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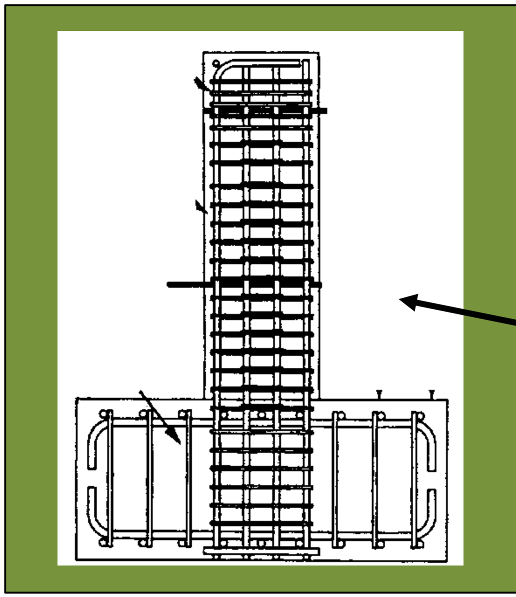
AN ULTIMATE CHOICE BETWEEN SHAKING TABLE TEST AND HYBRID SIMULATION FOR ADVANCING SEISMIC ANALYSIS AND DESIGN

By

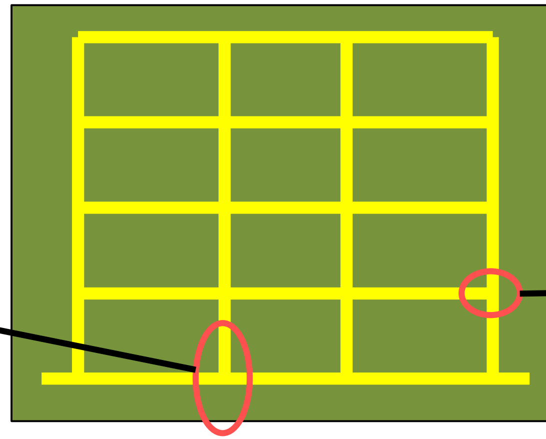
Masayoshi Nakashima
Masahiro Kurata
Kazuhiro Hayashi

My View about "Needs for Large-Scale Testing"

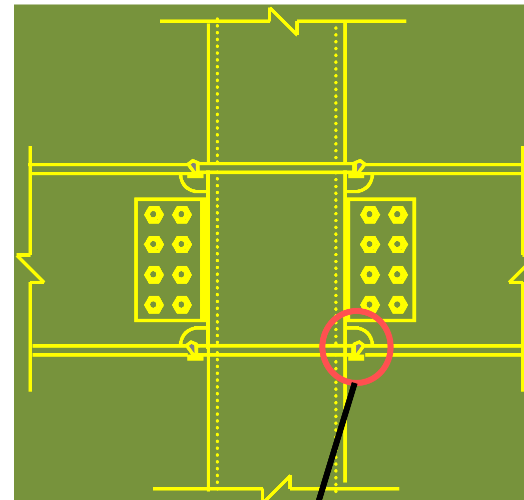
Difficulties in duplicating details in reduced-scale specimens



