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A model for plastic hinges in tubular beam impact

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ABSTRACT: A numerical model for the analysis of hollow beam impact have been developed. The moment-rotation relationship of a plastic hinge is used in a nonlinear, implicit code for transient analysis. The moment-rotation curve is obtained from a basic skeleton curve, by adding a second one with irreversible characteristics. Both models may be selected from a variety of functions. A hysteretic model may also be chosen, as the code allows to deal with a wide range of structural problems.

1. INTRODUCTION

A number of nonlinearities must be taken into account in order to study the response of tubular beams impact. First of all the problem involves large deformations of the beam. Unilateral contact conditions are present at the impact region. The stress-strain behaviour of the material exceeds the simple elastic or even elastoplastic models; more realistic description of the constitutive relationships are required. In the case of beams with hollow sections, as is the case of pipes, instability of the cross section leads to a sudden drop in the flexural beam stiffness. Several numerical models have been proposed for hollow beams, ranging from detailed finite element discretization (hydrocodes), to simple elastoplastic hinges models, passing through simplified kinematical assumptions for the plastic hinge mechanism. The range of applications are different for each kind of model.

The so called "hydrocodes" are well suited for impact analysis. These codes makes use of explicit methods to integrate the equations of motion. Even though the provide a detailed insight of the response, they are expensive to use in terms of CPU time. In contrast implicit codes, such as those typical for structural response analysis, may be used. These codes are much less consuming in CPU time and the quality of the response depends much on the models they use. With this type of codes it is of paramount importance the proper model of the moment-rotation characteristics of the plastic hinge. In this communication a numerical model for the plastic hinge of hollow beams is described. It was intended to extend the scope of an implicit code (SAMCEF 1992) and it allows to deal with a variety of structural problems.

2. EXPLICIT AND IMPLICIT CODES

Two kinds of codes may be used for impact analysis: explicit or implicit ones.

Explicit codes are characterized by the use of explicit methods for the integration in time. These codes are well suited for problems involving short time periods of the response, such as wave propagation problems. The structural model is accomplished by small finite elements, usually with very simple interpolation of the displacements within the element. The central difference scheme is used for time integration, resulting in a very cheap solution, provided the mass matrix is lumped. On the other hand a great limitation of this method is its conditional stability.

A detailed insight in stress and deformations can be obtained with the aid of explicit codes. But, on the other hand, a large number of time steps are required to follow the impact response, leading to large CPU times.

Implicit codes are characterized by making use of implicit algorithms for the time integration. They are unconditionally stable and allow to advance through the response with very much large time steps than the explicit codes. As a result they are comparatively less expensive than the explicit ones. However the structural model –which is typically also larger than for the explicit codes– must be able to retain the relevant behaviour of the response. In the next section a numerical model for the plastic hinge is given.

Sonzogni and Géradin (1994) presents results for a hollow beam impact with both an explicit code: DYNA3D (Hallquist 1983); and an implicit one: MECANO (SAMCEF 1992). In that case the CPU time for the explicit code was almost 18 times greater than that of the implicit code, for comparable results.

