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SEVEN-STORY BUILDING SUBJECTED TO SEISMIC LOADING: EXPERIMENTATION AND MODELING

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Abstract

This article presents a research program on a structure representing a seven-story residential building tested on the shaking table in the NEES [6]. The building was designed using a displacement based capacity approach for a site in Los Angeles resulting design lateral force. The structure is composed of 2 main perpendicular walls connected by slotted connections. The numerical calculations have been made up to failure of the specimen, at the local but also at the global level, using multi-fiber beams. Constitutive laws are based on damage mechanics and plasticity to describe cracking of concrete and the plastic behavior of steel. It is shown that the model is able to describe the global behavior of the structure and qualitatively the distribution of damage at the base of the specimen

Keywords: Beam; wall; shaking table; damage; concrete

1. Introduction

Earthquakes are a major threat in seismically active parts of the world. Engineers are trying to design structures which can handle onslaughts of earthquakes. To analyze the impacts of an earthquake on a building, engineers study the building's structural performance in controlled test environments. The University of California, the Portland Cement Association of Skokie and NEES Consortium Inc [6] have participated in a research project around uniaxial shaking table test on a seven-story reinforced concrete wall building. Four tests at different intensities have been used coming from the Sylmar Medical Facility free field record. Natural accelerograms at 4 different levels obtained during 1994 Northridge Earthquake have been used (PGA = from 0.42g to 1.08g). In order to follow the evolution of the stiffness, the apparent mode has been measured after each test.

The numerical calculations have been made up to failure of the specimen, at the local but also at the global level, using multi-fiber beams. To simulate the behavior of concrete under cyclic loading a damage model with two scalar damage variables is used, one damage in tension and the other for damage in compression. Unilateral effect and stiffness recovery (damage deactivation) are also included. Inelastic strains are taken into account thanks to an

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isotropic tensor. In order to reduce computational cost we choose the Euler-Bernoulli beam theory to describe the global behavior of the structural components

2. Description of the Structure

The building has structural walls as the lateral force-resisting system. A full scale replica of the building was created (Figure 1). This is a slice of a residential building, 20 meters in height and 275 tons in weight [3], [6]. The structure is composed of 2 main perpendicular walls (web wall and flange wall) connected by slotted connections. They constitute the main skeleton of structure supporting the seven slabs. Between the level 1 et level 2, the width of walls are reduce from 20 cm to 15 cm. A pre-cast column as well as bracing are used to limit torsion behavior. The gravity columns support slabs are also present. They are considered embedded in the shaking Table.

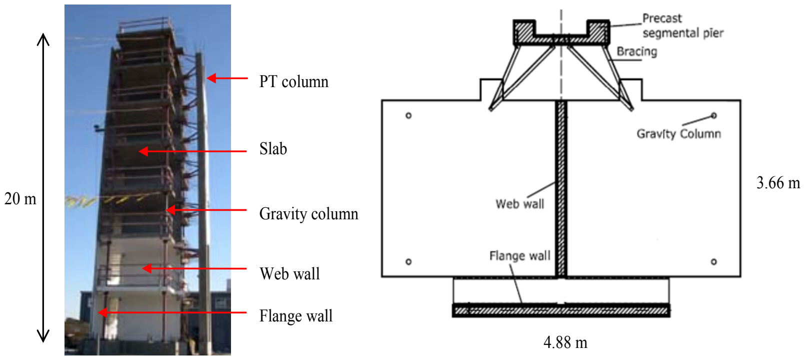


Figure 1. Geometrical data of the building

Table 1 gives the mass values of structure.

Table 1. Mass of diffrent components

	Mass [kg]
Foundation	21432.222
Slabs	101604.608
Web Wall	24947.56
Flange Wall	33263.4133
PT column	30158.1981
Gravity Columns	4717.3568
Braces	181.4368

Only the directional Y (parallel to the web wall) was applied to the shaking table successively with amplifying magnitude of acceleration. Four tests at different intensities (from EQ1 test to EQ4 test) have been used coming from the Sylmar Medical Facility free field record obtained during 1994 Northridge Earthquake. The different sequences are presented in Figure 2.

