National Conference with International Participation

ENGINEERING MECHANICS 2008

Svratka, Czech Republic, May 12 – 15, 2008

THE NON-LINEAR RESPONSE OF REINFORCED CONCRETE FRAME STRUCTURES TO SEISMIC LOAD

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Summary: *The response of reinforced concrete structures to dynamic loads is featured the non-linear properties in general. If we take these facts into account for solution of the equation of motion and also take into account of cyclic load to the resultant response, we will get a more real estimate of behavior of structures as compared to the linear calculation. In the contribution a fiber model based on realistic material models is proposed for reinforced concrete sections and for a non-linear dynamics analysis. Numerical examples are presented in the terms of moment-curvature relationships and load-displacement diagram of the structure. Accounted of a new method which is the basis of nonlinear pushover method and which provides the simplification of an access by the way of response spectrum design reinforced concrete frames closes this contribution.*

1. Introduction

Under dynamic loading conditions with high strain rates reasonable descriptions of load-carrying capacity and ductility of reinforced concrete structures are necessary. For such purposes moment-curvature relationships in the critical cross sections are of the importance. On the basis of experimental results, load-carrying and ductility of the reinforced concrete section under high strain rates increase. It is believed that the increases are due to changes in material properties of concrete and steel under high strain rates. This is generally called strain rate effect of materials.

A realistic description of the sectional behavior under dynamic bending moments and normal forces is thereby only possible, when strain rate effects as well as memory effects of concrete and steel partitions are taken into account properly. For a description of the response reinforced concrete structures the non-linear calculation dynamics problems by direct integration method is necessary. This approach can provide us the accuracy conception of the response to load (e.g. seismic load), but it can't afford a complex knowledge about dissipation properties and load-carrying capacity structure.

For better insight of dissipation properties and behavior of the structure the "pushover" method is proposed. This method is the basis of nonlinear method and provides simplification of an access by way of response spectrum design reinforced concrete frames. The response spectrum, now a central concept in earthquake engineering, provides a convenient means to summarize the peak response of all possible single degree of freedom systems to a particular

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component of ground motion. It also provides a practical approach to apply the knowledge of structural dynamics to the design of structures and development of lateral force requirements in building codes.

2. Influence of non-linear materials behavior to response of structures

The idealization of building structures, for example supposition of linear behavior of structure materials, can lead to inaccuracy assignment of their response. This inaccuracy is expressed especially by structures where used material has dramatically non-liner behavior (reinforced concrete structures) and where load is coming to limiting state of stress.

The Stress-strain curve of concrete under uniaxial compression suggested in Eurocode 2 is used for its most parts for the description of static damage evolution of unconfined concrete (Fig. 1). The figure 1 presents examples of stress-strain curves for linear and non-linear condition behavior of unconfined concrete. For the steel reinforcing wires is use a bilinear constitutive law.