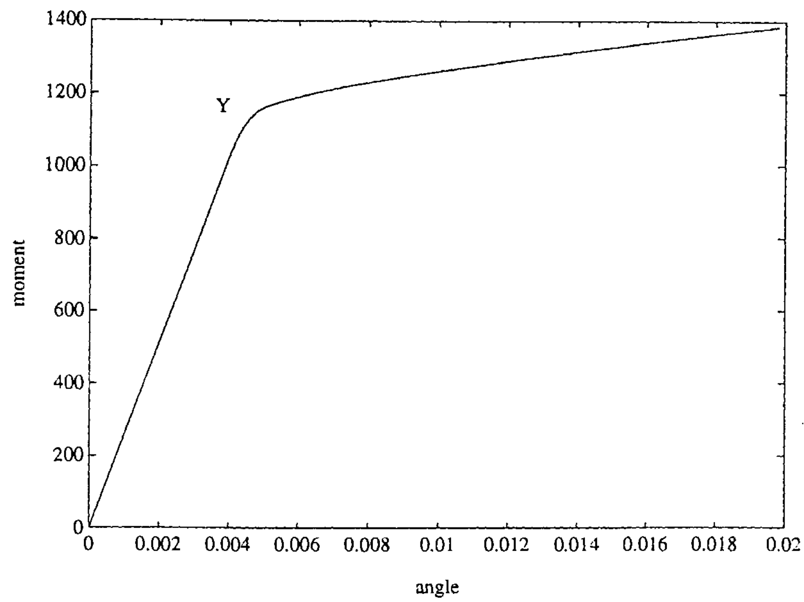
3. MODEL FOR THE PLASTIC HINGE

In the implicit code the structure is modeled with the beam theory. This means that a whole structural element may be represented by a single numerical element, provided the mass is adequately represented. Special hinge elements are placed at critical locations. A numerical model for the response of these hinge elements have been developed. The moment-rotation curve is described by selecting three different models. One model, for the basic skeleton curve. A second model, for the cyclic characteristics of the response. A third model, for the instability of the section.

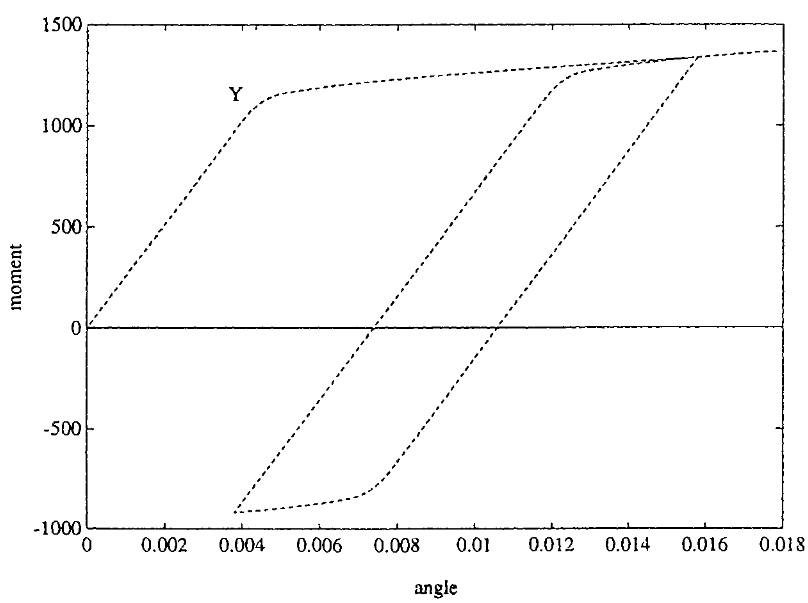
A basic curve describing the monotonic relationship between moment and rotation is adopted (Figure 1-a). It may be selected among several types of curves which cover most of the practical cases encountered in structural analysis, such as: bilinear, polygonal, polynomial, or transcendental functions.

The basic curve so defined is taken as skeleton curve to construct the successive branches of unloading and reloading which represent the hysteretic cycles, in problems of cyclic response (Figure 1-b). Either a Masing type or an elastic-unloading-and-nonlinear-reloading type are implemented in the model.

In the case of an unstable or degrading skeleton curve, this one is constructed by adding to the basic curve an additional one possessing an irreversible degrading



(a)



(b)

Figure 1. Basic curve (a) and Hysteretic cycle (b).

nature. In this way, dropping of strength as well as stiffness, as it may happen in the case of a slender hollow section, can be approximately taken into account (Figure 2). Additional curves for a hollow beam buckling type are considered in the model. The basic curve, in this case, is intended to represent mainly the behaviour of the buckled section and so the large deformation range of the hinge. The additional curve has a transient, irreversible nature. It represents the complement of the basic curve to the whole unbuckled section strength and stiffness. It is modeled with a straight line up to a maximum ($O - A_1$ in figure 2), and a polynomial descending branch ($A_1 - A_2$). Beyond the point A_1 a damage parameter ρ increases monotonically, vanishing at point A_2. This damage parameter governs the elastic behaviour (unload and reload) such as the path $A_i - A_j - A_i - A_2$. The elastic damaged stiffness is given by K. Once the point A_2 has been reached, the additional curve completely vanishes and the moment rotation curves becomes equal to the basic curve henceforth.