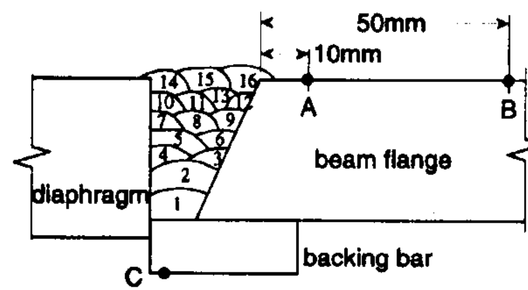
RC Column



Building Frame

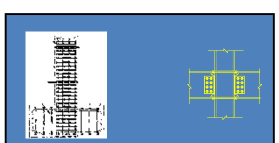


Steel Connection

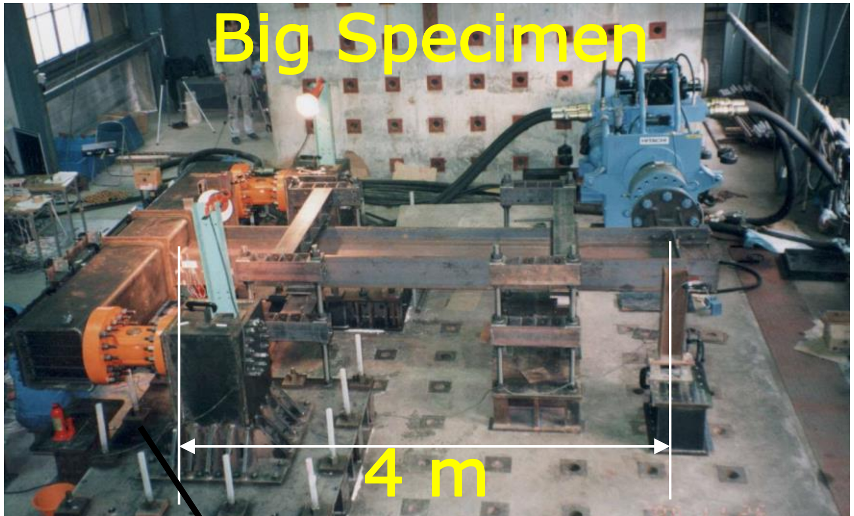


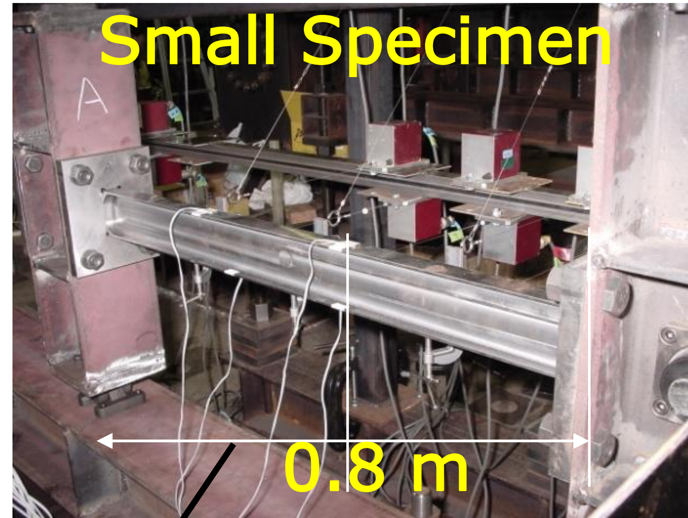
Weld

Sorry, we cannot scale down.

