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Framework Model for the Simulation of Fracture Behaviour of Concrete

Modèle de treillis pour la simulation du comportement à la rupture du béton

Ein Fachwerkmodell zur Simulation des Bruchverhaltens von Beton

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SUMMARY
A framework model is used for the computer simulation of fracture behaviour of concrete. During the loading process the model degenerates to total collapse due to the failure of struts. Without delineating the geometrical correct shape of particles in material structure the model can be used for microscopical or macroscopical studies. The results of the simulation of a uniaxial tension test are presented.

RÉSUMÉ
Un modèle de treillis est utilisé pour la simulation du comportement à la rupture du béton. Au cours du processus de charge, le modèle dégénère jusqu'à ruine totale par suite de rupture des diagonales. Bien qu'il ne décrive pas la forme géométrique correcte des particules du matériau, le modèle peut être utilisé pour des études microscopiques et macroscopiques. Les résultats sont présentés pour la simulation d'un essai de traction uniaxiale.

ZUSAMMENFASSUNG
Für die Computersimulation des Bruchverhaltens von Beton wird ein Fachwerkmodell benutzt, das durch das Versagen von Stäben während der Belastungsgeschichte bis zum Totalkollaps degeneriert. Ohne die geometrische Gestalt der Partikel im Materialgefüge abzubilden, kann das Modell für mikroskopische und makroskopische Studien verwendet werden. Die Ergebnisse der Simulation eines Zugversuches mit ideal einachsiger Lasteinleitung werden vorgestellt.

1. INTRODUCTION

In material research a numerical method is useful not only in supplying tests of specimens in laboratory, but also giving realistic informations about the crack opening and crack growth inside the specimen. In recent years several models for describing the fracture behaviour of brittle materials have been put forward. Some authors, e.g. /1/, use a mesh for FEM which delineates the structure of concrete exactly. At Bochum another way has been chosen. The model conception is based on Hrennikoff's /2/ idea of the solution of linear elastic continuum problems by framework models. This model allows simulations on micro- and macro levels without altering the number of elements. Only the strut parameters are changed due to the alteration of specimen size.

2. MODEL CONCEPTION

The strut arrangement results from the idea of modelling stress trajectories between equidistant lattice points /3/. The basis cell is a cube, see fig. 1, with edge struts, surface diagonal struts and space diagonal struts. The struts itself behave linear elastic up to given strain rates. On exceeding the maximum tensile or compressive strain the affected struts are removed from the system, representing cracks. Due to the parameter quantification, large displace-

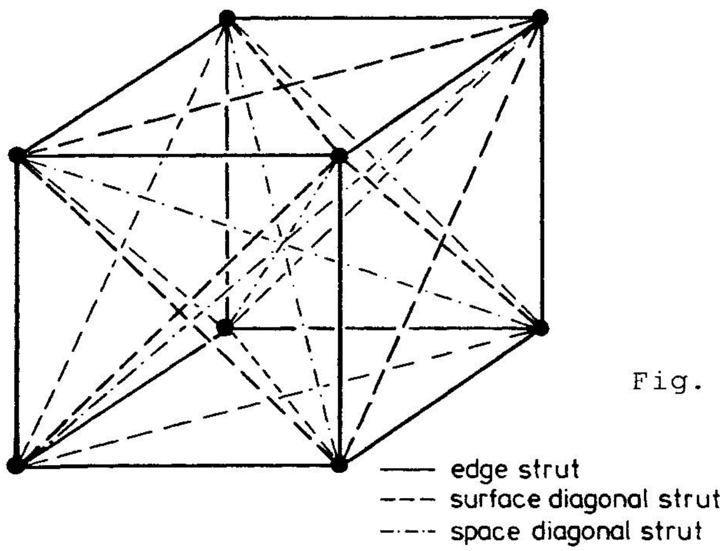

Fig. 1: Basis framework cube

ments may hardly occur. But in heavily degenerated states strut series may buckle or snap through. Thus, a fully geometrically and physically nonlinear analysis of the system has to be performed.

