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PHASE II OF THE ASCE BENCHMARK STUDY ON SHM

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ABSTRACT

The task group on structural health monitoring of the Dynamic Committee of ASCE was formed in 1999 at the 12th Engineering Mechanics Conference. The task group has designed a number of analytical studies on a benchmark structure and there are plans to follow these with an experimental program. The first phase of the analytical studies was completed in 2001. The second phase, initiated in the summer of 2001, was formulated in the light of the experience gained on phase I and focuses on increasing realism in the simulation of the discrepancies between the actual structure and the mathematical model used in the analysis. This paper describes the rational that lead the SHM task group to the definition of phase II and presents the details of the cases that are being considered.

Keywords: Damage Localization, Structural Health Monitoring.

INTRODUCTION

Identification of damage from the analysis of vibration signals has received significant attention in the civil, mechanical and aerospace fields. The problem most commonly considered is that where data is recorded at two different times and it is of interest to determine if the structure suffered damage in the time interval between the two observations. The behavior of the system during the observation periods is typically assumed linear and the damage is identified as changes in system parameters. A solution can be obtained in principle by using the measured data to optimize a model of the structure in the two states and inspecting the differences. In practice, however, a solution is difficult because: a) the real structure is always more complex than the mathematical model selected b) the measured data is limited and imprecise and c) the number of system parameters is typically so large that the inverse problem posed is ill-conditioned.

Many techniques that try to circumvent or minimize the difficulties listed previously have been proposed (Doebling 1997). Examination of the literature reveals, however, that the assumptions used to establish the various approaches vary widely and it is unclear what is the true capability of the current state of the art in damage detection of civil engineering structures. In an attempt to address this situation the Dynamics Committee of ASCE formed a task group on

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Structural Health Monitoring in 1999. The strategy adopted by the task group was to explore the damage identification problem with techniques selected by the participants but with the focus placed on a common structure and a set of common clearly defined assumptions.

Phase I of the Analytical Study on the Steel Building Benchmark

The first benchmark structure selected, as depicted in fig.1, is a 2-bay by 2-bay, 4-story steel frame owned by the university of British Columbia (Black and Ventura 1998). The study on phase I included an examination of data generated with a 120 DOF model and with a 12 DOF shear building model of the structure. Cases with known and unknown input and damage scenarios including symmetrical and unsymmetrical loss of stiffness in the bracing system were considered. Complete details of the damage cases, input excitation and other pertinent aspects of the study of phase I can be found in Johnson et. al. (2000). Interim reports on the work from the various groups that participated in this phase were presented at the 14th Engineering Mechanics Conference and the final documentation is expected to appear as part of a special issue of the *Journal of Engineering Mechanics.*

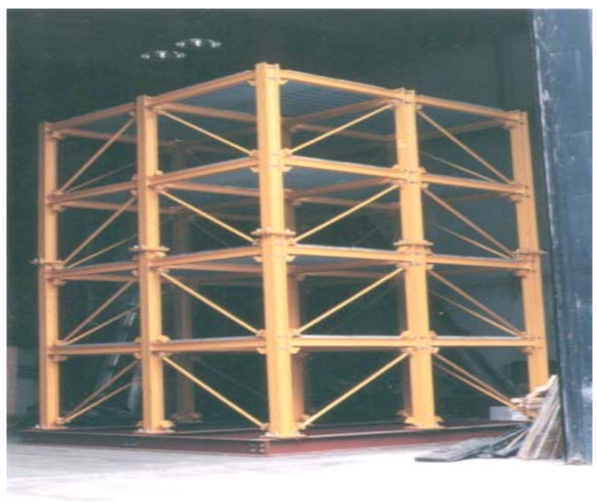

Fig. 1 The benchmark structure

Motivation for Phase II

Experimental data on the benchmark structure was collected in the summer of 2000. The data was analyzed and the results discussed by some members of the SHM task group at the joint meeting of ASME-ASCE that took place in San Diego in the summer of 2001. Following discussion and assessment of the results obtained, the consensus of the SHM Task Group was that moving the research focus to the analysis of experimental data was premature. In particular, it was decided that there had not been sufficient investigation of the problem in the controlled environment of simulations and that, without these studies, one would not be in a likely position to affect real progress. It was decided, therefore, to formulate a phase II of analytical work.

DEFINITION OF PHASE II

The essential feature of the work in phase II is improvement in the simulation of discrepancies between the ‘truth model’ and the analytical model defined by the user. In phase I this discrepancy was either nonexistent or forced by requiring that the analysis be carried out using a shear building model while the data to be analyzed was generated with a 120 DOF model obtained by initially allowing 6 DOF at each joint and then imposing the constraint that the floors are rigid in the horizontal plane. In phase II the situation considered is somewhat less contrived. In particular, the user in this phase is given the freedom to model the structure as he or she desires but the parameters that are used to define the truth model (the model that generates the simulated data) differ from the nominal values available to the user. For example, while the nominal structure has a center of mass that is located in the geometrical center of the floor plan, the location of the center of mass in the truth model has an eccentricity with respect to the geometric center that varies from floor to floor.