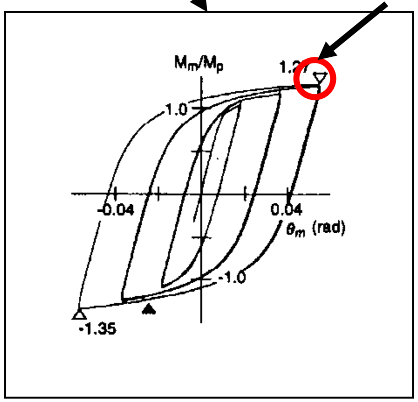


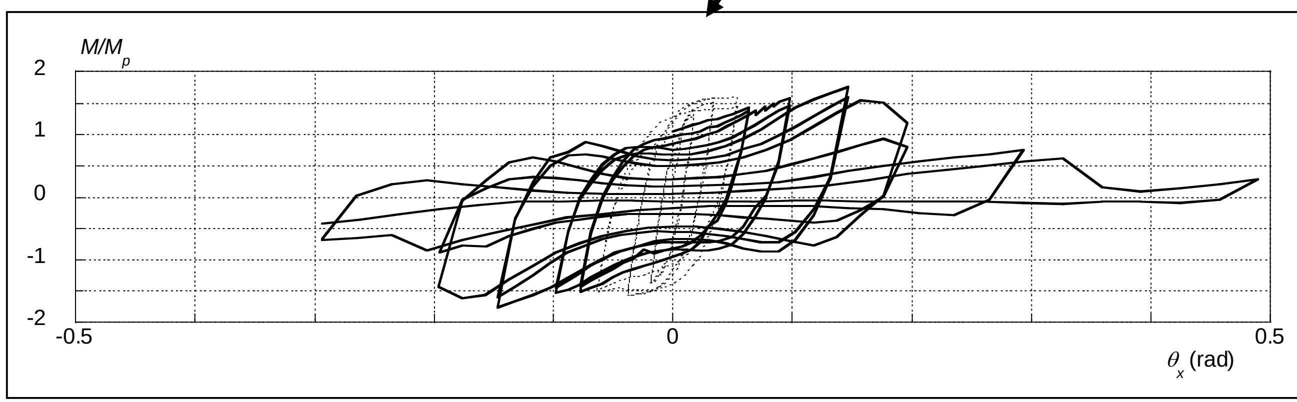
Is "Full-Scale" Needed?





Farcture





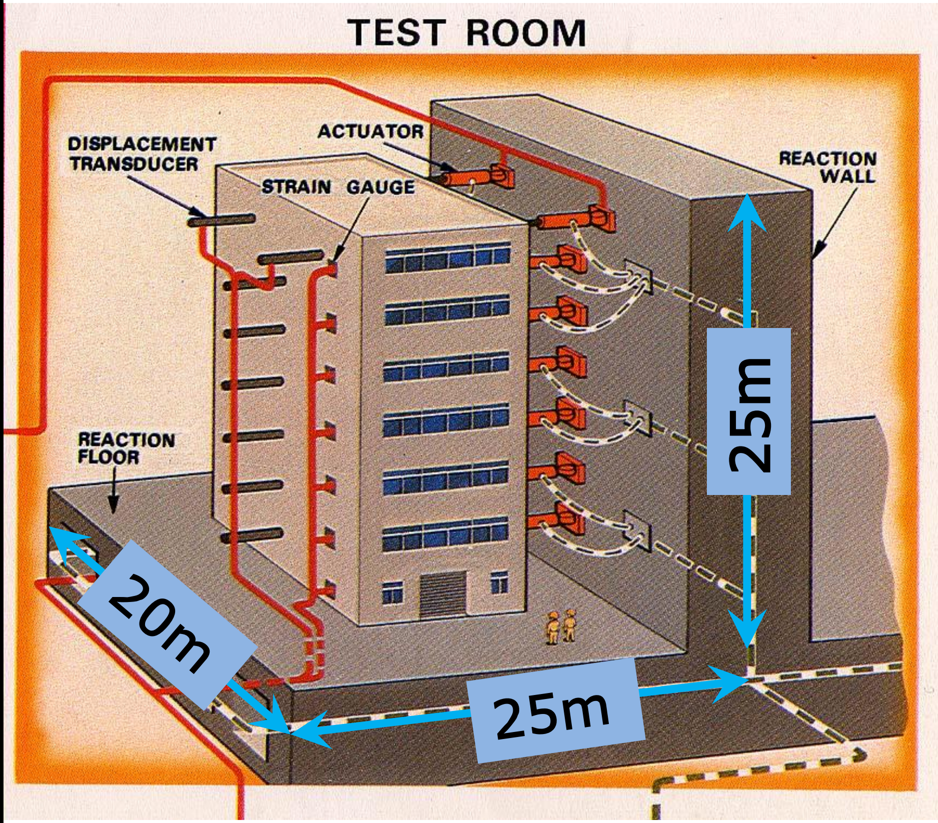
Ductile, but failed
after so so deformation

Infinitely Ductile?

