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BENCHMARK BUILDING MODEL FOR STRUCTURAL CONTROL AND DAMAGE IDENTIFICATION

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ABSTRACT

This paper presents the benchmark building model for structural control and damage identification. The 3-story benchmark building model (almost full scale) was designed, simulated in FEM and been tested on the shaking table. With the modular design concept, various type of structures (w/without bracing, stiffness eccentric, earthquake excitations. The structural parameters, mathematical model, simulation results and shaking table test data are collected in the data bank. The data bank is open to public and can be used to develop and verify the system identification and damage detection algorithms. In the same time, the 3-story benchmark building model was used as the benchmark problem for the structural control system. The modular bracing system can fit various types of control devices. Different control devices and control algorithms can use it to back-to-back compare the control systems. The design detail, connection of the control device, responses of the bare frame and the passive controlled responses were shown in this study. All theses data was open to public, researchers can use it to develop and verify their control system. The main object of this study is to propose the benchmark models and support the development of structural control and damage identification.

Introduction

During the last decade, several benchmark structural control models have been developed through the sponsorship of the ASCE Committee on Structural Control and the International Association of Structural Control and Monitoring (IASCM). The main objective of developing these models has been a standardized evaluation of the performance of various control systems/ algorithms when applied to different structural systems. An extensive analysis of benchmark structural control problems formed the basis for a special issue of Earthquake Engineering and Structural Dynamics. Recently, the well-defined analytical benchmark problems have also been developed for bridge structures subjected to seismic excitation through the sponsorship of the ASCE Structural Control Committee.

The main object of this study is to propose the benchmark models and support the development of structural control and damage identification. To achieve this object, a serious

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FEM analysis was done to get a suitable design of the benchmark building structure which can has suitable and obvious nonlinear behaviors under the capacity of the shaking table in NCREE. After the structural element was designed, the modular concept was introduced into the construction of the benchmark model. More structural types (such as stiff eccentric, soft floor, torsion coupling, rapid switch column …etc), more rich of the data bank we can got. As results, the modular design make the benchmark model can transform into different structural types and allowed to have nonlinear behaviors. As all the nonlinear behaviors were concentrated on the rapid-switch column, the shaking table test can be done in series and rapidly. All the structural parameters, mathematical model, simulation results and shaking table test data are collected in the data bank, researcher can use it for free to develop and verify their damage identification algorithms.

In the other hand, the benchmark model for structural control was designed and tested on the shaking table. In the past four years, various kinds of control devices have been tested on this benchmark model. This study want to achieve this goal is to set analytical benchmark models based on large experimental models that allow researchers in structural control to test their algorithms and devices and directly compare. As results, both the bare frame and the passive controlled benchmark structure were tested and all the tested data were collected into the data bank. The structural control researchers can use it to develop the control system and compare to the others.

Design of the Benchmark Building Model

In order to have the real structural responses of the full-scale structure, the benchmark model war designed. There were several design points needs to be considered:

1. The benchmark model needs to have obvious nonlinear behavior under the capacity of the shaking table in NCREE (Size:5m x 5m/ Load: 50n tons /PGA: 2g).
2. The benchmark model must to be adjust to fit various structural types easily and quickly.
3. The nonlinear elements must be easily changeable.
4. The dead load of the benchmark model must reflect the realistic.

According to theses points, serious FEM simulations were done though “ABAQUS”. Finally, the three stories benchmark model was selected to be 3m long, 2m wide and 3m height for each story, totally the structural height is 9m. The mass of each floor (including the columns) was 6 tons; the total mass was 18 tons. The size of column was selected asH150X150X7X10, the size of beam was H150X150X7X10. The corresponding frequencies and mode shapes were shown in figure 1. The elements which have nonlinear deformation under various PGA levels of excitation (El Centro NS) were listed in table 1. The time history responses of the input ground motion, relative displacement of three stories and hysteresis loops of the structural elements under 500gals El Centro earthquake excitation in FEM analysis was shown in figure 2. The design plots: Front-view, side-view and 3D-view of the three-stories benchmark model for damage identification wetre shown in figure 3.

