Simplified Modeling Strategies for non linear dynamic calculations of RC structural walls including Soil-Structure Interaction

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Abstract

This paper presents "blind" numerical calculations using multifiber beam elements, damage mechanics and plasticity constitutive laws. The calculations were performed in laboratory Sols Solides Structures-Risques (3S-R) in order to participate to two international benchmarks (NEES and SMART 2008) dealing with the non linear dynamic behavior of reinforced concrete structural walls tested on shaking tables. A numerical tool for simulating Soil-Structure Interaction (SSI) is also presented. The new element is based on the "macro element" concept and it is used to perform parametrical studies on the NEES structure considering different types of soils.

1. 7-story building (Benchmark NEES): Numerical modeling and influence of SSI

The University of California at San Diego (UCSD), the Portland Cement Association (PCA) of Skokie, IL., and the NEES Consortium Inc (NEESinc) have performed a seismic research project around an uniaxial shaking table test on an embedded mock-up representing a full-scale vertical slice of a seven-story reinforced concrete wall building. The specimen is composed of two perpendicular walls linked with slotted connections and it is considered embedded on the shaking table (NEES [8]).

Multifiber Timoshenko beam elements are used to reproduce numerically the experimental behavior of the structure (Kotronis and Mazars [5]) (Figure 1). The constitutive models used are: La Borderie [6] damage model for concrete and Menegoto-Pinto [7] model for steel. Concentrated masses are considered at each floor taking into account the mass of the corresponding slab and the upper and lower part of the wall. Calculations have been performed with FEDEASLab developed at UC Berkeley.

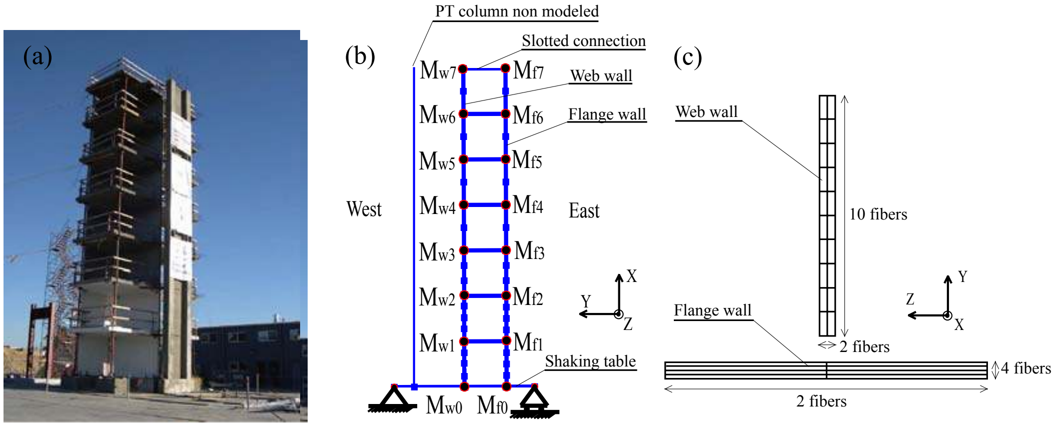


Figure 1: Photo of the NEES building and multifiber mesh

It is shown that the modeling strategy describes accurately the global behavior of the structure (figure 2) and qualitatively the distribution of damage.

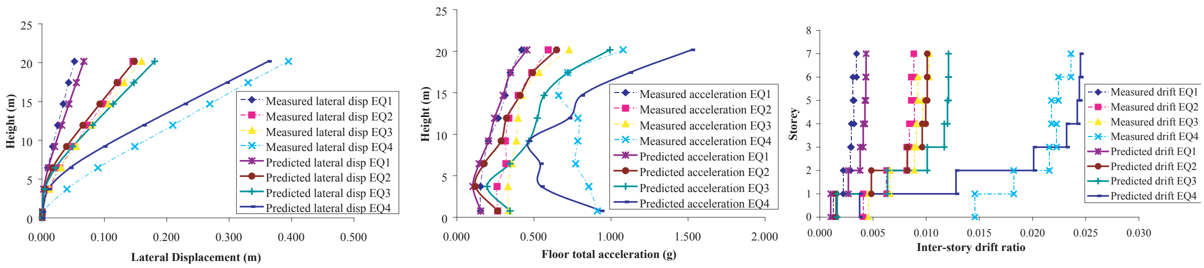


Figure 2: NEES building - Maximum lateral displacements, accelerations and inter-story drift ratio at different levels of the structure for 4 sequences, comparisons between experimental (dotted lines) and "blind" prediction numerical results (continuous lines).