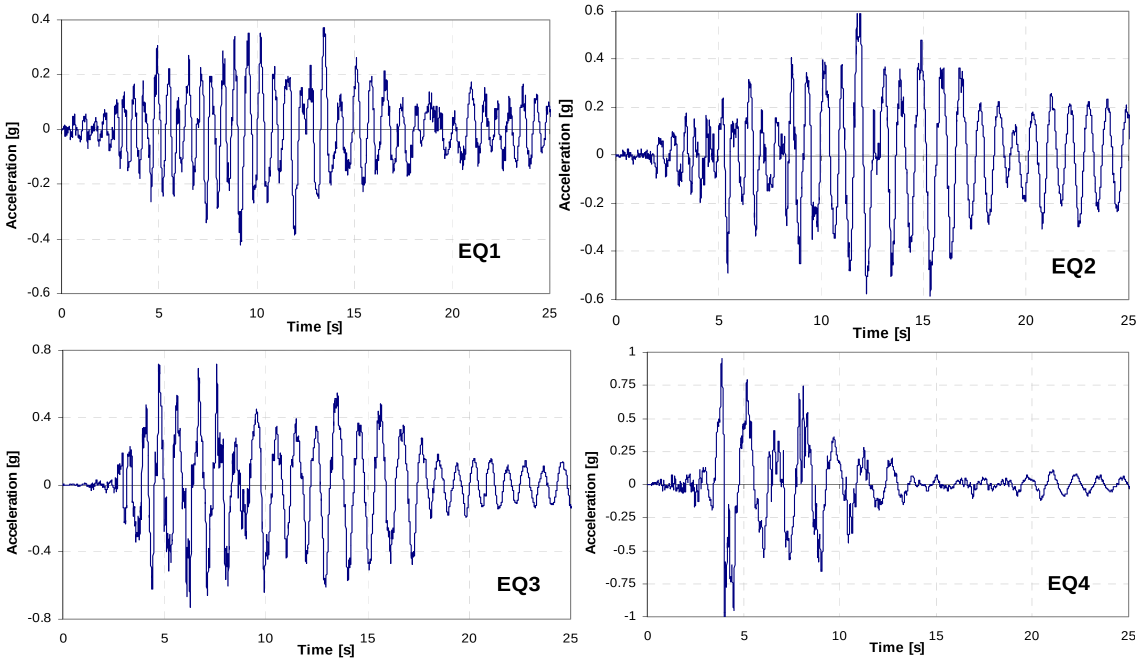


Figure 2. Sequences used for the analyses

During each test, global and local measurements were made (displacements, accelerations, moments…) The apparent mode has been measured after each test to follow the evolution of stiffness. Detailed information on the experimental program and results can be found in [6].

3. Numerical Simulation

Non-linear dynamic analysis of civil engineering structures requires large scale calculations. The necessity to perform parametrical studies led us to adopt a simplified approach in order to reduce the computational cost. In this paper the performance of simplified modeling strategies to simulate the non linear behavior of reinforced concrete structure is presented. The structure is modeled using multi-fiber beam elements and so the number of degrees of freedom of the mesh is reduced [5], [7], [8]. The user can define at each fiber a material (in our case concrete or steel) and the appropriate constitutive relation (Figure 3). Using an Euler Bernoulli formulation the shear deformations are not modeled so we can use 1D version of the non linear constitutive laws in the fibers (torsion is also kept linear). The finite element code used is Aster [1, 2].

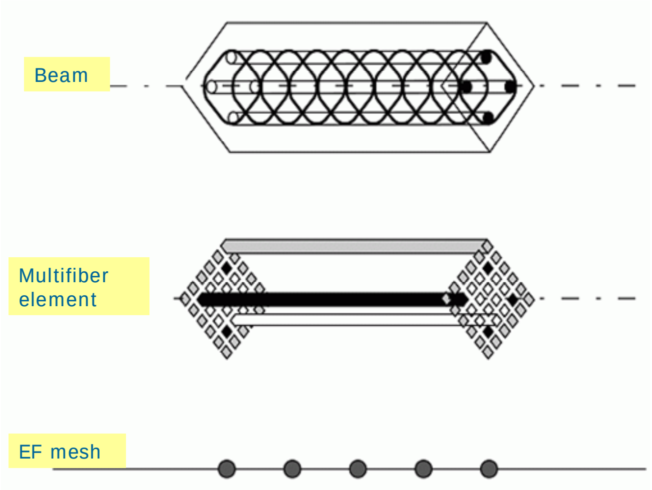


Figure 3. Multi-fiber beam element

The finite element mesh is presented in Figure 4. The 2 walls are modeled with 22 multi-fiber Euler Bernoulli beam element. Each section of walls is divided into 80 fibers. The pre-cast segmental piers (PT column), the bracing system and the slotted connections are simulated by linear bar elements. The gravity column not taken into account into the numerical model. The shaking table has been reproduced using a horizontal elastic beams. The weight load of each floor are concentrated at each storey. The torsion stiffness is constant during the whole computation. The adherence between steel and concrete is assumed perfect. Assuming a 2% critical damping factor for the first and second vibration mode, the damping parameters α and β were calculated and used subsequently to form the Rayleigh damping matrix [C]= α[M] + β[K], M and K being the mass and stiffness matrix.