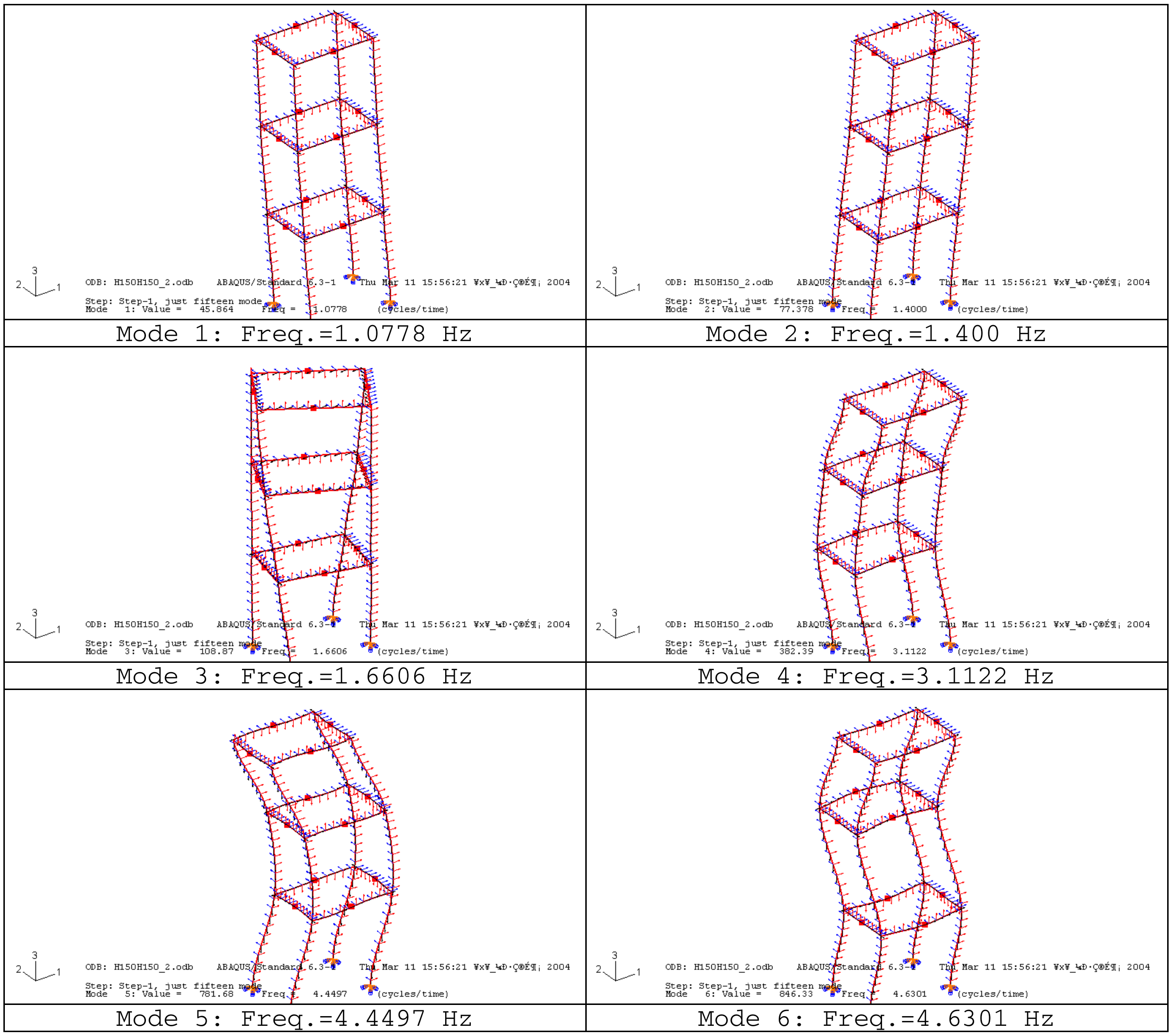

Figure 1: The mode shape and modal frequencies from the FEM.
（Column：H150X150X7X10 / Beam：H150X150X7X10）

Table 1. Table of the elements which have nonlinear deformation under various PGA levels of excitation (El Centro NS).