The basic program system has been developed in 1984 /4/. Special numerical techniques have been adapted to perform the simulation analysis on a vector computer effectivelly and fully automatized. The following variations are possible:

- 2D/3D simulations
- uniaxial / multiaxial loading
- compression / tension tests
- load / displacement control
- rigid load induction / "weak" load induction
- influence of viscosity

Additionally, the program system allows an implementation of any material law, e.g. the input of a stress-crack width diagram, which results from the fictitious crack model of Hillerborg /5/.

3. MODELlING CONCRETE

As mentioned before, the model conception allows to choose any level of delineating concrete structure /6/. According to the specimen size the strut parameters have to be altered. Fig. 2 shows an example for microscopical studies. A single strut represents the stress flow mainly through an aggregate particle, another one mainly through the mortar matrix, and a third one is affected by the bond between matrix and aggregate. Fig. 3 shows an example for macroscopical studies. With a given aggregate size distribution and concentration, the three-dimensional composite structure of concrete is simulated to specify the strut parameters. Since exact modelling of the real structure is not required, the strut parameters are stochastically endowed with values by a computerized random number process.

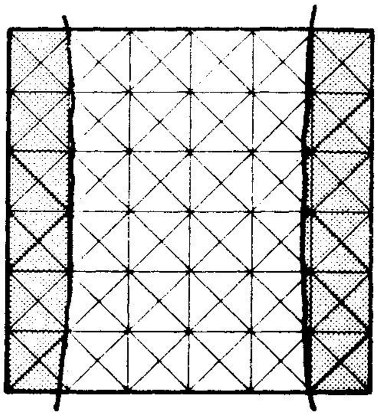

Fig. 2: Example for simulations on a microlevel

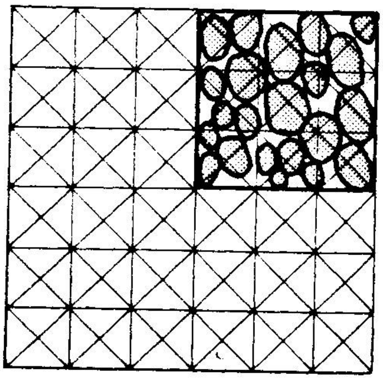

Fig. 3: Example for simulations on a macrolevel

4. EXAMPLE

In this chapter the simulation of an ideal uniaxial tension test at a square plane framework will be presented. The concrete is delineated on a macro level. The struts behave linear elastic without any influence of viscosity. The strut parameters are only defined by the stiffness, the tensile strength and the compressive strength. The typical nonlinear behaviour of the total system is determined only by degeneration or cracking, respectively. All quantities of the strut parameters are normally distributed with a variance of 50 %, modelling a very inhomogenous concrete.

The simulation framework consists of 31 x 31 nodes and 3660 struts. The loading acts on the upper edge of the system in a way, that all nodes on this edge displace equally in vertical and freely in horizontal direction. The opposite edge is supported correspondingly. To calculate the load-displacement path up to the total collapse a displacement control is used here.

