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Numerical Analysis of RC Beams Subjected to Blast loading Based on Moment-Curvature Relationship

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ABSTRACT

An improved numerical model which can simulate the nonlinear behavior of reinforced concrete (RC) subjected to blast loading is proposed on the basis of the moment-curvature relationship of RC section. Since dynamic increase factors (DIF) are usually defined in terms of strain rate of materials, a new DIF equation of a RC section as a continuous function of the curvature rate is constructed. The plastic hinge length is considered in order to reflect the plastic deformation after yielding of the main reinforcement. A modification of the moment-curvature relationship is also introduced to consider large bond-slip between concrete and reinforcing steel at yielding stage. Finally, correlation studies are conducted by comparison between experimental and analytical results to verify the validity of the proposed model.

INTRODUCTION

With increasing need to ensure the safety of reinforced concrete (RC) structured subjected to bombing attacks, research to evaluate the effect of blast and impact has been rapidly extended to civil structures. Under the impact and blast loading conditions, the material properties are enlarged with an increase of strain rate. To simulate the behavior of RC structures, this paper introduces an improved numerical model based on the moment-curvature relationship of a RC section. In addition, an expressions of the dynamic increase factor (DIF) for the moment-curvature relationship, not for the stress-strain relationship, are newly designed in this paper to consider an increase of the material properties.

NUMERICAL MODELLING

To simulate the nonlinear behavior of RC structures, this paper adopted monotonic stress-strain relationship for concrete proposed by Kent and Park and modified by Scott et al. (Scott et al. 1982), and reinforcing steel is modeled as a linear elastic, linear strain hardening material. Additionally, the DIF equations for concrete and reinforcing steel is introduced to this model in order to take into account the strain rate effect. Among the numerous mathematical models, simple relations proposed by Saatcioglu et al. (Saatcioglu et al. 2011) are used in this paper for concrete and reinforcing steel.

Since the monotonic moment-curvature relationship of a RC section is idealized as the tri-linear relationship in this paper (see Fig. 1), a DIF equation needs to be designed for a RC section, not for materials. The moment-curvature relationship should be modified to consider the anchorage slip at the critical regions such as beam-column joint, and thus the bending stiffness of the elements located within the plastic hinge length is replaced by the equivalent bending stiffness to take into account the additional rigid body motion caused by the bond-slip. For the dynamic nonlinear analysis of RC structures, the Newmark method on the basis of the Timoshenko beam theory is adopted in this paper.

APPLICATION

Beam B100(12)-D3 tested by Magnusson and Hallgren (Magnusson and Hallgren 2000) is employed to verify the accuracy of the proposed nonlinear method. A blast loading was uniformly applied to the simply supported RC beam passing through a sufficient distance of the shock tube. This beam modeled with 10 elements including the two elements corresponding to the plastic hinge region (at mid-span). Fig. 2 presents a comparison of experimental result with the numerical result. As shown in this figure, the evaluated displacement history (Case B) which consider the bond-slip shows a good agreement with the experimental result. Also, it can be found that the result without considering the effect of bond-slip (Case A) produces a remarkable different from the experimental data.

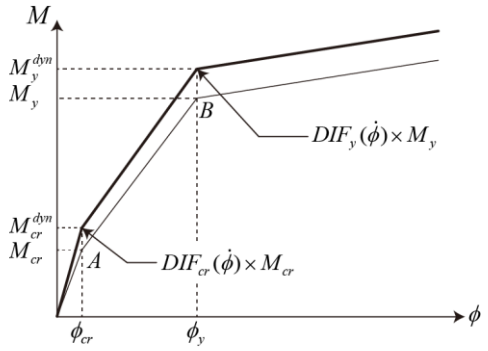

Fig. 1 Moment-curvature relationship of a RC section

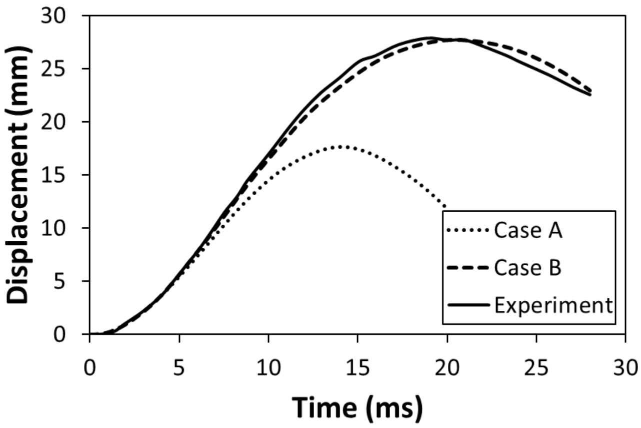

Fig. 2 Displacement history of B100(12)-D3

CONCLUSION

This paper introduces an improved numerical method for a RC beam subjected to blast loading on the basis of the moment-curvature relationship of the RC section. The equivalent bending stiffness is also implemented within the plastic hinge regions to reflect the large plastic deformation. The proposed model is then verified by comparison between the experimental and numerical results, in which the numerical result show good agreement with the experimental result.

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