El Centro	Strong-Axis	Weak Axis
100 gal	None	None
200 gal	None	Column: 2F(C11, 20), 1F(C21, 30)
300 gal	None	Column: 3F(C1), 2F(C11, 20), 1F(C21, 30)
500 gal	Beam: 2F (B2001), 1F(B3001) Column: 1F(C30)	Column: 3F(C1, C10), 2F(C11, 20), 1F(C21, 30)

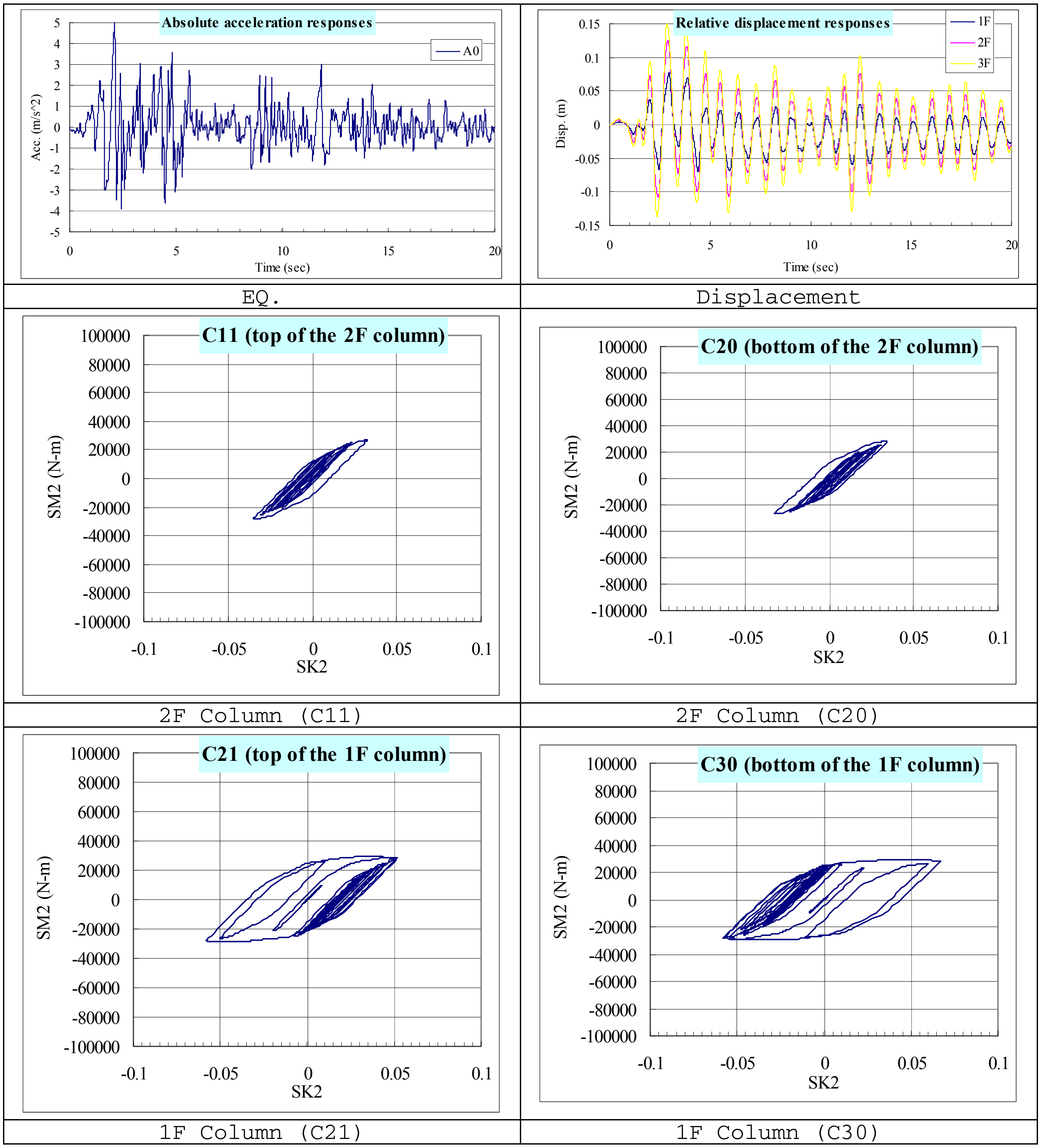

Figure 2: The time history responses of the input ground motion, relative displacement of three stories and hysteresis loops of the structural elements in FEM analysis.

Shaking Table Tests for Damage Identification

After the benchmark model were designed and simulated in the FEM simulation, two benchmark modes were build according to the design plots shown in figure 3, and been tested on the shaking table in NCREE. Seven structural types were tested on the shaking table tests as shown in figure 4.

Benchmark model A: The long-direction was the strong direction of the column. The linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise)were done first and then the nonlinear tests (nonlinear excitation cases : 300、500 、1000、1500、1000、1200gals El Centro NS; The white noise tests were done before and after the nonlinear test.).