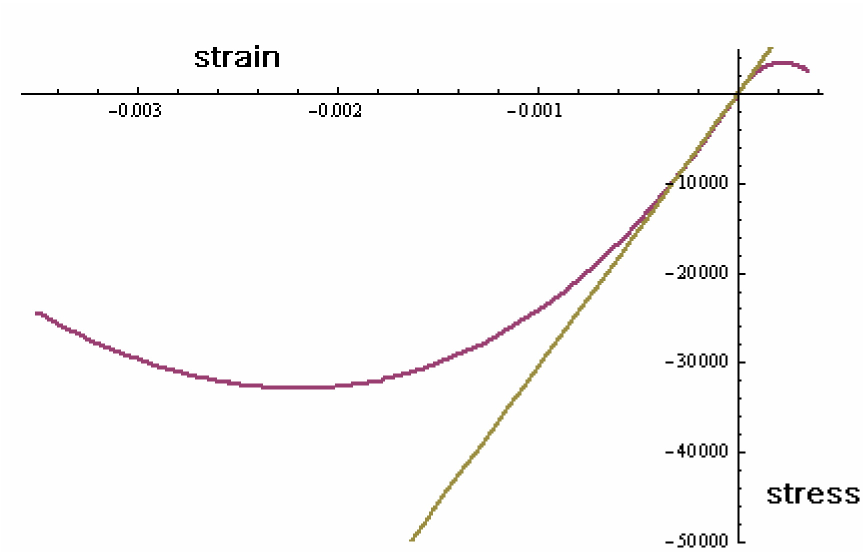

Fig. 1: Stress-strain curve of concrete under uniaxial compression

From the point of view of damage theory the dynamic behavior of concrete results from static damage evolution until cyclically reaped load, which depends on the loading history and takes into account memory effects of concrete and steel. The figure 2 presents examples of moment-curvature relationships for two states. The first example for red and thick curve represents the case of cyclically repeating bending moment which increases in time and a normal force is zero. The second curve is the same case, but normal force is -50 kN. It is inspectional the second case has higher load-carrying and it validates the fact that normal force performs an important function in strain of cross-section.

For detailed analysis of ferro-cement frame constructions was defined the non-linear calculation uses a fiber model based on realistic material models. Fiber models are very suitable to study the nonlinear behavior of reinforced concrete sections. The cross-section is subdivided into two kinds of fibers, namely, concrete fibers and steel fibers. The constitutive laws are attributed to each fiber represented by its central point.

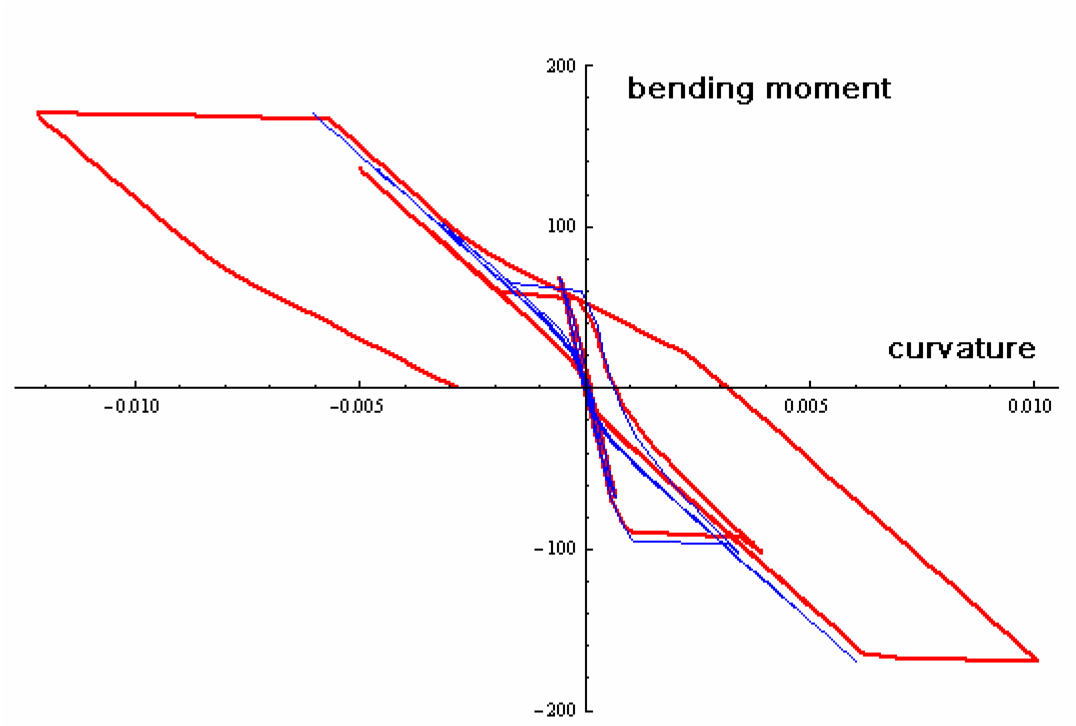

Fig. 2: Banding moment - curvature of cross-section relations for reinforced concrete material

3. Use of non-linear accesses and simplifying methods

The primary algorithms were based on requirement of definition of dynamic structure's response, frequency calculation and oscillation shapes and calculation of time depended response. Within this calculation we can observe, apart of redistribution of internal intensity based on change of tenseness, also change of oscillation shape frequency.