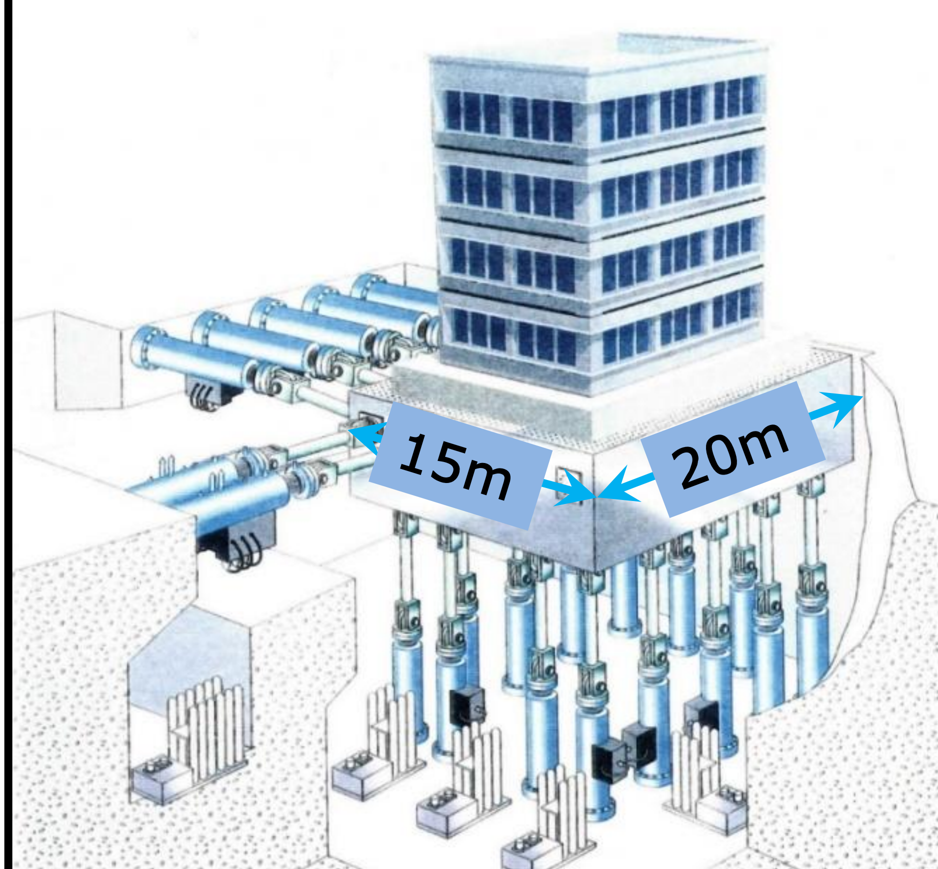
Reduced-scale specimens often fail to reproduce prototype behavior.

Suppose you agree with me about the roles of experiment and the need for large-scale testing. Suppose one day, a person come to you and offer to donate one of the two test systems below. ➔ ***Which one of the two will you take?***

Strong Floor/Wall System



Shaking Table System



Strong Floor/Wall System

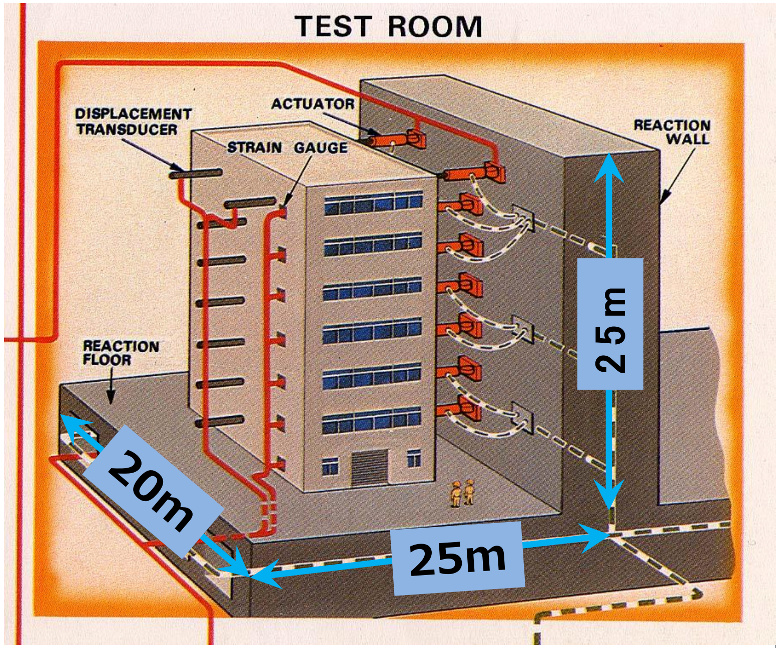
A space of 25 m (length) by 20 m (width) by 25 m (height)

