"BLOC" Program for Elasto-Plastic Calculation of Fissured Media

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The 'BLOC' Program was written by Coyne et Bellier in 1980 at the request of Electricité de France for calculation of the behaviour of containment buildings up to rupture when pressure or temperature rise indefinitely.

Such calculations require a correct modelling of the effect of cracking on strains and stresses in the different materials (concrete, reinforcing bars and prestressing cables) and of the exact position of the bars and cables in the concrete.

It can be shown that the composite material known as prestressed concrete (consisting of concrete plus reinforcing bars plus prestressing cables) can be effectively represented by an assembly of stiff blocks connected together through (i) unilateral joints with Coulomb friction, where all the deformations take place, and (ii) 'elasto-plastic spring's with unidimensional behaviour, representing the two types of reinforcement.

For axisymmetrical structures, there are also elasto-plastic 'steel hoops' to model the circumferential reinforcement and horizontal prestressing cables and 'concrete rings' for annular concrete stress and strain. Joints and hoops have non-linear elastic reactions, while the bars and cables are elasto-plastic.

The Raphson-Newton incremental solution method can be modified if desired to retain the basic matrix, as explained in the paper.

The particular model studied for Electricité de France represents the raft, gusset and wall of an axisymetrical containment buildings. The inner, outer and shear reinforcing bars, the prestressing cables and also the steel liner are represented with elasto-plastic materials with their correct position in concrete.

The accident starts from the initial LOCA state: inside pressure 4bars, temperature 120°C, and then pressure rises at 0.3bar/hour and temperature at 2°C/hour. Calculation showed crack opening, general deformations and stress distribution after 0.5hour, 1hour, 2hour, 3hour, etc. until 25hours, after which collapse occurred hoop.

'BLOC' is quite economical on computer time. It has been compared with beam loading tests and which an experimental prestressed concrete ring beam representing a slice of the containment tested by Electricité de France up to failure. The program yields similar results to these tests and FEM elasto-plastic programs that are much more expensive to run. It has been used for thermal stress/strain analyses and rock mechanics problems.

1 INTRODUCTION

Continuum mechanics models are commonly used in design of reinforced or prestressed concrete structures for the analysis of behaviour under service stresses. Many computer models, especially FEM are suitable for this purpose.

However, failure mechanisms and associated loadings cannot be represented correctly by these models. The behaviour of cracked structures is determined largely both by the properties of the unilateral contacts between the blocks formed by the interacting cracks, and by the precise layout of the reinforcement.

The modelling of discontinuities in finite element models was introduced by Goodman (1) in 1969, in the form of a special joint element. However, these models lend themselves poorly to the accurate representation of steel reinforcement. Moreover, the work of Cundall (2) on rigid block models implied that the need for a representation of the continuous medium could be eliminated if prime object of interest is the behaviour of the structure at failure.

The method we developed in 1979 uses Cundall's 'rigid block' concept, with a different model of inter-block contacts, which is described below. A computer program was developed, named 'BLOC', and a sample application is presented. Simultaneously, Kawai (3,4) and Gussman (5) have developed models that have many points in common with our own.

2 MODEL GEOMETRY AND KINEMATICS

The structure analysed is formed by a juxtaposition of indeformable blocks (Figure 1). Each block has three degrees of freedom, two degrees of plane translation (ξ_x, ξ_y) and (ξ_r, ξ_z), and one degree of rotation (ξ_θ). The assumption of block indeformability defines the kinetmatics of the medium composed of n blocks with 3n degrees of freedom. The deformability of the medium is therefore confined to the relative displacements of the individual indeformable blocks.

The mechanical behaviour is governed by the mechanical behaviour of the contacts between the blocks, where all deformations are.

The model is currently two-dimensional, plane or axisymmetrical, but can be extended to three dimensions without any particular theoretical difficulty.