The non-linear dynamics analysis is impractical for solution a standard building structures. There are cases where the non-linear approach is well founded. For example structure which is excited of load causing a local damage or creating a plastic joint in the structure. The seismic load is a typical case which allows control of the inelastic response mechanism.

The concrete example of influence the non-linear analysis on response of structure is the reinforced concrete beam exciting a harmonic load f = 5 sin (10 t). The first natural frequency is 18,02 s^{-1} and for standard linear approach the ratio of the forcing frequency to the natural frequency is 0,555 and it is markedly clear of resonance. During vibration of the structure softening of structure is coming and the change of tangential stiffness of structure leads to displacement of natural frequency. The value of natural frequency decrease and the frequency ratio comes more closely to the value 1,0. This situation leads to increase of displacement and inertial forces of structure. As shown in figure 3 and figure 4, the increase can lead to creation of the plastic hinge or the damage of structure. The transient component of vibration for a non-linear solution gives more different the response of structure than a linear solution. The steady-state vibration affords the same response the structure owing to the hardening of the system. The example was solved by the Newmark direct integration method for Rayleigh damping.

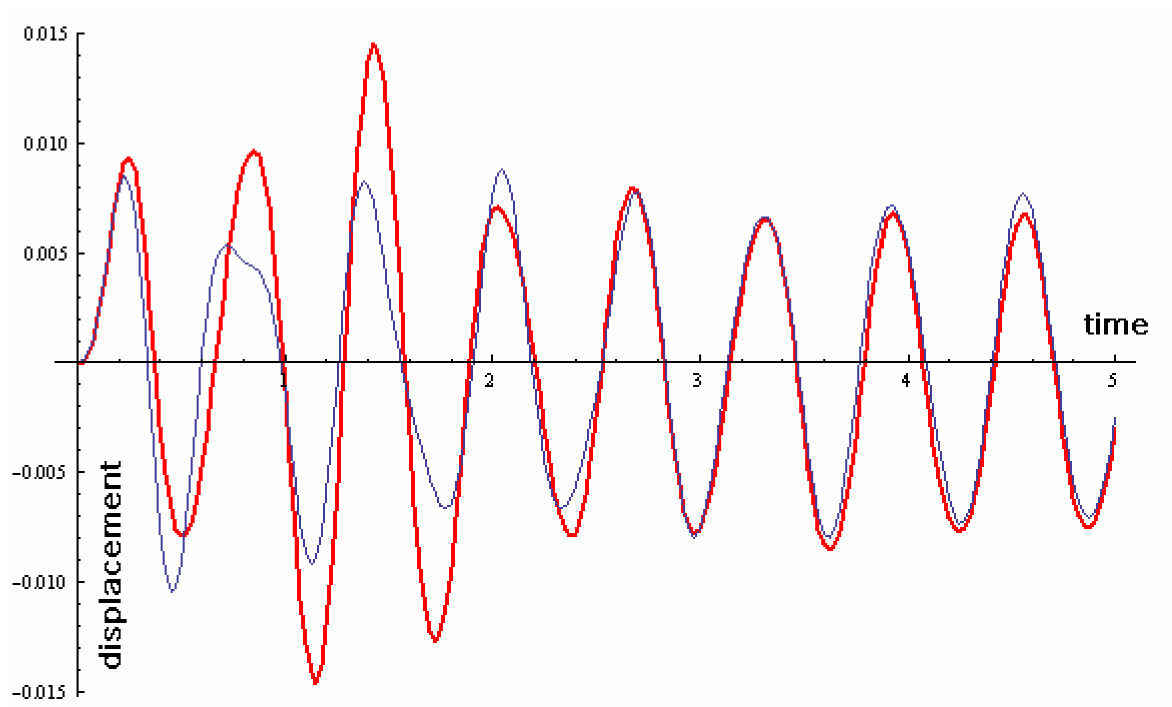

Fig. 3: Displacement of the structure in time for non-linear analysis (red and thick curve) and for linear analysis (blue and thin)

