Wise Dynamic Testing for Enhanced Understanding of Structures

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Large shaking tables

• At the E-defense-----
  The bed can support 1200 metric tons and 20m tall structures, but we can test only 5 story buildings.

• At the UCSD shaking table----
  They can test 10-story buildings but very small floor area.
Large shaking tables

- Total weight of actual tall building will be heavier over 100,000 metric tons and its height is higher than 300m in Japan and 800m in the world.
- We need new wise ideas for understanding the behaviors of actual large structures due to large earthquakes.
Intuitions and experiences

• Before Galileo Galilei, we have not any equation for knowing strength of a beam or a column, but humankind is wise and has good intuition.
• They could built very beautiful buildings and architectures such as Pyramids, Parthenon, Pantheon or 5 story pagodas.
• These buildings have very good performance for a long time, but many buildings were also collapsed by many reasons.
Earthquake disasters

• In some cases, engineers in the ancient time learned better construction technology by observing collapses and failures.

• In 20\textsuperscript{th} and 21\textsuperscript{st} century, we have had many severe earthquake disasters and we have learned much from these events and understood the structure behavior better under earthquakes.
Engineers must know what will happen before it happen.
Aims of structural tests 1/3

- Humankind has built many buildings and many big cities.
- But not all we have done are based on our experiences.
- Then we have to know what will happen in the actual building structures in future earthquake event by any possible ways before any troubles happen.
- The static tests and the dynamic tests should give us a lot of important information and important knowledge.
Aims of structural tests 2/3

• Making safer structures, more economical structures and higher performance structures.

• Structural materials such as concrete, steel and other materials can be changed to increase strength.

• We have to test the structures and to understand new structural systems.
Aims of structural tests 3/3

• Making a design guideline, a design standard and a design code.
• Increasing sympathetic friends of engineers and researchers understanding about new ideas and new design.
• Persuading the building owners about our design and persuading general public about new ideas.
Realistic dynamic tests are most effective method and they have strong visual persuasive power.
Collapse tests of very small steel frames

- When the specimen size is 1/10 of the actual scale of a structure.
- Stress level becomes 1/10 of actual stress in the structure.
- Nonlinear effect of the structural member cannot be treated correctly in the 1/10 specimen.
- P-delta effect becomes also very small when the specimen’s weight is too light.
Centrifuge and container at the Obayashi Research Institute
High gravity in big centrifuge

• 3, 12 and 30 story steel frames have tested here.

• The centrifuge could produce 100G gravity and the testing container could have a 2m high specimen.

• We could test 200m tall buildings using this strong machine theoretically.
3-story weak tube columns and strong beams

Direction of excitation
Elevation
12-story strong columns and weak beams
Final collapse of 12 story frame
30-story shear wall and outrigger

1.8M

30F

15F
Story shear & deformation angles
A tiny seismic isolated structure was tested in 1982
Homogeneous equation of structural dynamics

\[
\begin{pmatrix}
M_x & 0 & 0 \\
0 & M_y & 0 \\
0 & 0 & M_z
\end{pmatrix}
\begin{pmatrix}
\frac{d^2 x}{dt^2} \\
\frac{d^2 y}{dt^2} \\
\frac{d^2 z}{dt^2}
\end{pmatrix} +
\begin{pmatrix}
k_{11} & k_{12} & k_{13} \\
k_{21} & k_{22} & k_{23} \\
k_{31} & k_{32} & k_{33}
\end{pmatrix}
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix} =
\begin{pmatrix}
0 \\
0 \\
0
\end{pmatrix}
\]

\[M_x = M_y = M_z\] in the actual structures
Homogeneous equation of structural dynamics

\[
\begin{pmatrix}
M_x & 0 & 0 \\
0 & M_y & 0 \\
0 & 0 & M_z
\end{pmatrix}
\begin{pmatrix}
\frac{d^2 x}{dt^2} \\
\frac{d^2 y}{dt^2} \\
\frac{d^2 z}{dt^2}
\end{pmatrix} +
\begin{pmatrix}
k_{11} & k_{12} & k_{13} \\
k_{21} & k_{22} & k_{23} \\
k_{31} & k_{32} & k_{33}
\end{pmatrix}
\begin{pmatrix}
x \\
y \\
z
\end{pmatrix} =
\begin{pmatrix}
0 \\
0 \\
0
\end{pmatrix}
\]

\[M_x \neq M_y \neq M_z\] in the dynamic tests
5-story seismic isolated structure and 5-horizontal inertia masses
Old reinforced concrete frames added supplemental dampers
Elevation view testing system

Natural period of the system: $T_1 = 0.6$ sec
Introduction of column axial forces

- Soft spring washers
- 80 ton axial force by post-tensioning
- Column
- Beam
- 850 mm
- 2,750 mm
- 600 mm
- 5,500 mm
Heavy steel inertia weight and reinforced concrete frame
Conclusions

• Structural engineers must make safer buildings and safer cities for people.
• We need to do not only the static structural test but also dynamic test.
• But often, the test facilities have some limitation.
• Researchers and engineers have to use these facilities under the combination with deep thinking and innovative ideas.