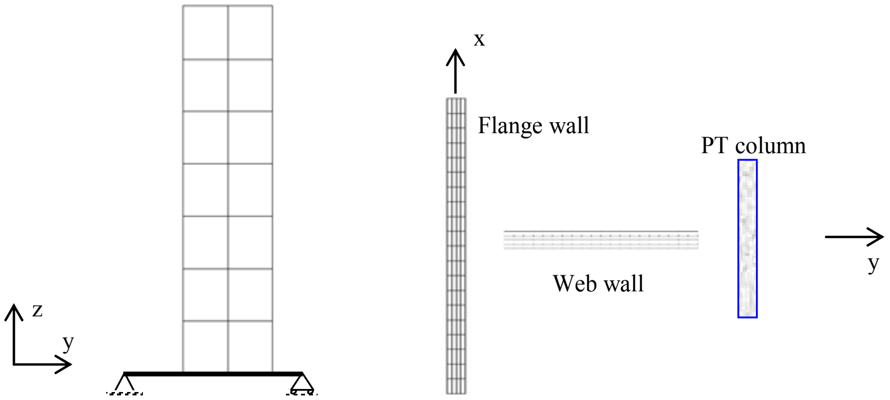


Figure 4. Finite element mesh

The reinforcement steel is modeled with an isotropic cinematic hardening law. Constitutive model for concrete under cyclic loading ought to take into account some observed phenomena, such as decrease in material stiffness due to cracking, stiffness recovery which occurs at crack closure and inelastic strains concomitant to damage. To simulate this behavior we use a damage model with two scalar damage variables one for damage in tension and one for damage in compression [4]. Unilateral effect and stiffness recovery (damage deactivation) are also included. Inelastic strains are taken into account thanks to an isotropic tensor.

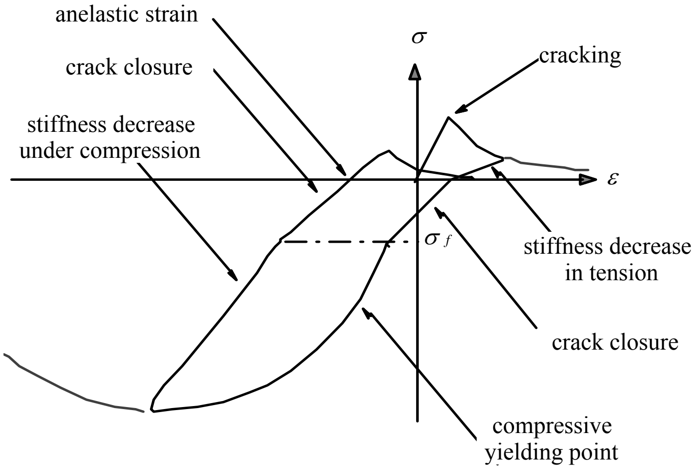


Figure 5. 1D cyclic response of the La Borderie model

4. Main Resultants

The numerical results at the X and Y direction for the sequence T6 of the experimental program are presented in Figures 7 and 8. Due to an unreliable displacement transducer at the top of the specimen comparison of displacements is presented only at the fifth floor. Simulation predicts satisfactory the maximum displacement especially in the X direction-where the loading was more severe - and there is no shifting between the curves.

For the model, the damage variable used in the uniaxial constitutive law for concrete (Figure 5) vary normally between 0 (non damaged section) and 1.0 (completely damaged section). By filtering their values between 0.8 and 1.0 we omit the micro-cracks and we have an image of the bigger cracks of the model. Figure 12 presents the damage pattern due to tension at the end of the calculation for the EQ4 test. Main damages are located at the base of the structure. This is in accordance with the local behavior observed experimentally (Figure 13).