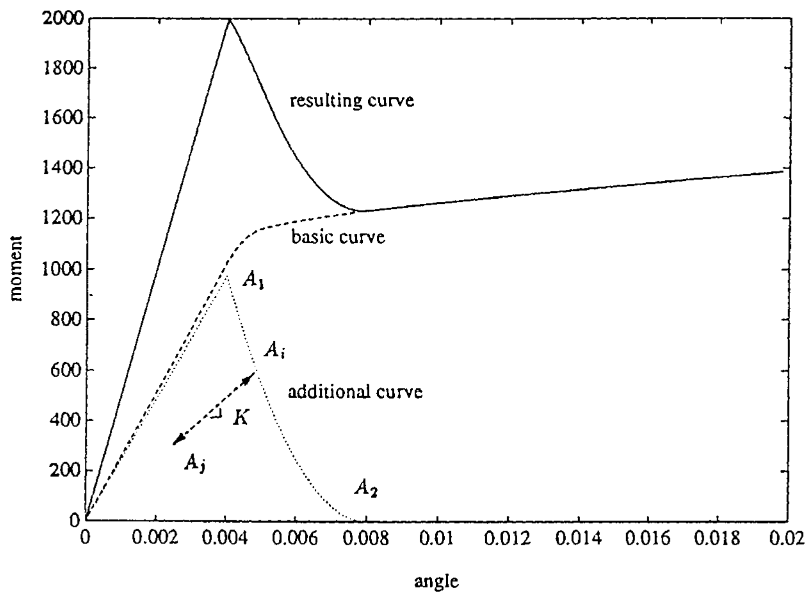


Figure 2. Unstable section model

4. PARAMETERS OF THE MODEL

The hinge model is quite general and may be used for a wide range of structural problems. It is, however, an empirical description of the constitutive equations as it requires previous experimental results to know the response curve of the hinge, and to adopt the model parameters.

A theoretical model of the hinge may be used instead of the experimental results. In the paper by Sonzogni and Géradin (1994) a theoretical model for the response of a rectangular thin walled section of a beam, has been used as input parameters for the hinge model. Some results of the theoretical model of the hinge, for a given section, are shown in Figure 3, together with experimental results from Kecman (1983).

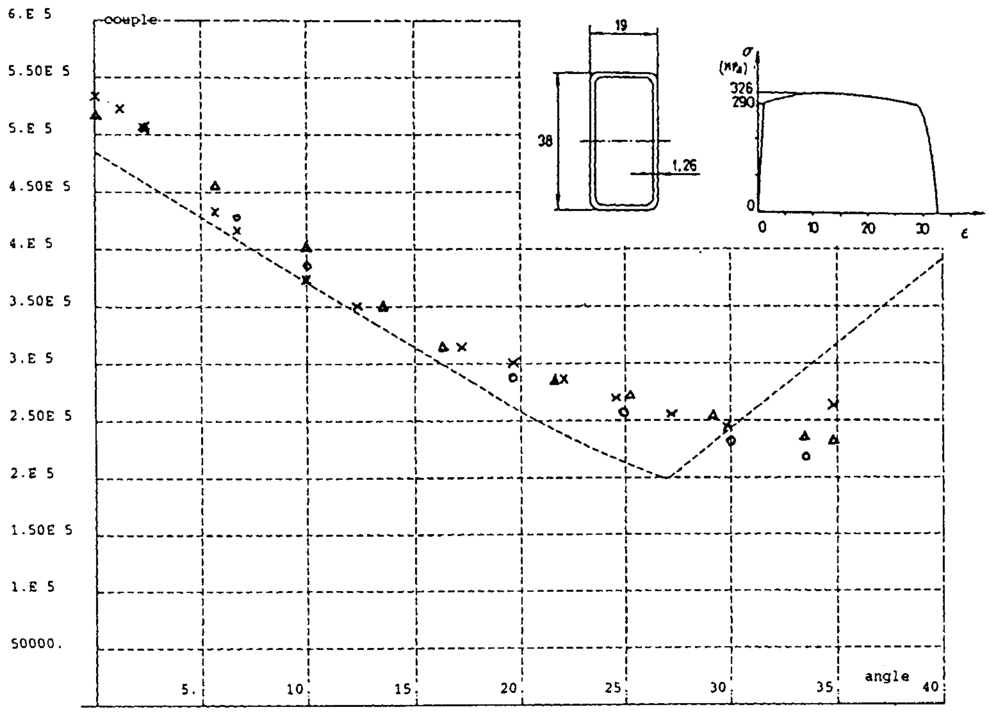


Figure 3. Theoretical vs experimental results for the collapse model. Dotted line: theoretical curve; discrete points: experimental results.

Applications to pipe response have not been performed yet. The model allows to treat this problem in the same way as done for rectangular cross sections. Some results are expected to be presented at the conference.

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