Moreover, this simplified approach helps reducing computational costs. It appears now possible to use this kind of modelling strategy to investigate numerically the behaviour of a wider variety of configurations that is practically impossible to study experimentally. Following this remark we investigate hereafter the influence of SSI on the behaviour of the NEES structure for 5 different types of soils going from very low characteristics soil (soil 1) to very high characteristics soil (soil 5).

The NEES structure is considered now posed on a new SSI macro element taking into account plasticity of the soil and uplift of the foundation (Grange [1], Grange *et al.* [2]). In other words, the structure is supposed to have a rigid shallow and rectangular foundation lying on the soil (dimensions 4.5m x 2.8m).

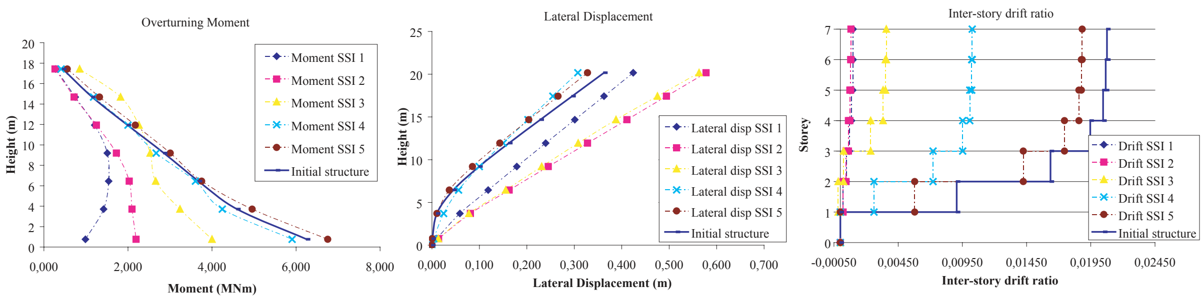


Figure 3: NEES building - Maximum overturning moments, lateral displacements, and inter-story drift ratio at different levels of the structure for the sequence EQ4, for the 5 different soils (dotted lines) and the structure considered embedded on the shaking table (continuous lines).

Results show that SSI decreases the forces at the base of the building (figure 3) and changes the influence of the higher modes. Using the Karhunen-Loéve method (Gutiérrez and Zaldivar [4]) one can perform a modal decomposition and show that mode 2 is preponderant for soils 1 and 2 but mode 3 influences mainly the behavior of the structure lying on soil 3. This change in the behavior can lead to a concentration of damage at the upper levels of the building, develop smaller lateral displacements but more important residual forces.

3. Benchmark SMART 2008: Numerical modeling

In the last years, a large number of dynamic experimental tests have been performed on structural elements or entire structures. However, the investigation of 3D-phenomena (like torsion) is rare. This is the context of the "SMART 2008" benchmark (Seismic design and best-estimate Methods Assessment for Reinforced concrete buildings subjected to Torsion and non-linear effects [9]) organized by the Comissariat à l'Energie Atomique (CEA Saclay, France). The purpose is to study the behavior of a non symmetrical building (Figure 4) at a scale ¼ under seismic loading applied thanks to the shaking table of CEA. The strategy adopted in 3S-R to model the structure is the use of Timoshenko multifiber beams (Figure 4) associated with constitutive laws based on damage mechanics for concrete and plasticity for steel. This choice allows reducing considerably the time of calculation without loosing access to information needed in order to analyze the behavior of the structure (displacements, base forces, stresses, strains, damage…). Calculations have been performed with the Finite Element Code Cast3m (version 2007) developed by CEA.

