Modeling and Model Updating of a Full-Scale Experimental Base-Isolated Building

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Evolution of GA Population

Before Updating

After Updating

Summary of parameters changed by the updating:

• largest change in Young’s Modulus: 11.6% (x-direction beams in floors 2–3);
• largest change in the stiffness of rubber bearings: 4.7% (KSB1: 1119 kN/m → 1193 kN/m);
• largest change in the stiffness of rubber sliders: 15.2% (KSB2: 1464 kN/m → 1727 kN/m);
• largest change in the stiffness of steel dampers: 9.1% (KSB1: 3859 kN/m → 4045 kN/m).

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Motivation and Objectives

• Base isolation and other seismic protective systems mitigate a building’s response to seismic input while also ensuring the safety of the building’s occupants and contents.
• Full-scale testing of buildings and structures that incorporate these systems is expensive but offers valuable insight into their dynamics and mechanical behavior.

These systems often behave nonlinearly, creating a substantial challenge for modeling and predicting the responses induced by other hazardous natural excitations outside of the testing regime, responses in retrofit design studies, or probabilistic response modeling.

This study uses experimental response data, model identification, and optimization to update a finite element model to accurately simulate the dynamic response of the base-isolated building.

Experimental Set-Up

A base-isolated test structure at Japan’s E-Defense lab underwent initial testing in March 2013 [4] and subsequent testing in August 2013; this study focuses on the first day of testing (8 Aug. 2013).

The structure was mounted on E-Defense’s 6-DOF shake table, the world’s largest.

The structure consists of a four-story, asymmetric, moment frame with a setback and coupled transverse-torsional motion. The 690-ton superstructure is roughly 14 m × 10 m × 15 m.

The building rested on a passive base-isolation layer composed (on 8 Aug. 2013) of:

• two rubber bearings (designated RB1 and RB2 below),
• two elastic sliding bearings (SB1 and SB2), and
• two passive U-shaped steel yielding dampers (each of which, SDP1 or SDP2, has one steel yielding element in the x-direction and the other in the y-direction).

The building was subjected to random excitations along different table axes — i.e., in the x-, y-, and z-directions — and scaled versions of historical and synthetic earthquake ground motions.

Tri-directional accelerometers were at three corners on each floor, and two corners on the roof (the top story is different), for a total of 14 locations and 42 superstructure accelerations.

Tri-directional accelerometers were on the shake table, providing a total of 12 base acceleration channels.

Finite Element Model and Updating

A finite element model (FEM) was developed in ABAQUS® based on the structure design drawings.

- The beams, columns, and shear walls were modeled by solid concrete elements and embedded reinforcing steel bars modeled by transverse reinforcing elements; initial material properties are taken from design code.
- The floor slabs and the nonstructural walls (autoclaved lightweight concrete [ALC] plates) were modeled with shell elements; initial nominal Young’s moduli were chosen as typical for these elements.
- The isolation-layer devices were modeled with spring elements; initial values are from a linear force-displacement regression analysis [1].

The mass matrix M, the stiffness matrix K, and stiffness matrices Ki with unit changes to the ith ho-is-oriented parameter θi, i = 1, ..., n, are exported from ABAQUS for further analysis in MATLAB, where modified stiffness K = K0 + Σi=1,n θiKi(θi = 0 → minθi).

The parameter vector θ has nθ = 26 elements, including:
- the Young’s modulus of the x- and y-direction beams on floor 1, floors 2–3 and floor 4, the columns in floors 1–3 and 4, the nonstructural walls, the shear walls, the floor slabs, and the stairs — the x- and y-direction stiffness of: the rubber bearings, rubber sliders, and steel dampers pairs.

Define an error metric of the differences between the identified frequencies f(θ) and the corresponding FEM frequencies f(FEM(θ)) and between the corresponding mode shapes φ(θ) and φ(FEM(θ)):

\[ E = \frac{1}{n} \sum_{i=1}^{n} \left( f(FEM(θ)) - f(θ) \right)^2 + \frac{1}{n} \sum_{i=1}^{n} \left( φ(FEM(θ)) - φ(θ) \right)^2 \]

A genetic algorithm optimization is used to find parameter values that minimize the error metric. A genetic algorithm optimization is used to find parameter values that minimize the error metric. (A Nelder-Mead Simplex method has also been studied, but tended to get stuck at local minima.)

The updated values are allowed to vary within bounds that are about 5% of the original values.

The updated MCAQ(θ) can be used as a linearized model for a base-isolated structure.

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Results

Among the 200 samples in the first generation, the error ranges from about 1000 to almost 1500, the minimum error decreases gradually and converges, such that most of the population has an error smaller than 10% after the 46th generation.

The first six frequencies (and their percent of the original) and updated FEMs are shown in the table above; the maximum frequency error drops by nearly an order of magnitude. The improvement in the mode shape correlation is shown in the MAC graphic.

The updated MATLAB model is being merged with a set of bidirectionally-coupled Base-Wen models already developed to simulate the nonlinear behavior of the isolation-layer devices.

Controlable damping devices will be added to the isolation layer, and new control strategies will be developed to mitigate the response of this building.

Legend
- RB1
- RB2
- SB1
- SB2
- SDP1
- SDP2

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