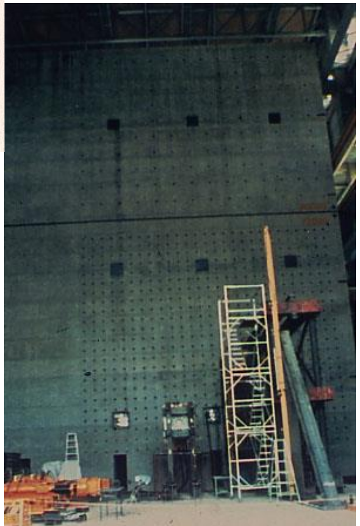
Founded in 1979 at Building Research Institute (BRI), Japan

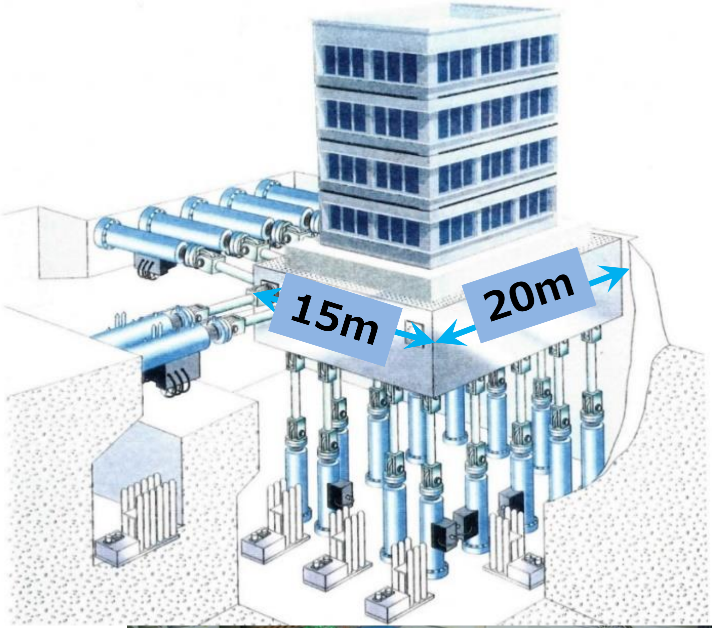
Shaking Table System

A table of 20 m by 15 m

