analysis of the structure.

Keywords: reinforced concrete, frame, nonlinear analysis, benchmark, cross-sectional analysis, unified design procedure

1. Introduction

Nonlinear analysis of reinforced concrete structures used to be limited to research projects. Current software also provides practicing engineers with nonlinear analysis tools. The new generation of concrete codes further propagates nonlinear analyses. Due to the increasing application of nonlinear analysis programs their reliability has to be ensured. Numerical computations of existing experiments often give the impression of perfect accuracy. However, for the design of new structures not a recomputation but a reliable prediction is necessary. A series of benchmark problems for reinforced concrete frames is suggested and run with four programs in section 2. The frames are modeled by both three-dimensional and frame elements. Regarding frame elements, the study reveals the lack of a cross-sectional model capturing the nonlinearities of all six internal forces. Therefore, a new hybrid approach is suggested in section 3. Embedding the new model into a nonlinear structural analysis program facilitates a complete interaction between system and cross-sectional level, and provides the opportunity for a unified design procedure (section 4).

2. Benchmark for nonlinear RC frame analysis

The proposed benchmark consists of seven types of experiments. The first four investigate the behavior of frame elements separately for normal force, shear force, bending moment and torque. To investigate geometric nonlinearity a column under eccentric axial compressive load is included. Important effects of the nonlinear analysis are the redistribution of internal forces in statically

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indeterminate structures and the interaction of the internal forces. Therefore a two-hinged frame and a grid are analyzed. None of the programs is able to analyze all experiments satisfyingly. There is no clear tendency to overestimation or underestimation of the stiffness and the bearing capacity [1]. The results do not answer the question whether frame or three-dimensional elements are more adequate for the modeling of reinforced concrete frames. The assumptions which are made within beam theory provide a good approximation. In contrast, 3D models require a high effort in modeling and computation, and difficulties remain in the definition of boundary conditions and the reinforcement, so frame elements seem to be more appropriate. However, so far no general accepted cross-sectional model exists which considers material nonlinearities for all six internal forces. Therefore in section 3 a new hybrid approach is presented.

3. Cross-sectional analysis

The distinct material nonlinearity of frame elements can be captured at cross-sectional level. A cross-sectional analysis determines the strain state corresponding to given sectional forces. Existing cross-sectional models can be classified into resultant models, truss models, uniaxial fiber models, wall models as well as models based on finite element analyses. However, so far there is no generally accepted model for arbitrary cross-sections under spatial section forces.
A new hybrid approach is proposed [2]. The approach combines a uniaxial fiber model with a wall model. The cross section is divided into two components. The stirrups, the adjacent concrete and longitudinal rebars form a notional, thin-walled cross section assembled from membrane elements. The second component comprises the remaining concrete and longitudinal reinforcement; a uniaxial stress-strain state is assumed. The uniaxially stressed areas only contribute to biaxial bending and normal force, the membrane elements additionally bear torque and transverse forces. The strain state of the cross section is described by generalized strain measures, their longitudinal derivatives, and additionally by the transversal and shear strains of each membrane element. It is determined by equations of equilibrium, continuity and the constitutive laws.

4. Unified design procedure

In the conventional design procedure initially the internal forces are determined by a linear elastic structural analysis. Afterwards the cross sections are designed for the resulting internal forces. In contrast to the computation at system level, the design of the cross section normally takes into account material nonlinearities. The contradiction between the linear determination of internal forces and the nonlinear design of cross sections is partially resolved by the introduction of the new generation of European reinforced concrete codes [3]. The interaction between cross section and system level is now considered in a more consistent way. However, the interaction is limited to biaxial bending and normal force. Inconsistencies also remain at cross-sectional level. The design for biaxial bending and normal force is carried out by limiting the strains under the assumption of a purely uniaxial stress state. In contrast, the limit states for transverse forces and torsion are defined in terms of stresses and are based on idealized truss models. The combined effect of torsional and shear forces is considered only empirically. Interactions between bending and normal forces on the one hand and transverse and torsional forces on the other hand are only partially considered. The hybrid cross-section model presented in section 3 allows for a unification of the design procedure. The limit state for all force components is defined in terms of principal strains. In the servicablity limit state the limitation of the stresses and the crack width also may be substituted by a limitation of the strains, either in form of smeared or local strains.

5. References

[1] GHAVAMIAN S., and CAROL I., ”Benchmarking of Concrete Cracking Constitutive Laws: MECA Project”, *Computational Modelling of Concrete Structures*, 2003, pp. 179–187.

[2] LÖHNING T., SCHENK J., and STAROSSEK U., “Cross-Sectional Analysis of Spatial Reinforced Concrete Frame Elements” *Proceedings, 11th International Conference on Civil, Structural and Environmental Engineering Computing,* St. Julians, Malta, 2007.

[3] MANCINI G., ”Non Linear Analysis and Safety Format for Practice”, *Proceedings, The First fib Congress,* Osaka, Japan, 2002, pp. 53-58.