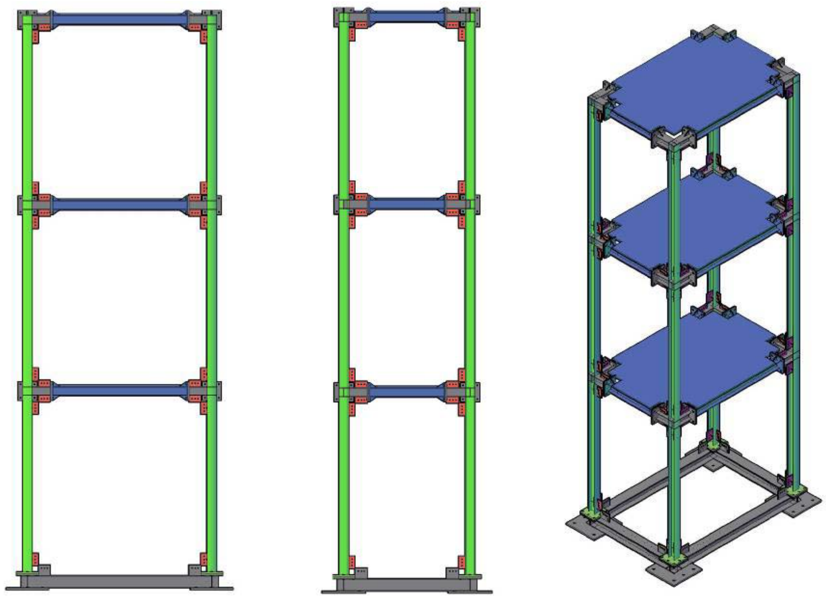

Figure 3. Front-view, side-view and 3D-view of the three-stories benchmark model for damage identification.

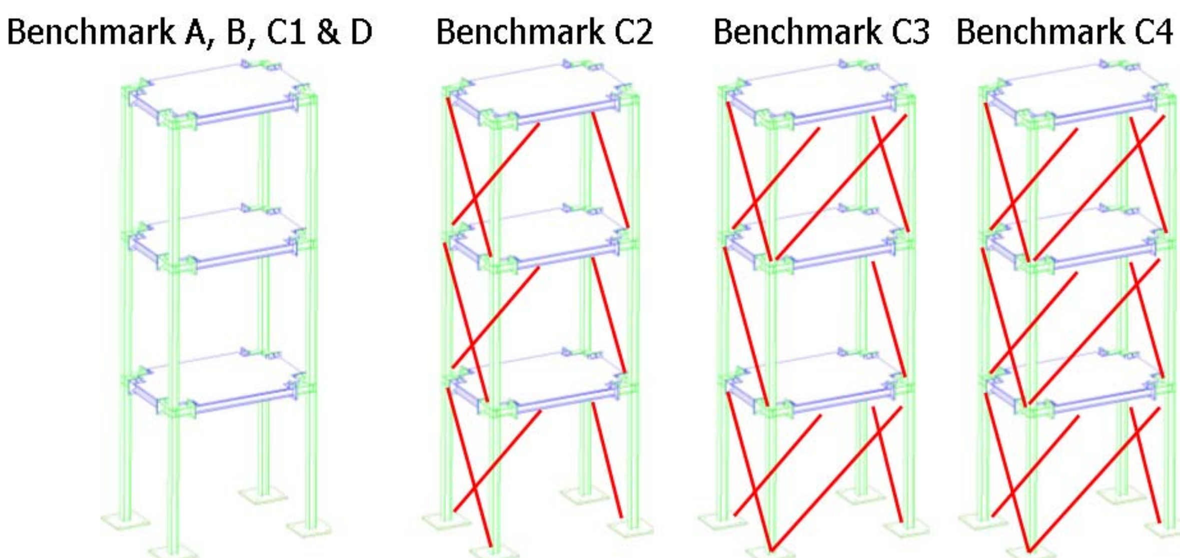

Figure 4. Structural types of the three-stories benchmark model.

Benchmark B: The long-direction was the weak direction of the column. The linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise)were done first and then the nonlinear tests (nonlinear excitation cases : 100、1000、500、300、100gals ChiChi/TCU082 NS; The white noise tests were done before and after the nonlinear test.). The test cases were listed in table 2.