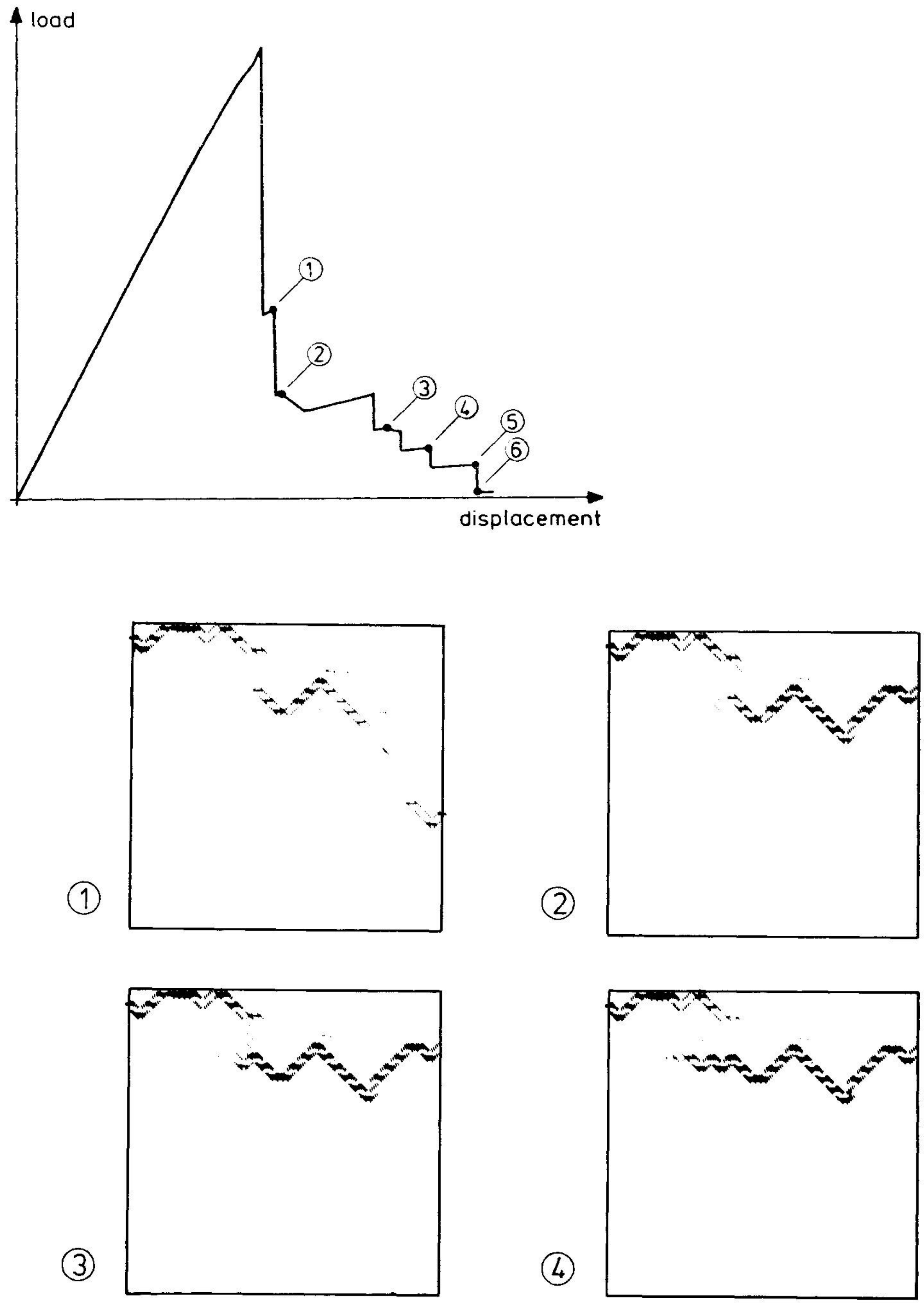

Fig. 4: Results of the simulation of an uniaxial tension test at a plane framework

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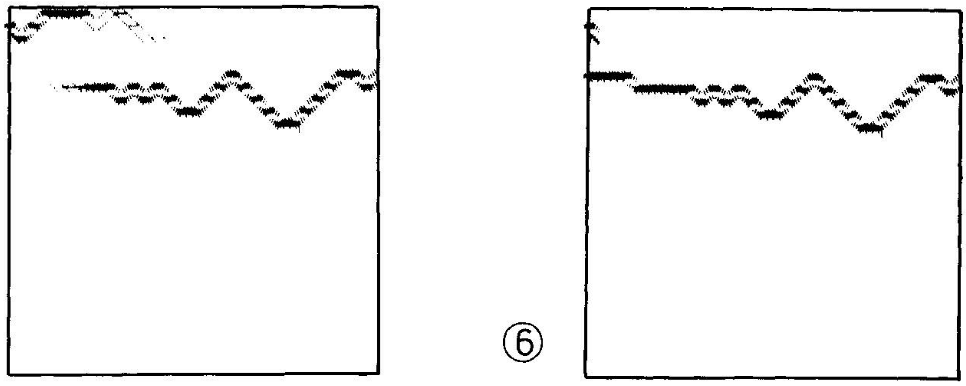

Fig. 4: continued

Fig. 4 shows the graphical interpretation of the tension test simulation. Load-displacement curve and crack plots for six selected load levels are given. According to the strut parameters the first cracks appear randomly. At the unloading branch several horizontal cracks are visible but only one crack runs in horizontal direction and marks the failure mechanism, while the other cracks close just before the total collapse.

The result of this simulation study shows the general applicability of the presented framework model for simulations of fracture behaviour of concrete.

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