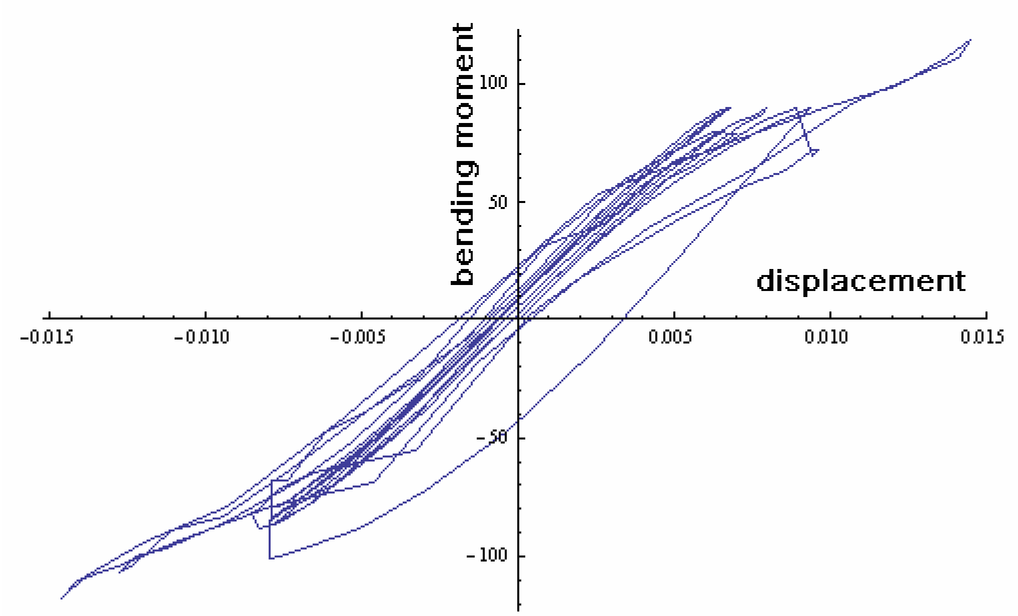

Fig. 4: Bending moment-displacement curve for non-linear analysis

The oscillation shape frequency has essential influence on a defining the size of seismic power. Because we are able to track the oscillation shape frequency (softening of structural system) we can track also the influence of this change on the size of the seismic power. Appropriate lateral load patterns are applied to a numerical model of the structure and their amplitude is increased in a stepwise fashion. A non-linear static analysis and tracking of tangential stiffness of structure are performed at each step. Knowledge of this stepwise softening can lead to the modification of modal structures properties. The changes of natural frequencies of structure have influence upon resulting value of seismic load. If we find equilibrium between softening of structure and seismic load we can give better prediction of dynamic properties of structure on the bases of state of stress than we choose estimate of ductility coefficient of structure.

The comparison of results for the direct integration method and pushover method gives the similar response of structures. The simplifying methods lead to better understanding dynamics properties of structure and provide better estimate of ductility of structure.

4. Conclusions

The simplified non-linear method, which are, like any approximate method, subject to several limitations, provide a tool for a rational yet practical evaluation procedure for building structures for multiple performance objectives. The formulation of the methods in the acceleration – displacement format enables the visual interpretation of the procedure and of the relations between the basic quantities controlling the seismic response. If we take into account the non-linear structure behavior and the reduction of seismic shake influenced by it's softening, we can strengthen the influence of the first oscillation shape given by the linear calculation to the overall structure's response. It is necessary to execute a detailed analysis of all types of structure because the influence of non-linear behavior is not possible to generalize for all types of structures.

Acknowledgement

The paper was written with the support of VZ 04 CEZ MSM 6840770005.

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