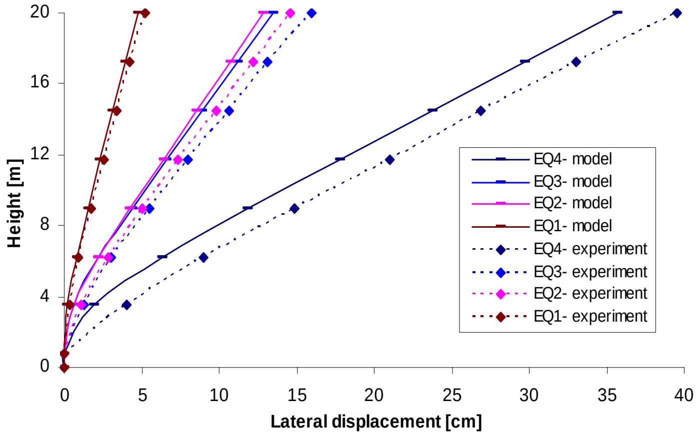


Figure 6. Maximum lateral displacement 4 tests

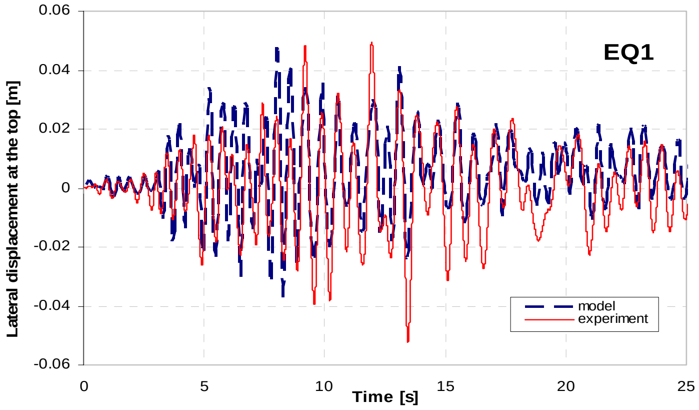


Figure 7. Comparison between calculated and measured lateral displacement for EQ1

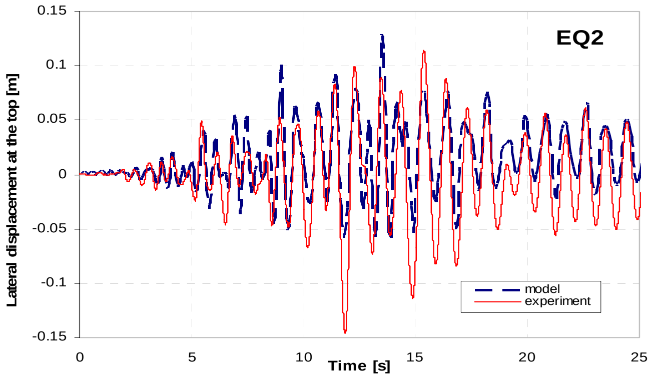


Figure 8. Comparison between calculated and measured lateral displacement for EQ2

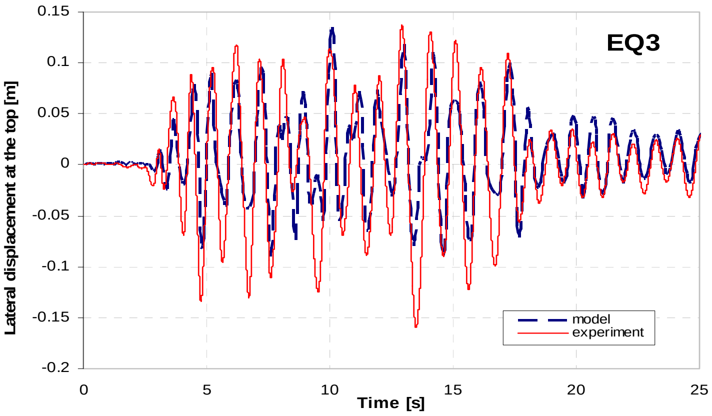


Figure 9. Comparison between calculated and measured lateral displacement for EQ3