Benchmark C1: The long-direction was the weak direction of the column. Only the linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise) were done. For each excitation, both 50 gals and 100 gals of intensities were tested.

Benchmark C2: The long-direction was the weak direction of the column. The bracing system (L150x150*2) was installed as shown in figure 4 to simulate the stiff eccentric condition. Only the linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise) were done. For each excitation, both 50 gals and 100 gals of intensities were tested.

Benchmark C3: The long-direction was the weak direction of the column. The bracing system (L150x150*2) was installed as shown in figure 4 to simulate the soft floor condition (2F). Only the linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise) were done. For each excitation, both 50 gals and 100 gals of intensities were tested.

Benchmark C4: The long-direction was the weak direction of the column. The bracing system (L150x150*2) was installed as shown in figure 4 to simulate the full brace condition. Only the linear tests (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise) were done. For each excitation, both 50 gals and 100 gals of intensities were tested.

The sensor arrangement of the shaking table test was shown in figure 5. The displacement, velocity, acceleration and strain of the column were measured. All the test data was collected in to the databank. In addition to the original data, the data bank also provided the simple drawing of the structural responses and the FFT amplitude. Figure 6 was one of the drawing which shown the time history responses of the displacement, acceleration and the FFT amplitude of benchmark model B under 1000gals Chi-Chi/Station:TCU082 earthquake excitation.

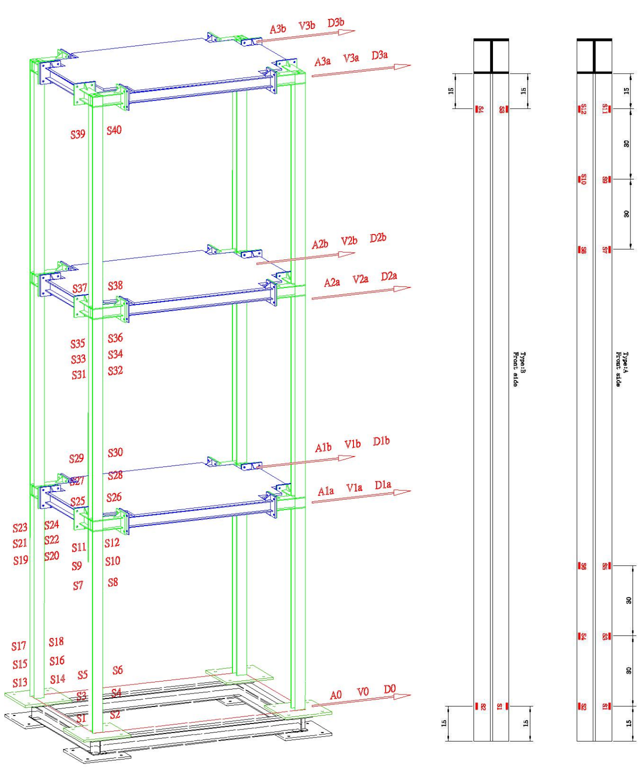

Figure 5. Sensor arrangement of the three-stories benchmark model.

Table 2. List of the test cases of Benchmark model B in the shaking table test.

