Finite element code MASA
(**MA**croscopic **S**pace **A**nalysis)

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1 Introduction

Finite element program MASA (MAcroscopic Space Analysis) is aimed to be applied for nonlinear three-dimensional (3D) analysis of structures made of quasi-brittle materials, such as concrete, stones, ceramics and similar materials. Although different kind of materials can be analyzed, the program is mainly intended for the nonlinear analysis of concrete and reinforced concrete (RC) structures. Theoretical background is continuum mechanics and irreversible thermodynamics. The program can be used for solving mechanical problems, such as static and dynamic analysis of structures, non-mechanical problems, such as analysis of transport processes in porous media, and for the study of coupled problems, such as analysis of concrete at high temperature or analysis of corrosion of reinforcement.

To prepare input data as well as to analyze the results of the finite element analysis, commercial pre- and post-processing package FEMAP® is used. It generates nodes, nodal connectivities, boundary conditions, material data and loads, which are required for the finite element analysis. The link between FEMAP® and MASA is realized through an input interface program, which from FEMAP® output data (neutral file) generates input data for the FE code. The interface program can run directly from the MASA main control graphical used interface. Moreover, to generate post-processing output results from the numerical results of the FE code, an output interface program is used. The post-processing output results can be read and graphically interpreted by FEMAP®.

2 Analysis of mechanical problems

The most important part of the finite element code for nonlinear analysis of materials and structures is the constitutive law. In the current version of the FE program MASA different material constitutive laws are available (microplane model, plasticity and damage based models). For standard analysis of concrete and RC structures, normally the rate dependent microplane model for concrete is used (Ožbolt et al., 2001; Ožbolt et al., 2005, Ožbolt et al., 2006, Ožbolt et al., 2008). Depending on the discretization of reinforcement, 1D truss or 3D solid finite elements, uniaxial elasto-plastic stress-strain relationship with or without strain hardening or classical plasticity based models can be employed, respectively (Belytschko et al., 2001). Using the FE code it is also possible to perform creep and shrinkage analysis of concrete structure. Creep law is based on the generalized Maxwell chain model (Ožbolt and Reinhardt, 2001).

To model transfer of stresses from reinforcement to concrete bond model should be applied. The bond model used in the code is based on the discrete bond-slip relationship that is defined by zero length non-linear spring elements (Ožbolt et al., 2002). Moreover, in the modeling of concrete structures, especially for connections between concrete and steel structures (e.g. fastening technology), very frequently special contact elements are needed. Therefore, in the code special nonlinear spring contact elements can be used.

Besides physical (material) nonlinearity, geometrical nonlinearity can also be accounted for, i.e., large displacements and finite strains. For this purpose in the case of microplane model Green-Lagrange strain tensor is used as a strain measure and stress tensor is co-rotational (Bažant et al., 2000). For plasticity based models that are used for modeling of steel, logarithmic strain measure and Kirchhoff stress tensor are used (Belytschko et al., 2001).

In the numerical analysis of materials which exhibit fracture and damage phenomena, such as concrete, that is based on the smeared crack approach one has to use so-called localization limiter to prevent localization of damage into a zero volume in order to make the analysis independent of the size and allayment of the finite elements. In the program MASA two approaches can be used. The first is relatively simple crack band approach (Bažant and Oh, 1981) and the second one is more general nonlocal approach of integral type (Bažant and Ožbolt, 1990, 1996). Note, however, that the nonlocal approach is rather CPU demanding, requires rather fine discretization and there are problems with boundaries and identification of material parameters. Therefore, the analysis is almost exclusively carried out using relatively simple crack band approach.

In the mechanical part of the FE code 3D cyclic static and dynamic analysis can be carried out. Static analysis is of implicit type, based on the secant system solver (Belytschko et al., 2000). The finite element analysis, which can be also rate dependent, is written as total Lagrange formulation. Dynamic analysis, principally rate dependent, can be performed for a single body or for a multiple bodies (at the moment two bodies). The analysis is direct time integration of explicit type. In case of multi body dynamics, contact mechanics is employed (Travaš at al., 2009). To calculate contact forces Lagrange multiplier method is used (Belytschko et al., 2001). If necessary (e.g. penetration problems), re-meshing strategy can be used.

3 Thermo-hygro-mechanical analysis

With the FE code it is possible to analyze behaviour of concrete exposed to high temperature (fire). A three-dimensional model that is based on the thermo-hygro-mechanical coupling between thermal (temperature), hygral (moisture and pore pressure) and mechanical properties of concrete is implemented (Ožbolt et al., 2008; Periškić, 2009). The microplane model is used as a constitutive law for concrete with model parameters being temperature dependent. The finite element analysis is incremental, i.e. it is performed through a number of loading (time) steps. For given temperature, humidity and loading boundary conditions, in each time step moisture pore pressure, temperature, stresses and strains are simultaneously calculated. The analysis is based on the implicit iterative scheme. Besides degradation of concrete resistance due to the effect of high temperature (reduced strength and temperature strain induced damage) it is also possible to predict explosive spalling of concrete cover.

4 Chemo-thermo-hygro-mechanical analysis

One of the phenomena that significantly influence durability of RC structures is corrosion of steel reinforcement. The calculation of corrosion current density, during the process of electrochemical steel corrosion in concrete, requires modelling of the following physical and electrochemical processes: transport of capillary water, oxygen and chloride through the concrete cover, immobilization of chloride in the concrete, transport of OH^- ions through electrolyte in concrete pores and cathodic and anodic polarization (Ožbolt et al., 2009, 2010). The model is formulated in the framework of continuum mechanics following basic principles of irreversible thermodynamics. The mechanical part of the model is based on the hygro-thermo dependent microplane model of concrete. Damage and cracking phenomena are modelled within the concept of smeared cracks (weak discontinuity). The interaction between non-mechanical processes (distribution of temperature, capillary water, oxygen, chloride and generation of steel rust at steel-concrete interface) and mechanical properties in concrete (damage) is taken into account. There is full coupling between mechanical and non-mechanical processes in both directions, before and after depassivation of reinforcement. In the finite element analysis direct integration of implicit type is employed.

5 Conclusion remarks

FE program MASA can principally be applied for three-dimensional analysis of any structure (frames, plates, shells etc.). However, due to the relatively high memory requirement it can effectively be used for failure (damage) analysis of structural members (slender and deep beams, plates etc.) and optimization of structural details (frame edges, anchorage zones, punching problems etc.).

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