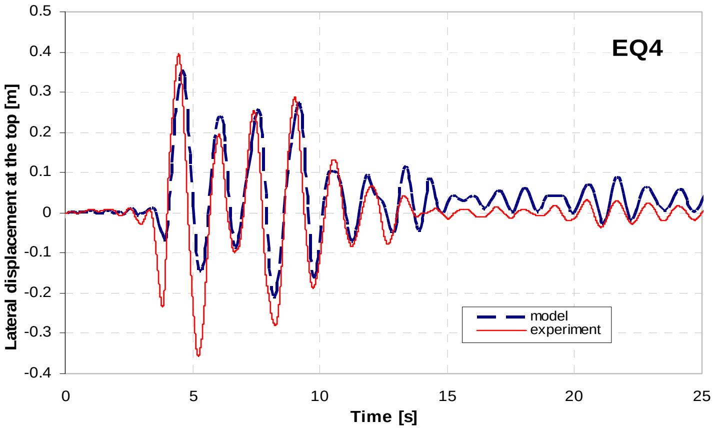
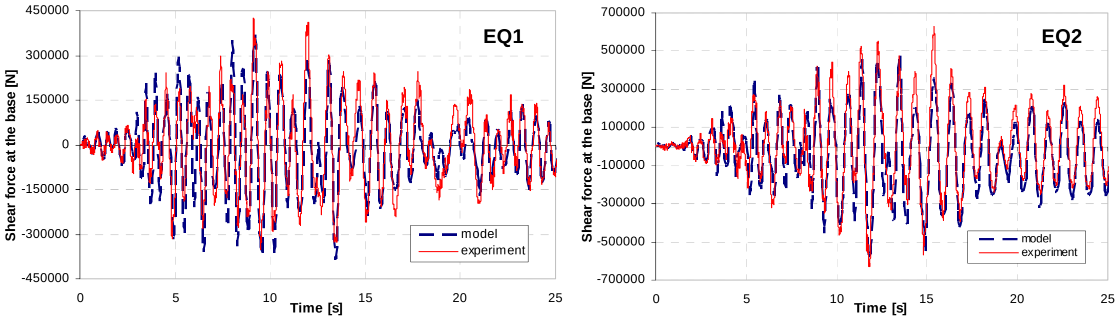


Figure 10. Comparison between calculated and measured lateral displacement for EQ4



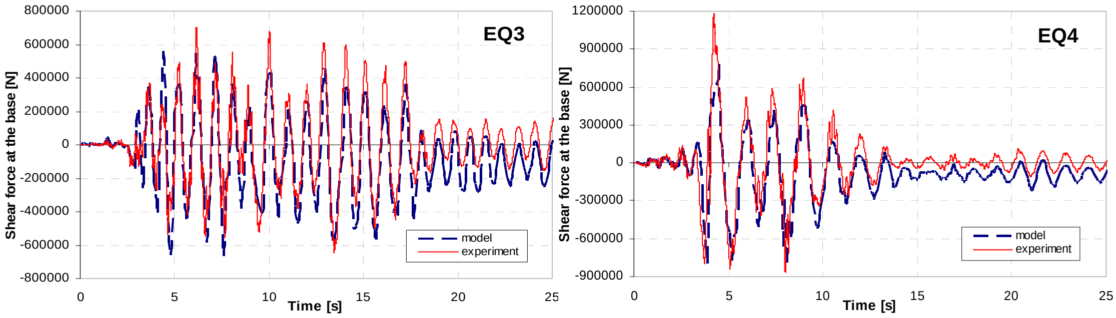


Figure 11. Shear force at the base of structure

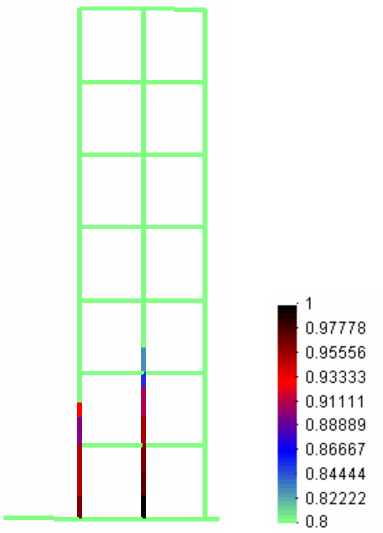


Figure 12. State of damage for EQ4 test

Figure 13. State of damage for EQ4 test

6. Conclusions

This work investigates the simplified modeling strategy to simulate non linear behavior of a seven-story residential building tested on the shaking table. The simulation is performed using Euler- Bernoulli multi-fiber beam elements that provide a compromise between numerical cost, quality of results and facility of modeling.

As demonstrated by the results presented in the paper, the model was able to reproduce with good approximation the response of the structures. This confirms that the level of the discretisation and the type of numerical elements adopted in model are sufficient to describe the non linear behavior of the R/C structures subjected to severe ground motion. This is so also thanks to the stress-strain laws chosen to model the behavior of concrete and steel.

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