3 PROPERTIES OF MODEL ELEMENTS

Unilateral contacts, with Coulomb friction: these are the salient feature of the model. The blocks are simply in contact with each other and the rheology of the medium is defined by the laws governing contacts between solids. The unilateral character of the contact produces a non-linear elastic type of behaviour, and tangential behaviour with Coulomb limit friction is elasto-plastic in nature. It is assumed that (i) the faces in contact remain plane (rigid blocks criterion), and (ii) the normal stress at any point is proportional to the relative penetration of the two faces:

$$\tau_n = k_n V \qquad (1)$$

where $k_n = E/e$ (2) , Eis Young's modulus and e is the distance between the centres of the blocks.

This assumption implies that the deformability of the medium is concentrated at the joints. The elastic properties of the structure analyzed are thus correctly taken into account, and the joint serves to model the unilateral character of the contact.

The tangential behaviour of the joint is elasto-plastic of the Coulomb type, involving the total normal and tangential forces on the joint. In the elastic domain, tangential sliding is proportional to the total shear force.

By integrating the stresses along the interface, a non-linear elastic matrix can be calculated, relating the normal force and couple acting on the element to the state parameters (normal displacement and rotation of forces) of the joint. It is also possible to calculate an elasto-plastic (scalar) matrix relating the shear force increments to the relative tangential displacement increments of the two faces.
Since the blocks are rigid, the relative displacements of the joint faces are expressed directly from the displacement and rotation of the centres of the blocks concerned. This leads to a relationship between the forces and couples (and increments thereof) acting on the blocks, and the displacements and rotations (and increments thereof) of the blocks.

The equilibrium equations mean that the assembly of the matrices thus obtained is done in the normal way.

Bilateral elastic contacts: these are contacts in which the mutual actions between two blocks are linearly related to the relative displacements of the blocks. This type of contact may help to analyze elastic structures, or uncracked elastic parts within a cracked unit.

Reinforcement elements: these elements are considered as perfect elasto-plastic or strain-hardened springs, possibly prestressed, connecting two points between two blocks.

Elements specific to axisymmetrical models: steel hoops represent circumferential reinforcement, which may or may not be prestressed. They are connected to a point of a block and respond to the radial displacement of this point. Their behaviour is also elasto-plastic, with or without strain-hardening.
'Cracked ring' elements represent the circumferential strain energy. Each block has such a ring. Its behaviour is elastic in torsion and compression, without tensile strength.

4 TYPE OF LOADING

The response of this assembly of blocks to a mechanical force depends on the stress path because sliding between blocks is irreversible and the reinforcing steel undergoes plastic strain. Hence the loading is applied in increments.

5 TYPICAL APPLICATION

Figure 1 shows the model for the gusset and cylindrical wall of a prestressed containment to determine the ultimate pressure strength under initial thermal loading and steadily-increasing pressure. The reinforcement and prestressing steels, as well as the steel liner, have all been represented in their true position. The model has 294 elements: 46 joint elements, 44 'cracked rings', 204 reinforced elements, and only 44 'blocks', corresponding to 132 degrees of freedom.

Figures 2 and 3 show the deformation at half-load and under ultimate load, revealing the failure mechanism. This model has been compared with non-linear finite element models, with 'Goodman' joints, and has yielded closely comparable results, at much lower cost.

6 CONCLUSIONS

The method described is used to test failure mechanisms and to calculate the corresponding ultimate loads. The main advantages it offers are simple modelling, the possibility of representing all the prestressing and reinforcement steels simply and correctly, and fewer degrees of freedom, hence lower cost (the program can be run on a microcomputer).

However, the model is sensitive to the arrangement of the interface elements, presupposing a given failure mechanism. This normally means testing several different models with different kinematically possible failure patterns. But the ease of modelling and low cost are ideal for this type of approach.

