MODAL PERFORMANCE FACTOR TESTING PROCEDURE FOR BASE ISOLATION SYSTEMS

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SITUATION

Almost indisputable belief that base isolation hardware should separate a building from shaking ground just by definition is extremely appealing. The examples are numerous. Sometimes, it was even stated that seismic forces in base isolated structures could be reduced by factor of 66 in comparison with conventional construction (**Tajirian et al.** 1990), though the degree of promised mitigation may vary. It is 10-20-fold per **Rodwell et al**. 1990, 7-fold per **Bailey & Allen** 1988 and **Zayas et al**. 1990, 5 to 10-fold per **Volkinburg** 1991, 5-fold per **Amin & Mokha** 1995, 6-fold per **Bachman** 1995, 5 to 10-fold per **Buckle** (**Prendergast** 1995). Although different in the specifics, all mentioned researchers and engineers predicted a sizable reduction of seismic forces in the buildings equipped with base isolators.

At the same time, some researchers express certain reservations about unconditional advantages of base-isolated structures in comparison with non-isolated ones (**Dillon** 1996, **Hall** 1995**, Shustov** 2000). Introducing the seismic isolation option, **UBC-97** is modestly describing the expected results of using base isolated systems as "equivalent to those of conventional structural systems".

It is obvious that the state and abilities of the contemporary isolating hardware are often overestimated. Therefore, development of a simple, effective and budgetary performance testing laboratory technique for the systems of base isolation would be very timely.

TESTING WHAT?

There is a need to specify what kind of testing is needed because the term "performance testing" happens to be persistently used in connection with a wide variety of testing of base isolation devices. Thus, the ASCE Standard for Testing Seismic Isolation Systems, Units and Components (**Draft D** 1997) which is a slight modification of the similar NIST guidelines (**Shenton** 1996) states that it "describes tests necessary to assess the structural, mechanical and environmental performance of these devices" according to the following mission list:

- Test for Effect of Virgin Loading.
- Test for Effect of Frequency of Loading.
- Test for Effect of Vertical Load.
- Test for Effect of Load Direction.
- Test for Effect of Load Plane Rotation.
- Test for Effect of Bilateral Load.
- Test for Effect of Temperature.
- Test for Effect of Load Cycling.
- Test for Effect of Load Cycle History.

- Degradation Under Thermal Displacement Cycling.
- Test for Thermal Cycling Loading.
- Test for Effect of Creep.

Though all tests of the list may be important for verification of the ability of base isolators to remain undamaged during an earthquake, they are not meant to confirm experimentally the capacity of those devices to mitigate seismic forces. Neither can do it the evaluation of seismic isolation and energy dissipating devices performed by HITEC (**CERFNews**, 1998, **Ghasemi** and **Higgins**, 1999).

In contrast to the testing approaches mentioned above, the performance testing per this proposal is understood as an experimental verification of ability of a seismic isolator under consideration to reduce the earthquake-induced forces on a building structure in a process of standardized shake table excitations.

PERFORMANCE TESTING

Shake table tests have been conducted both on full-sized and scale models of buildings for years. However, those tests have two major drawbacks:

- They are rather expensive.
- Their results relate to the particular structures the experiments were performed on.

Figure 1. PEER project #5051999 shake table testing (courtesy KRON 4 news).

At some testing facilities, however, in order to cut down the expenses, a multi-story structure is reduced to a single-story one with all the upper stories being substituted by the corresponding surcharge. To see an example, visit the web site at **PEER** 2001 and watch the shake table testing broadcast by the KRON 4 news (Figure 1). The project there on display is entitled *Gravity Load Collapse of Reinforced Concrete Frames* and its goal is to investigate the progressive collapse of a 6-7-story reinforced concrete building columns of "new" and "old" technologies during earthquake simulation.

"Reduce-to-one-story" approach, unfortunately, is not a good idea because, instead of being distributed through the height of a multi-story building, the overall drift of the structure happens to be applied to one story only![1]

[1] By the way, the experiments presented at **PEER** 2001 and in Figure 1 look very suspicious: the "old technology" square column in the middle is loaded with the axial load (weight of the tributary surcharge) twice as much in comparison with the loads supported by any of the "new technology" circular columns on each side, which condemns the "old technology" to a premature failure and makes the testing deceptive.