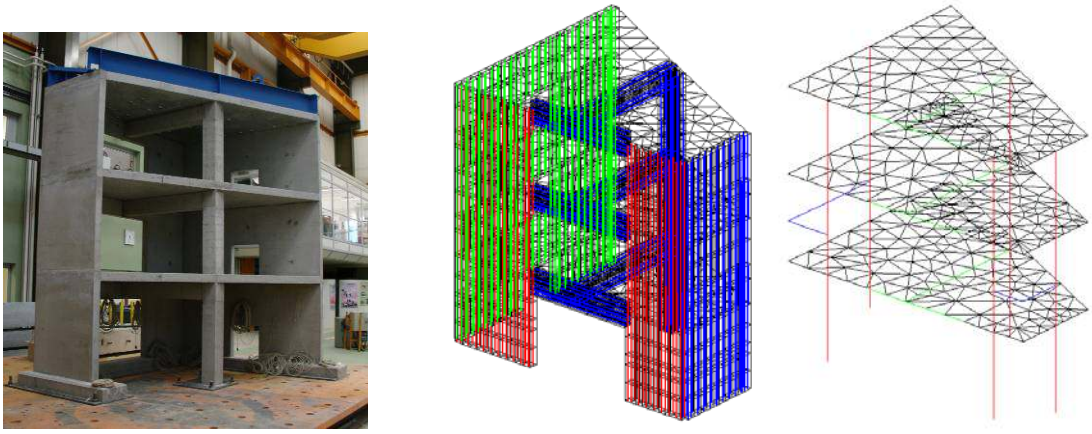


Figure 4: Photo of the SMART 2008 building and multifiber mesh

The different walls, the columns and the beams are represented by Timoshenko multifiber beams (Guedes *et al.* [3]) with La Borderie [6] damage model for concrete and Menegoto-Pinto [7] model for steel. The floors are represented by shell elements having a linear behavior. The links between the walls are reproduced through a rigid element between the first and the second floor.

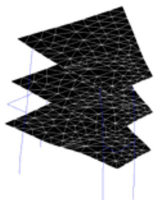
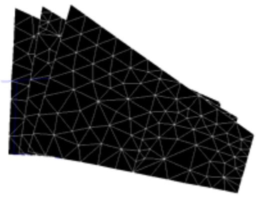
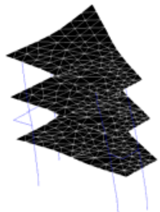
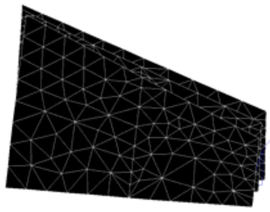
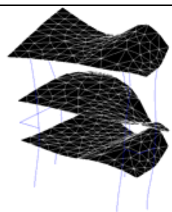
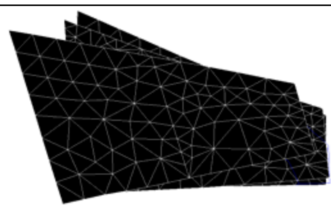
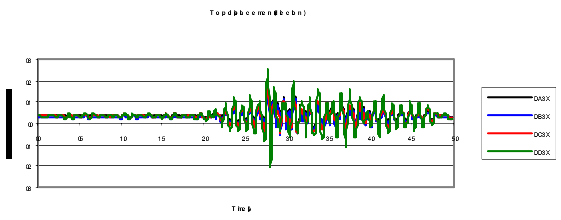
1er mode F = 9,96 Hz		
2nd mode F = 16,01 Hz		
3ème mode F = 32,21 Hz		

Figure 5: The first three modes of the SMART 2008 structure

The different modes of vibration of the structure (Figure 5) present the same tendency as the ones that have been obtained with more complex modeling strategies (i.e. multilayer shell elements, 3D elements). The evolution of the displacement at the top of the structure (Figure 6) under a provided earthquake sequence is presented in (Figure 7, "blind" results).



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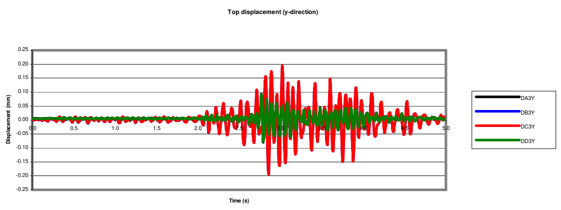
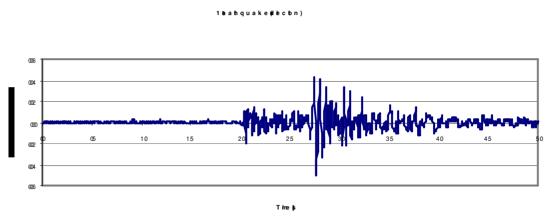


y-direction

Figure 6: SMART 2008 structure - Top displacement



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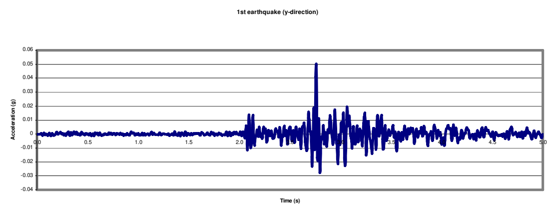

y-direction

Figure 7: Earthquake loading (0.05g)

The entire calculation for the 13 loading sequences provided by the organizers of the benchmark needs only 2 or 3 days with a recent computer whereas it can take several weeks for a multi-layer shell modeling and even more for 3D-element. Although 3D behavior like torsion and interaction between elements of the structure are still points that can be improved, Timoshenko multifiber beams are definitely an important tool for the practical engineer for the next years. The experimental campaign on the structure is scheduled by the beginning of July 2008.

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