Development of the UPRM hybrid simulation facilities: Substructuring techniques

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Abstract

Dynamic analysis is important to describe the real behavior of the structure subjected to dynamic loads as wind, traffic, blast, machinery and earthquakes. Puerto Rico is located in a high seismicity zone so that seismic analysis is essential to predict possible damages on structures and implement methods to prevent them. Nowadays, in Puerto Rico there are not enough facilities to conduct dynamic analysis of structures. For this reason, it is being implemented a hybrid simulation facilities at University of Puerto Rico at Mayagüez. These facilities increase the research potential in in structural and earthquake engineering allowing to performed more accurate dynamic tests and analyze more realistic prototypes. Hybrid simulation is a technique that combines physical measurements and analytic models for evaluating the dynamic performance of structures subjected to earthquake loads. This method allows to model most of the structure analytically and test a part of interest physically in the laboratory. The hybrid facility will be calibrated with the analysis of a 3-story 2-bays steel frame subjected to a Canoga Park seismic record. Exterior columns of the first two stories will be tested in the laboratory at a 1:4 scale while the rest of the structure will be modeled analytically using the software OpenSees and OpenFresco. Fully numerical coupled simulations were executed to obtained reference results that can be used to validate laboratory tests. This research is focused on three cases of coupled simulations: 1) one-story hybrid with conventional substructuring technique (CS), 2) one-story hybrid with pinned substructuring (PS), and 3) one-and-a-half story hybrid with pinned substructuring technique.

Objectives

- Implement hybrid simulation facility at UPRM.
- Test more realistic prototype and improve the accuracy of dynamic tests
- Performed coupled simulations to evaluate the effectiveness of different substructuring techniques.
- Obtained reference results so that laboratory test can be compared.

Introduction

- Hybrid simulation is a technique that combines physical measurements and analytical models for evaluating the dynamic performance of structures, usually subjected to seismic loads.
- Depending on the loading rate, hybrid simulation can be quasi-static for a step-by-step applied displacement, or real-time for a one-to-one time scale loading protocol.
- This method exhibits some advantages compared with other methods like conventional quasi-static and shake table.
  1. Detailed observation of specimen to capture local behavior
  2. It allows to model from a small to full scale
  3. More economical

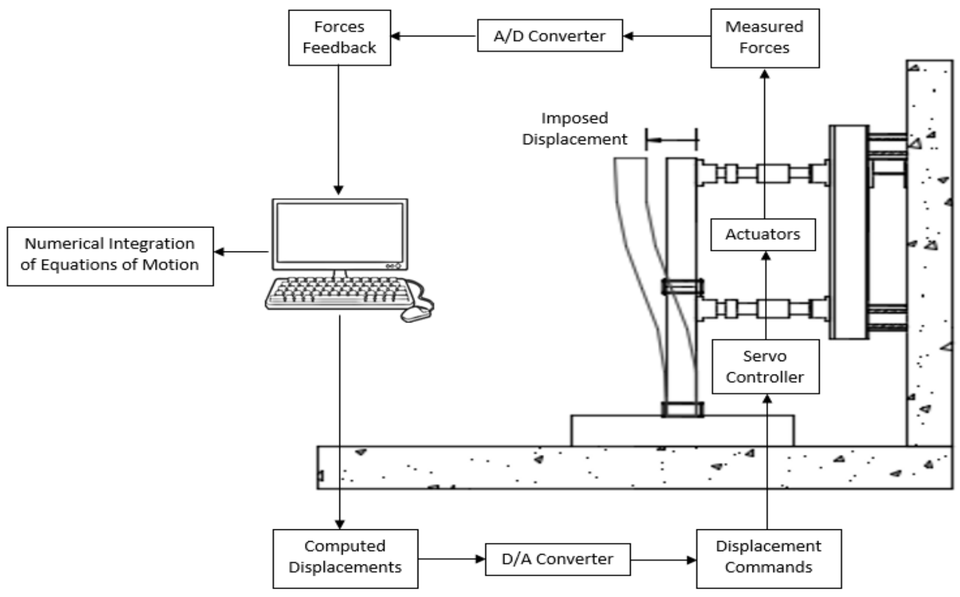


Figure 1. Hybrid simulation concept

Methodology

- Numerical analysis is performed for prototype model to obtain the global and local response of the structure.
- The prototype structure is divided into numerical and experimental substructures.
- Both numerical and experimental substructures are analyzed using the softwares OpenSees and OpenFresco.
- Coupled simulations were performed for two substructuring techniques: conventional substructuring technique (CS) and “pinned” substructuring technique (PS).
- Coupled simulation are compare with the prototype without partitioning.

Prototype Description

- The prototype is a 3-story 2-bay steel moment resisting frame modified from [2].
- Sections for beam-column elements are shown in Fig. 4a.
- Dimensions are 30 ft (9.14 m) per bay and story height of 15 ft (4.57 m).
- Concentrated plasticity is used from modified IK deterioration model [1].
- A 5 % damping ratio, NewmarkHSFixedNumIter integrator and a FixedNumIter test with 6 iterations are used in the analysys.