Test No.	Excitation case	PGA (ideal)	Direction	Output File Name
B1	Random	50	X-dir. / Weak Dir.	Random-X-50_X.txt
B2	Random	100	X-dir. / Weak Dir.	Random-X-100_X.txt
B3	El Centro NS	50	X-dir. / Weak Dir.	ELC-X-50_X.txt
B4	El Centro NS	100	X-dir. / Weak Dir.	ELC-X-100_X.txt
B5	ChiChi/TCU076/NS	50	X-dir. / Weak Dir.	TCU076-X-50_X.txt
B6	ChiChi/TCU076/NS	100	X-dir. / Weak Dir.	TCU076-X-100_X.txt
B7	ChiChi/TCU082/NS	50	X-dir. / Weak Dir.	TCU082-X-50_X.txt
B8	ChiChi/TCU082/NS	100	X-dir. / Weak Dir.	TCU082-X-100_X.txt
B9	Random	50	Y-dir. / Strong Dir.	Random-Y-50_Y.txt
B10	Random	100	Y-dir. / Strong Dir.	Random-Y-100_Y.txt
B11	El Centro NS	50	Y-dir. / Strong Dir.	ELC-Y-50_Y.txt
B12	El Centro NS	100	Y-dir. / Strong Dir.	ELC-Y-100_Y.txt
B13	ChiChi/TCU076/NS	50	Y-dir. / Strong Dir.	TCU076-Y-50_Y.txt
B14	ChiChi/TCU076/NS	100	Y-dir. / Strong Dir.	TCU076-Y-100_Y.txt
B15	ChiChi/TCU082/NS	50	Y-dir. / Strong Dir.	TCU082-Y-50_Y.txt
B16	ChiChi/TCU082/NS	100	Y-dir. / Strong Dir.	TCU082-Y-100_Y.txt
B17	ChiChi/TCU082/NS	100	X-dir. / Strong Dir.	TCU082-X-100-2_X.txt
B18	Random	50	X-dir. / Strong Dir.	Random-X1_X.txt
B19	ChiChi/TCU082/NS	1000	X-dir. / Strong Dir.	TCU082-X-1000_X.txt
B20	Random	50	X-dir. / Strong Dir.	Random-X2_X.txt
B21	ChiChi/TCU082/NS	500	X-dir. / Strong Dir.	TCU082-X-500_X.txt
B22	Random	50	X-dir. / Strong Dir.	Random-X3_X.txt
B23	ChiChi/TCU082/NS	300	X-dir. / Strong Dir.	TCU082-X-300_X.txt
B24	Random	50	X-dir. / Strong Dir.	Random-X4_X.txt
B25	ChiChi/TCU082/NS	100	X-dir. / Strong Dir.	TCU082-X-100-E_X.txt
B26	Random	50	X-dir. / Strong Dir.	Random-X5_X.txt

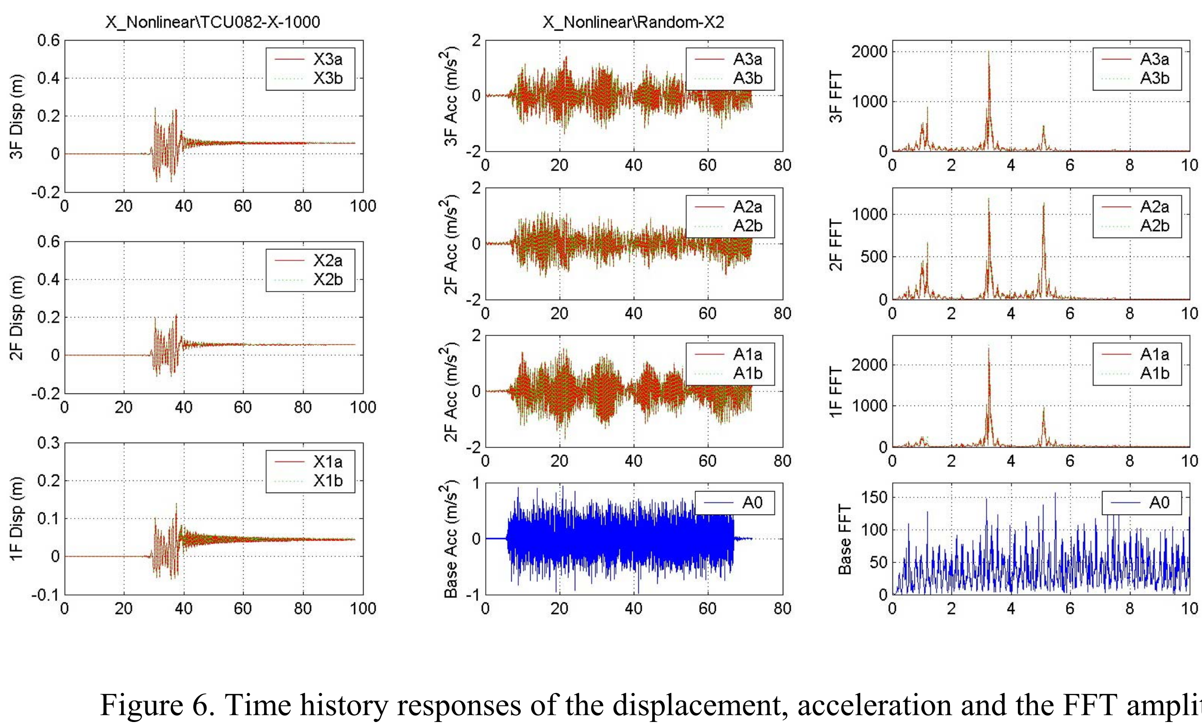

Figure 6. Time history responses of the displacement, acceleration and the FFT amplitude of benchmark model B under 1000gals Chi-Chi/Station:TCU082 earthquake excitation.