In all, 4 sets of parameters were treated as deviating from the nominal values that are available to the analyst, these are:

- *Mass Values:* The masses in the truth model deviate from the nominal by a factor that was selected at random from a uniform distribution having upper and lower limits of 1.1 and 0.9.
- *Position of the Center of Mass*: The nominal position of the center of mass in each story is at the geometric center of the floor plan. The actual position in the truth model, however, is shifted in each direction by an amount equal to α b, where b is the plan dimension (2.5m) and α was selected at random from a uniform distribution having upper and lower limits of –0.1 and 0.1.
- *Stiffness of the Bracing Elements*: The nominal axial stiffness of the bracing elements is the same throughout the structure. In the truth model, however, the stiffness was taken equal to the nominal value times a factor that, for each brace, was selected from a uniform distribution having upper and lower limits of 0.9 and 1.1.
- *Rotational Stiffness of the Beam-Column Connections*: The bolted connections between the beams and the columns in the benchmark structure are far from rigid. In contrast with the parameters on the three previous sets, modeling error from connection flexibility derives not only from the variability from one connection to the next but also from the fact that the nominal value of the rotational flexibility is not easily established from an examination of the connection details (and is thus unknown to the analyst). In the truth model used in phase II the flexibility of the connections from beams to columns is modeled explicitly by incorporating rotational springs at the end of each beam element. The nominal value of these springs was selected to match the first modal period of the benchmark structure obtained experimentally with all the braces removed. The stiffness of each connection was then taken as the nominal value times a factor selected from a uniform distribution with limits of 0.75 and 1.25. It’s worth emphasizing that in this case the user knows that the truth model has semi-rigid connections but has no information on what is the mean value of the rotational stiffness.

We conclude this discussion by noting that while the truth model incorporates variability, the parameters selected do not change from one simulation to the next.

Cases Considered

Phase II examines damage in the bracing and in the connection of the beams to the columns of the frames. When damage in the bracing system is contemplated the healthy reference is the fully braced structure. For beam-column connection damage the healthy state is taken to be the fully unbraced structure. The cases considered in phase II are outlined in Table 1.

Table 1. Cases Considered in Phase II

Case*	General Description	Members Affected (see Fig.2)
RB.fs	Nominal Healthy State for the Braced Condition	---------
DP1B.fs	50% loss of stiffness on 2 braces (1 brace on each of the two perimeter frames in the strong direction in the first level).	br1, br6
DP2B.fs	Same as DP1B but only 25% loss of stiffness	br1, br6
DP3B.fs	Same as DP1B and, in addition, 25% loss of stiffness on two braces on level 3 (1 on each perimeter frame, also in the strong direction).	br1, br6, br17, br22
RU.fs	Nominal Healthy State for the Unbraced Condition	-----------
DP1U.fs	Loss of rotational stiffness at 3 connections in the beams of level 1 in the perimeter frames in the strong direction and 2 connections in level 2.	b1-r, b2-lr, b5-r, b6-lr b14-lr, b18-lr
DP2U.fs	Two failed connections at level 1.	b2-lr, b6-lr

* The extension fs stands for full sensors. In these cases the user is provided with acceleration data obtained at 4 locations in each floor (see fig.2). The 5 cases listed are also to be repeated assuming that sensors are available only at the 2nd and 4th floors. For these the extension is changed from fs to ps (partial sensors).

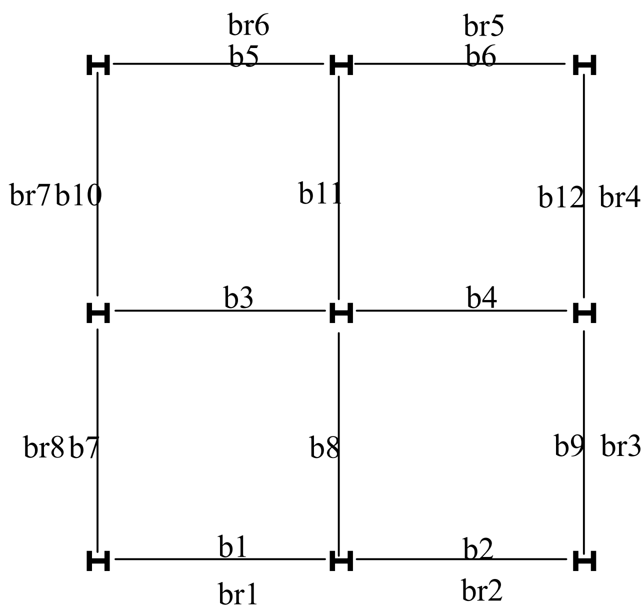

Fig.2. Numbering for beams and braces for level#1. In level#2 the first beam is b13 and the first brace br9 and so on (l and r stand for left and right).

Note that the cases considered in phase II are all nominally symmetric in both the reference and the damaged state and that the damage is always in the frames in the strong direction. The excitation is modeled as independent stationary white noise acting at the geometric center of each floor in each of the two horizontal directions (a total of 8 load vectors). White noise with an RMS equal to 10% of the RMS of the strongest signal is added to each one of the output channels. The load is assumed unknown to the user. While it is realized that modeling ambient excitation using stationary white noise is too optimistic (since the ambient excitation will not be rich at all frequencies of interest and may not be stationary) it was decided to proceed with this simple loading model because justification for a more complex one did not appear evident at the time the decision had to be made. The question of how to model ambient excitation in a more realistic fashion is one of the topics in the SHM Task Group research agenda.

CONCLUDING REMARKS

A second phase of the 4-story steel benchmark structure selected by the Task Group on SHM of ASCE has been defined. The first sets of results obtained by the participating groups appear in other papers of this conference. Details on the SHM task group activities and information for those that would like to participate in future work can be found at the group's web site http://wusceel.cive.wustl.edu/asce.shm/.

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