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A new analysis method for structural failure evaluation

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ABSTRACT

There are many possible approaches for structural failure evaluation which uses different nonlinear structural analysis methods. For computer implementation purposes, some important differences between them are the results precision, the amount of computer memory needed and computer processing time. For solving practical problems, a compromise between accuracy and computational effort is needed. In this work, a new method is presented for linear and nonlinear structural analysis. The new developed method was named Fibre Contact Element Method (FCEM). In the proposed method, structures are divided in a mesh of several small rectangular block elements (neighbour blocks do not need to be aligned). These elements are divided in several micro fibre elements. Fibres belonging to neighbour blocks are connected between contact points. Two degrees of freedom are considered per contact point and three degrees of freedom are considered for each block (in a 2D model). The elemental block stiffness matrix is obtained from the assembly of fibre stiffness matrix. A static matrix condensation is preformed to reduce the block stiffness matrix dimension. The elasticity and plasticity is concentrated on each fibre element. Global nonlinear response can result from flexural or from shear fibre cracking or yielding. In this work, comparisons between numerical and analytical results are presented. The new method seems to be accurate and fast enough for solving practical problems, namely for seismic damage assessment. Results seem to demonstrate that FCEM can be a valid option for using in structural failure evaluation.

1. Introduction

There are many computer methods for structural failure analysis. All of them have advantages and limitations, so it is very difficult to elect the best method for this purpose. For solving practical problems, probably the best method is the one that is accurate and fast enough to be used in current computers.

Structural analysis models can be divided in two major groups: macro-models and micro-models. Macro-models are those that represent big parts of the structure. Beam elements are examples of those models. On the other hand, micro-models allow to reproduce even small geometrical structural details, and capture the history of stress and strains at every point. Normally, structural analysis methods that use macro-models are faster than those using micro-models. However, macro-models tend to be less accurate [1,2].

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It is more difficult to model the fracture of brittle materials than to model the yielding of ductile materials. For this reason numerical evaluation of fracture process is an important issue.

The fracture propagation process in brittle materials (like concrete) can be modelled by using continuous or discrete formulations [3].

Finite Element Method (FEM) is one of the most popular methods that uses continuous models. FEM using fibre beam element models is also used for nonlinear structural analysis of brittle materials [4]. Fibre models are a strategy that fall in-between micro-modelling and macro-modelling [2].

There are two major groups of strategies for fracture analysis using FEM and micro-modelling: discrete crack and smeared crack methods. Discrete crack methods can also be divided in two groups: prescribed crack and embedded crack methods [5–7]. There are also several combinations of those approaches [8,9].

Classical structural analysis methods, such as FEM, solve partial differential equations of continuum mechanics. For this reason, they can consider only a small number of discontinuities and cannot encompass the entire fracturing process. Discrete Element Models (DEM) like particle models, lattice models or granular models can be a valid alternative [10]. However, these kind of models have also some problems and normally they need a great amount of computer memory and are time consuming [11]. Another discrete element method approach is the Non-Smooth Contact Dynamic method (NSCD), which is an implicit discrete element method that can be used for structural failure analysis of real problems [12].

Another discrete computer method is the Applied Element Method [13,14]. This approach seems to be able to reproduce structural failure of large structures with good precision [15,16].

Hybrid approaches that combines FEM and DEM characteristics have also been used for fracture analysis with success [17,18].

Trying to capture some of the best characteristics of the above described methods, a new method was developed, which is presented in this paper. This new method was named Fibre Contact Element Method (FCEM).

2. Fibre contact element method

In the proposed Fibre Contact Element Method (FCEM), structural systems are divided in small rectangular block elements. These elements are divided in very small fibre elements with rectangular cross sections. The neighbouring block elements are in contact with each other through several hinged contact points which composes a contact element (Fig. 1).

To facilitate the assembly of global stiffness matrix, a fibre element stiffness matrix is first obtained using the local coordinates system (q_1 to q_8) presented in Fig. 2.

The fibre stiffness and plasticity are concentrated in four springs placed at contact points (Fig. 2). The fibre stiffness are defined as:

$$k_{AN} = \frac{E_i \cdot A_i}{L_{AN}}, \tag{1}$$

$$k_{AV} = \frac{G_i \cdot A_i}{L_{AN}} \cdot \frac{5}{6}, \tag{2}$$

$$k_{BN} = \frac{E_j \cdot A_j}{L_{BN}}, \tag{3}$$

$$k_{BV} = \frac{G_j \cdot A_j}{L_{BN}} \cdot \frac{5}{6}, \tag{4}$$

in which E is the modulus of elasticity, G is the shear modulus, A is the fibre area, and L_{AN}, L_{BN} are the fibre lengths (Fig. 2).

Fibre element matrix associated to local directions (q_1 to q_8), can be obtained as

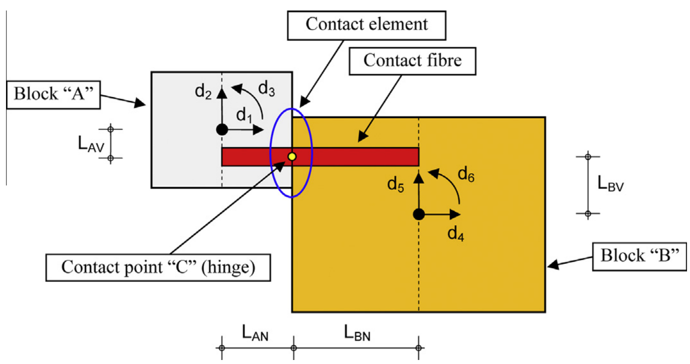

Fig. 1. FCEM model of two neighbouring block elements.