The following figures shows how hybrid simulation works combining the analytical and experimental substructures.

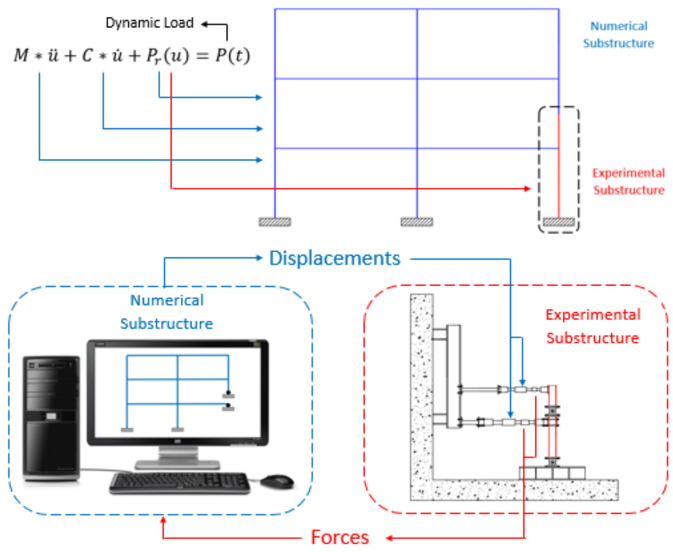


Figure 2. Hybrid simulation with analytical and experimental substructures.

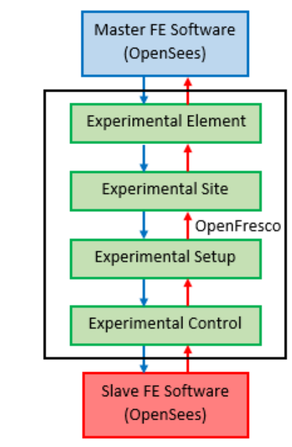
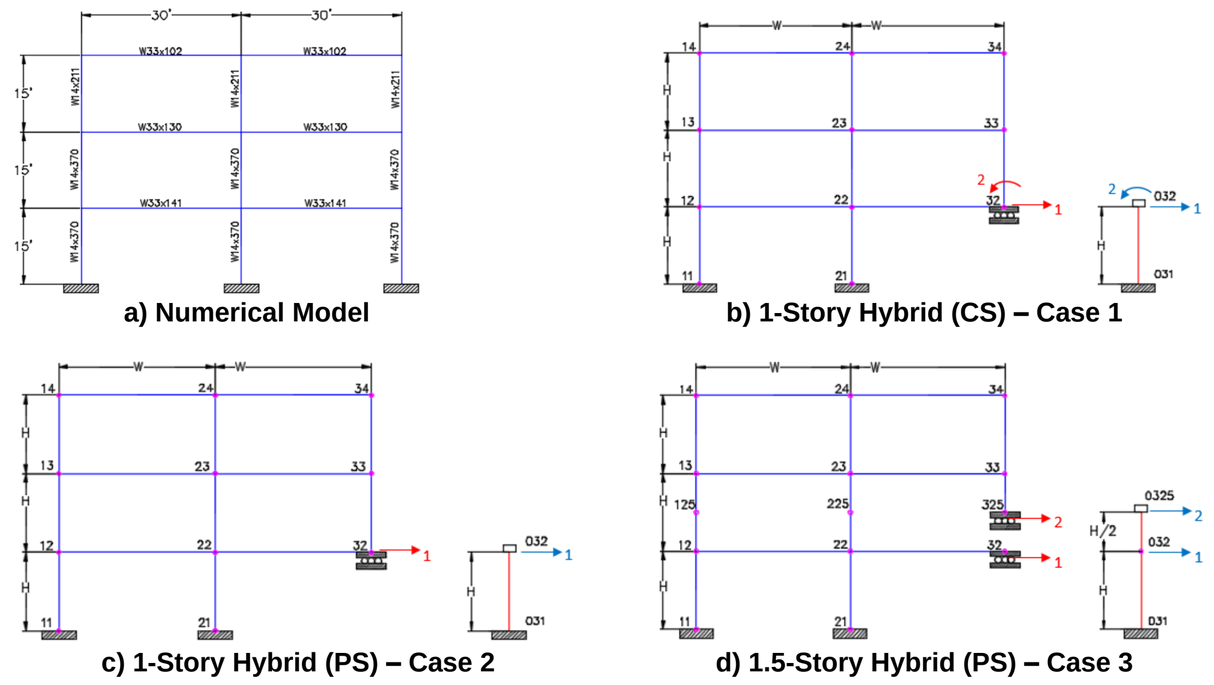


Figure 3. Simulating experimental substructure in finite element software

The following figure shows the numerical model and the coupled simulation with its substructuring techniques.