Although the model has generally yielded acceptable resutls for linear behaviour regions, this is not necessarily universally true. It must be repeated that this type of model, which is mainly designed for limit analyses, is essentially valid fo. ultimate behaviour. Furthermore, the processing of algorithms for non-linear problems especially in FEM analysis always demands some experience on the part of the analyst, and this also applies to the method presented here. But with certain precautions, and by keeping in mind the basic assumptions of the behaviour modelling, this rigid block method offers a simple and effective tool for analyzing the limit behaviour of reinforced and prestressed concrete structures.

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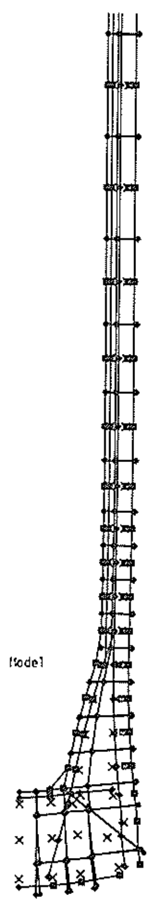

Fig. 1
Initial Model

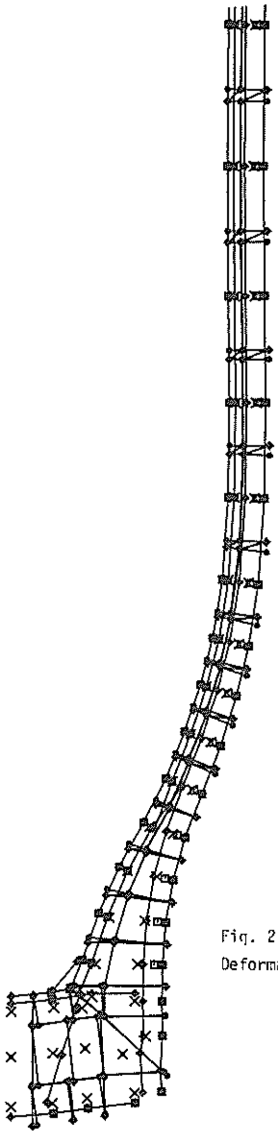

Fig. 2
Deformation at half load

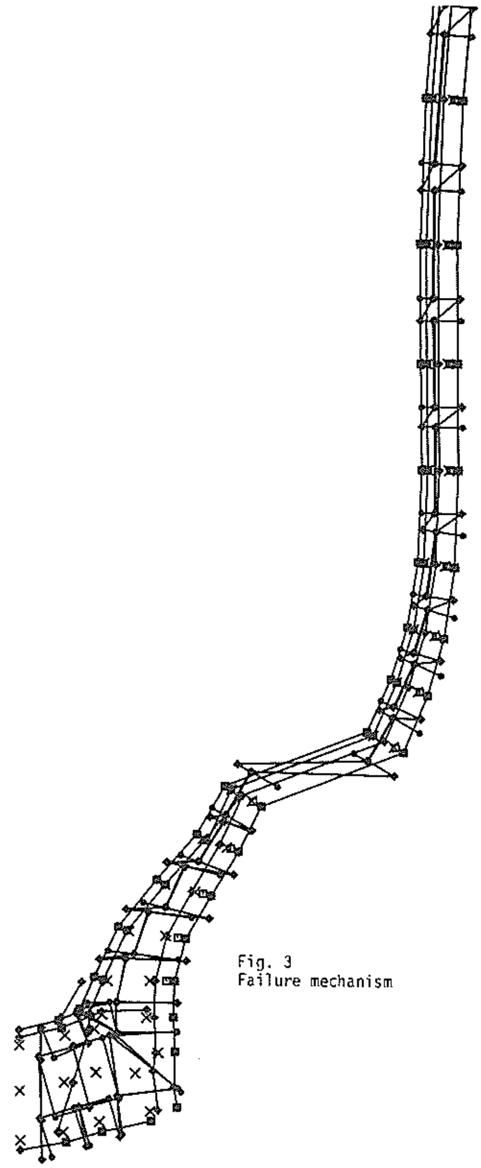

Fig. 3
Failure mechanism