ASCE DRAFT STANDARD

An alternative approach exercised in the ASCE Draft Standard for Testing Seismic Isolation Systems **(Shustov** 1997) is based on the assumption that there is no need to submit a proof of usefulness of base isolation irrespective of a structural type or a type of isolation hardware: the isolation effectiveness is taken for granted. The only worry is that the isolators themselves will not survive an earthquake. For this reason, all isolators should undergo 12 basic property tests listed above.

This approach also assumes that the properties of isolators being identified in the process of quasi-dynamic testing are reliable, that analytical methods engaged by engineers are quite adequate and, therefore, expected performances of the structures put on those isolators can be predicted quite accurately. Unfortunately, the recorded performances of base isolated buildings at the last California earthquakes did not support expectations. This was a primary incentive for developing a new testing protocol called *Modal Performance Factor Testing Procedure* (MPFTP).

PROPOSED TESTING PROTOCOL

MPFTP is a budgetary procedure intended to conduct a preliminary verification of whether the seismic isolator under consideration is the best choice for a specific project. It provides an earthquake performance criterion for comparison of different competing technologies. MPFTP incorporates two proven methods: the analytical modal participation factor technique and shake table testing of objects put on base isolators.

Purpose: MPFTP is conducted to determine ability of isolators to reduce horizontal inertia forces in essentially elastic superstructures under a standardized sequence of selected harmonic excitations induced with a shake table.

Sequence: Groups of horizontal harmonic excitations are resonant to all corresponding modal frequencies of the building. Each group consists of one, two and three cycles run at the following peak velocity increment: 20, 40, 80, 100, 120, 140 and 160 cm/sec. Tests shall be conducted in the order listed, with the vertical load equal to a fraction of the weight $\mathbf{P_d}$ proportional to the participation factor value corresponding to the running mode of excitation.

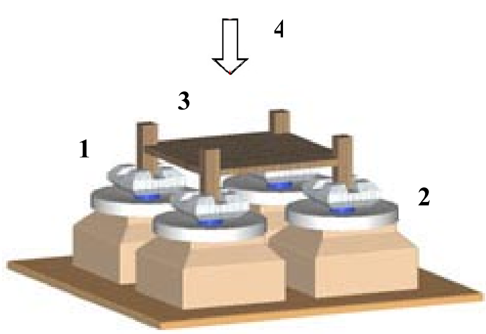

Figure 2. Testing rig per MPFTP.

Procedure: Place four specimens of the tested isolators **1** on a shake table (Figure 2) and secure to the supports **2** and loading slab **3**. Apply the correspondingly factored vertical load **4** to each specimen and allow the loads to stabilize. The tests should be run consistently, with sufficient pauses between cycles and changes in velocity increments to allow the heat developed during the previous test to dissipate.

Criteria: *Modal Performance Factor* (MPF) is specified as a ratio of an absolute value of the maximum accelerations of a non-isolated structure averaged along its height (computed) to the value of maximum acceleration of an isolated solid block that represents the superstructure (recorded) at a particular resonant modal frequency. The story stiffness $\mathbf{K_n}$ is assumed to be equal to 1500 ($\mathbf{P_d/ng}$), where $\mathbf{n}$ is a number of stories, and the damping ratios $\xi = 0.02$.

Special Requirements: Report of results shall include the values of MPF for the targeted number-of-story building, for each resonant modal frequency of it, and for each increment of the peak velocity. MPF = 1 means the isolated structure will have no advantages at an earthquake. MPF < 1 means the isolated structure is worse than the non-isolated one. MPF > 1 is a proof of the anticipated effectiveness of the tested isolation system.

COMMENTARY

One of the biggest challenges for an isolation system is a superstructure and, in particular, its ability to oscillate resonantly with the frequency of the ground. This ability, among other things, depends on the number of stories, which determines the actual spectrum of natural frequencies of the structure. However, there is no need to conduct testing of multistory models if the *Modal Performance Factor Testing Procedure* is used. MPFTP is based on the well-known fact that only a portion of the total weight of a multistory building is effective in producing a base shear during any particular mode of vibration.

Accordingly, one can avoid testing of the multitude of stories and deal just with a one-story model of a varying stiffness $\mathbf{K_p}$ and of mass $\mathbf{M_p}$ equal to the participation mass value, providing the shake table vibrates resonantly with the corresponding natural mode of the original structure.

It should be understood, however, that MPFTP is not intended to replace traditional testing of structural systems mounted on seismic isolators or to adequately substitute the much more realistic time-history ground inputs. Neither are they meant for a modal superposition.

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LINKS:

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