a) Numerical Model

b) 1-Story Hybrid (CS) – Case 1

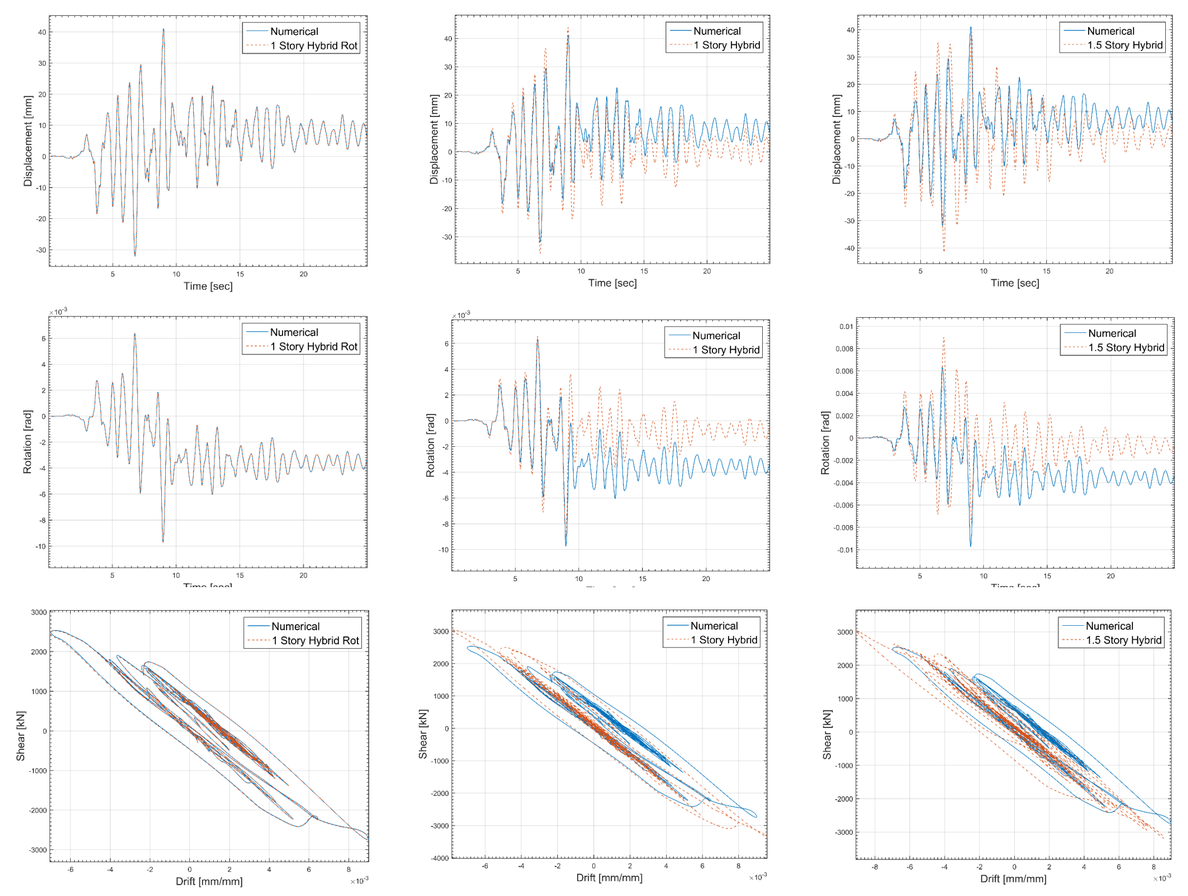
c) 1-Story Hybrid (PS) – Case 2

d) 1.5-Story Hybrid (PS) – Case 3

Figure 4. Numerical model and coupled simulations.

Results

Results obtained from each substructuring technique are compared with the fully numerical response.



Discussion and Conclusions

- Case 1 provided excellent results for both global and local response because both displacement and rotation are transferred.
- Cases 2 and 3 show a big difference after peak values where reached.
- Results from Cases 2 and 3 demonstrate that better methods are needed for more accurate analysis. These methods should be such that improve results while at the same time maintain a less complex experimental substructure (required actuators)

Ongoing and Future Works

- Performed hybrid simulation testing the experimental substructure physically in the laboratory.
- Test specimens at larger scales and more complex configurations.
- Test different types of structures as military infraestructure.
- Develop new substructuring techniques to minimize errors.

References:

[1] Lignos, D. G., and Krawinkler, H. (2009). “Sidesway Collapse of Deteriorating Structural Systems under Seismic Excitations,” Technical Report 172, The John A. Blume Earthquake Engineering Research Center, Department of Civil Engineering, Stanford University, Stanford, CA.

[2] Del Carpio Ramos, M., (2013). “Hybrid simulation of the seismic response of a steel moment frame building structure through collapse”. Ph.D. Thesis, University of New York at Buffalo, New York.