Benchmark D: The long-direction was the weak direction of the column. The linear tests 1 (El Centro, ChiChi/TCU076, ChiChi/TCU082, and white noise)were done first and then the linear test 2, which the column in 1st floor had a weak points, were done with the same excitation cases. Finally the nonlinear tests (nonlinear excitation cases : 100、1000、500、300、100gals ChiChi/TCU082 NS; The white noise tests were done before and after the nonlinear test.).

Shaking Table Tests for Structural Control

To expand the usage of the benchmark model,, the 3-story benchmark building model was also used as the benchmark problem for the structural control system. The modular bracing system can fit various types of control devices. Different control devices and control algorithms can use it to back-to-back compare the control systems. The design detail, connection of the control device, responses of the bare frame and the passive controlled responses were shown in this study. All theses data was open to public, researchers can use it to develop and verify their control system. The main object of this study is to propose the benchmark models and support the development of structural control and damage identification.

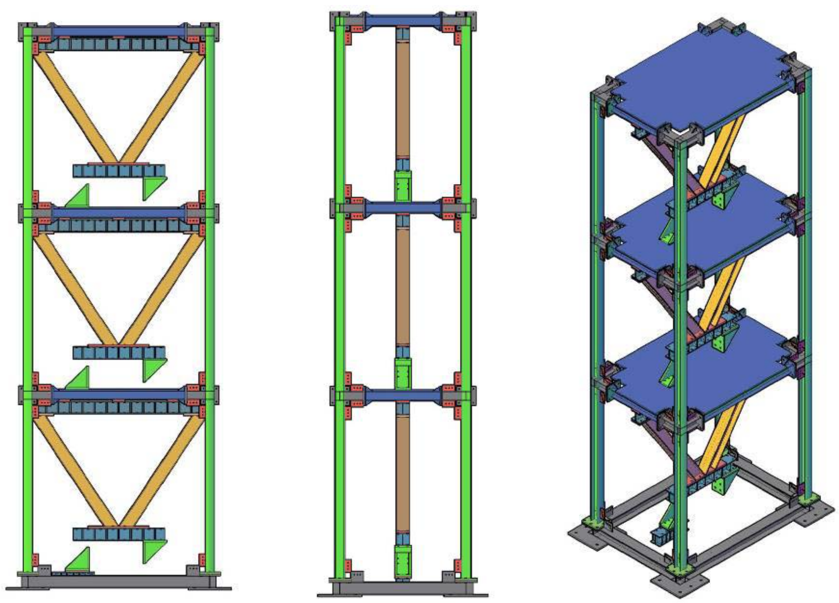

Figure 7. Front-view, side-view and 3D-view of the three-stories benchmark model for structural control.

To install the control device to control the structural responses induced by earthquake excitations, a strong middle bracing system was designed as shown in figure 7. The element size of the middle bracing was selected as H200x200. The modular design detail made the usage of various kind of control devices possible. Various control devices were install onto the benchmark model and been tested on the shaking table tests. Figure 7 shown the photos of the shaking table test of the three-story benchmark structure with passive damper in the fist story. All the test results and the performance tests of the control devices will be collected into the databank. The researchers can use these data and the original data of the benchmark model to back to back compare their control system. In addition, the semi-active controllable MR damper manufactured by NCREE was tested too. Researchers can use the mathematical models (provided in the data bank) of the benchmark model and the nonlinear MR damper to simulated their semi-active control algorithms. The following shaking table test with the semi-active control system can be done through the international cooperation program.

Figure 8: Photos of the three-story benchmark structure with passive damper in the fist story.

Summary and Conclusion

This paper presents the benchmark building model for structural control and damage identification. The design procedure, test cases, sensor arrangements and materials of the databank were illustrated. Both the benchmark model for system identification and structural control were presented. The databank include the structural parameters, shaking table test results of various structural types performance test results of the control device, mathematical model of the benchmark model and the control devices and the test results of the benchmark model with control systems. Not only the raw data, but also the simple drawings of the test data were provided.

The main object of this study is to propose the benchmark models and support the development of structural control and damage identification. As results, all theses data was open to public, researchers can use it to develop and verify their control system.

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