A review of code and performance based seismic design procedures of reinforced concrete high-rise building structures

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Summary

Reinforced concrete is commonly used in high-rise building construction. Performance based seismic approaches are necessary for sound design for such buildings but these present significant challenges due to reinforced concrete's (RC) complex behavior. It is intrinsically non-linear even in the elastic range due to cracking, and its ductility in flexure is strongly affected by the axial and shear loads supported concurrently.

The paper discusses the influence of modeling assumptions and analysis methods on the predicted performance of an idealized tall building, the 40 story tall RC building defined by the Los Angeles Tall Buildings Structural Design Council (LATBSDC) as a case study for application of its 2005 draft provisions[1]. This is a 126.5 meter tall reinforced concrete residential building 36 meter by 29.3 meter in plan. The lateral load carrying comprises bearing core walls coupled with 0.813 to 1.524 meter deep spandrel beams. The gravity system consists of 0.203 meter (8") thick post-tensioned concrete flat slabs supported on reinforced concrete gravity columns and bearing walls.

The paper presents the results of analysis of the building by nonlinear response history procedures in 475 and 2,475 year return period seismic events using Perform3D[2] and LS-DYNA[3] software. The significance of modelling assumptions – including the influence of the flexural stiffness of the floor slabs, and the way in which the core is modelled- are also discussed.

A key finding is that the Code approach underestimates the shear demand on the building by a substantial factor. This may invalidate the plastic rotation demand at the base of the core as the system behavior will be most likely dominated by shear. Hence, it is suspected that significantly reduced base shear response in Code design base earthquake (DBE) analysis may lead to designs which would likely fall short of satisfying 'Life Safety' objective for DBE even in cases where a dual system is utilized since stiffness of the rigid core and flexible moment frame systems will differ significantly.

Keywords: Nonlinear response history analysis, reinforced concrete, component modelling, fiber model, lumped plasticity, high rise buildings, uncertainty, core wall, LS-DYNA, Perform 3D, IBC 2006, UBC 97

1. Introduction

A performance-based philosophy has been explicitly required by regulatory authorities in Japan for buildings exceeding 60m since 1981. In China, height limits on tall buildings are set out in the Chinese code for seismic design of buildings GB50011-2001 and depend on the seismic zone, the structural material and the structural systems adopted.

United States codes such as the Uniform Building Code[5] and International Building Code[4] were developed with low and medium-rise buildings in mind. They permit only a limited number of structural systems for buildings taller than 49m in height which are not economic for buildings of

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significantly greater height, and do not include systems that are appropriate for most high rise buildings. The direct application of the standard procedures in these codes can lead to poor structural forms, relatively uneconomic structural designs and to buildings that will not perform well in moderate and severe earthquakes. Whilst these codes permit performance-based design they provide little specific guidance. The recent guidelines (as an alternate to IBC/UBC) developed in San Francisco and Los Angeles is starting to address these deficiencies.

This paper studies the significance of modeling assumptions on the performance of the building predicted by nonlinear response history analysis in 475 and 2,475 year return period seismic events.

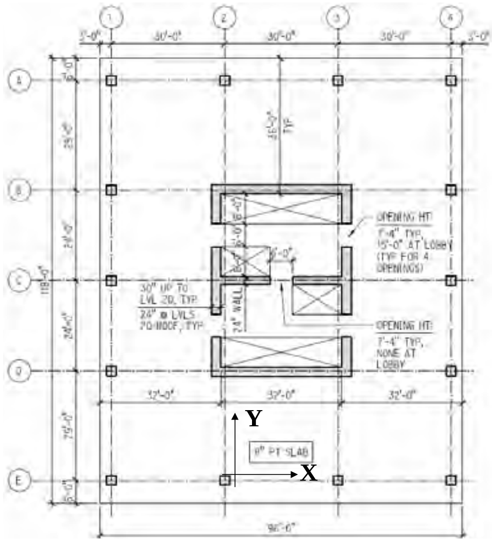

Fig. 1: Prototype building plan

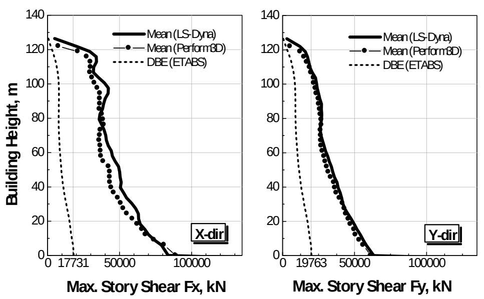

Fig. 2: Comparison of nonlinear mean maximum story shear along the building height

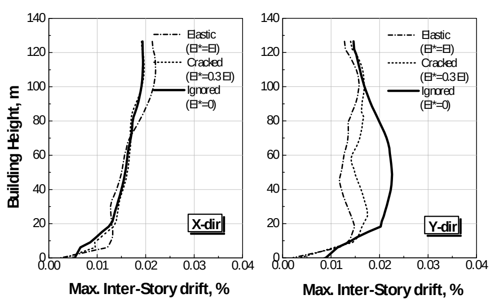

Fig. 3: Effect of flexural rigidity of Slab on nonlinear building response using LS-Dyna (MCE Chi Chi event)

2. Concluding Remarks

Non-linear response history analyses adopting different modelling techniques using LS-DYNA and Perform3D give very comparable predictions for the performance of the 40 story LATBSDC example building (Fig. 2).

A key finding is that the Code approach underestimates the shear demand on the building by a substantial factor. This may invalidate the plastic rotation demand at the base of the core as the system behavior will be most likely dominated by shear. Hence, it is suspected that significantly reduced base shear response in DBE analysis may lead to designs which would likely fall short of satisfying 'Life Safety' objective for DBE even in cases where a dual system is utilized since stiffness of the rigid core and flexible moment frame systems will differ significantly.

The study also showed that incorporating the flexural behaviour of the floor slabs into the NLTH model leads to a significant (and realistic) reduction in story drift (Fig. 3)

There is a significant scatter among the inter-story drift values obtained from different pairs of ground motions, but this is consistent with the scatter in spectral demands between the records used. There is less scatter in story shear force or bending moment, which are, to a degree, strength controlled and so less dependent on the individual input motions.