SECTION I. DYNAMIC FAILURE ANALYSIS OF CABLE STRUCTURES BY THE DEM METHOD

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1. Purpose: The current needs of structural engineering require effective tools for assessing the behaviour of structures until complete failure to be developed. Hereby, a new hybrid Discrete Element Method (DEM)-lattice approach is proposed which deals with the structure at macro-level, while taking full advantage of the most important feature of time-domain analysis – continuous real time monitoring of structural behaviour. The method is particularly useful in situations where traditional matrix methods are difficult to apply, namely highly geometrically nonlinear analyses, material nonlinear analyses; both in the pre-failure and post-failure stages.

2. Method of analysis: The modelling technique is described first. The structural mass is lumped to the nodes. Each mass then stands for a discrete element in terms of the DEM. External loading may be modelled as an extra mass added to appropriate nodes. Alternatively, prescribed force, acceleration and velocity time histories may be applied to loaded nodes. The structural members between nodes are represented by springs with initial stiffness directly calculable from the axial stiffness of the member. Supports are defined by specifying motion restraints to some elements as appropriate. Material nonlinearity can be incorporated by a suitable choice of a load-deformation curve for the springs. Two types of constitutive behaviour have been implemented in the computational program. Elastic-plastic hysteretic model with strain stiffening was used to model hot-rolled steel. A limit on accumulated plastic strain was imposed as a failure criterion [1]. For high-strength steel cables, a model with elastic-perfectly brittle behaviour in tension and exclusion of compression was used. Geometrical nonlinearity is inherent to the solution procedure and no special provisions are necessary to account for it. The solution procedure is essentially dynamic relaxation resulting in analyses being always dynamic. An outline of the solution algorithm is shown in Fig. 1 for an analysis of run time *T*. Analysis is always done in the time domain. Details on the mathematical treatment for the method are given in [2].

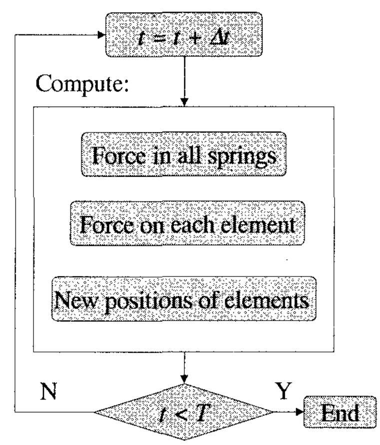

Fig. 1. Solution algorithm

3. Verification for accuracy: A 60m long cable fixed at both ends was subjected to uniformly distributed load (UDL) of 1.67kN/m^2. The cable was modelled by 11 elements connected by 10 springs and the UDL lumped into element mass. Six analyses were carried out varying the distance between the fixed ends from 60m (initially straight cable) to 59.2m at 0.2m increments. A typical deformed shape is shown in Fig 2. The expression that gives the relation between the horizontal component of the cable force F_h, the UDL q, the span l and the sag at midspan f is, $f = ql^2/8F_h$, [3]. The values of sag yielded by the computation were compared to those calculated by the above expression for values of F_h equal to those yielded by the computation. The comparison is shown in Fig. 3. For all cases very good agreement is witnessed.

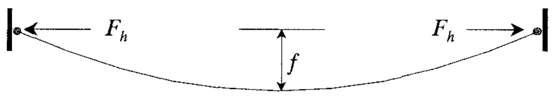

Fig. 2. Deformed shape of cable

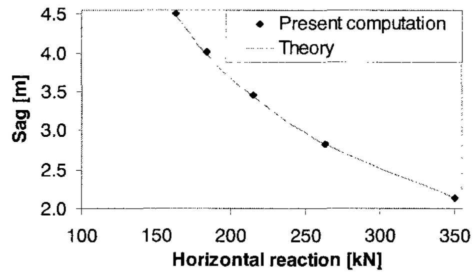

Fig. 3. Relation horizontal reaction - sag

4. Failure analysis example: An analysis of a 30m/30m cable net, square in plan was performed. The mass of all elements was 0.8 ton and the mass of the element at the centre was 18 ton. The other parameters were A = 5x10^{-4} m^2 , E = 2.1x10^{8}kN/m^2 and tensile strength σ_t = 1x10^6 kN/m^2. The structure was released from its initial flat configuration and the deformation and failure process monitored. Large damping was applied to simulate incremental static loading conditions. The deformed shapes before and after failure are shown in Fig. 4 and Fig. 5 respectively. Failure starts from the most loaded springs in the middle just as expected. The time history of verical reaction force displayed in Fig. 6 shows the momentary decrease of reaction force just after failure and the beginning of recovery of reaction force because of the heavy mass remaining attached to the structure.

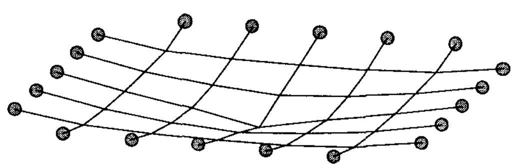

Fig. 4. Deformed shape before failure

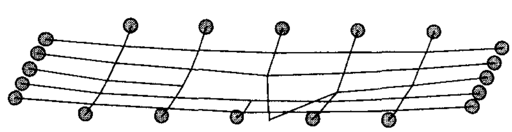

Fig. 5. Deformed shape after failure

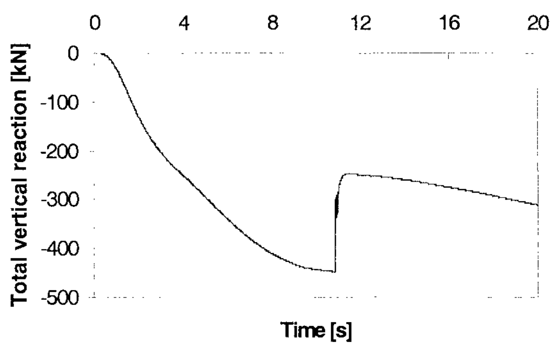

Fig. 6 Time history of reaction force

5. Conclusions: A direct time domain method for the analysis of cable structures was formulated, its accuracy tested, and its ability to trace structural behaviour through and after failure demonstrated. There is not need to assemble a stiffness matrix, so remeshing and reformulating the model at run time is avoided a priori. Special provisions need not be made for nonlinear effects. The method is best suited for dynamic analysis of cable structures, e.g. during earthquake or impact.

References:

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3. Timoshenko S.P. and Young D.H., “Theory of structures”, 1965, New York: McGraw-Hill, pp. 135-148