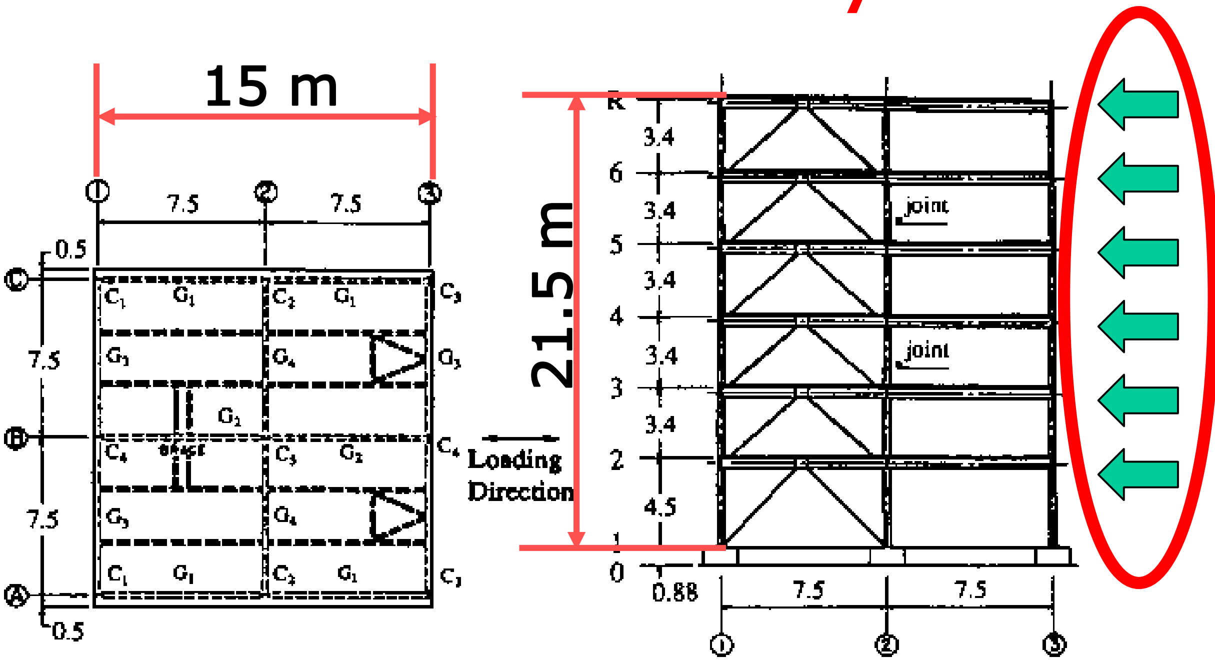
Founded in 2004 at E-Defense of National Research Institute for Earth Science and Disaster Resilience (NIED), Japan



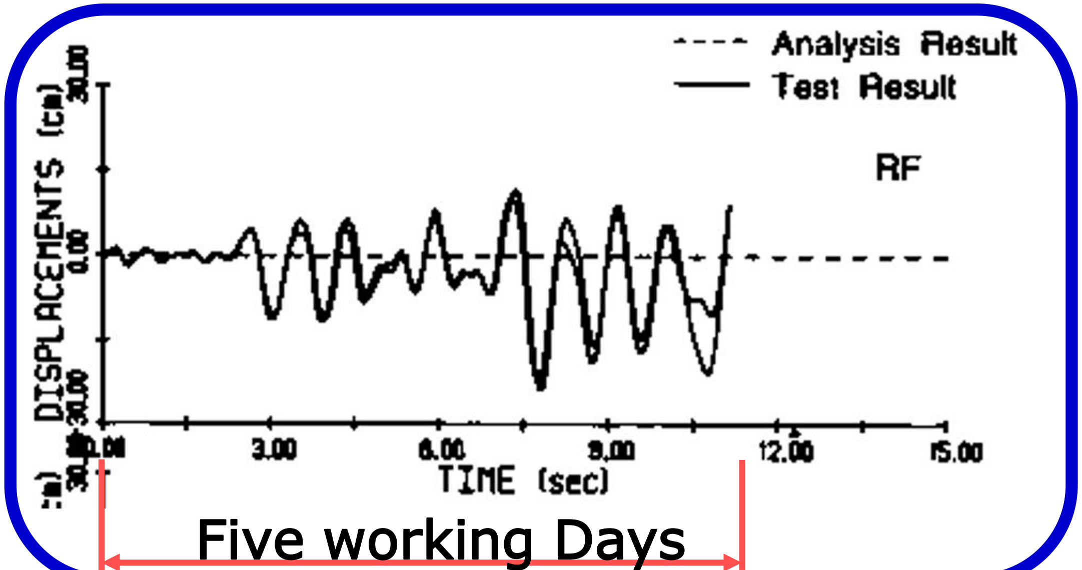


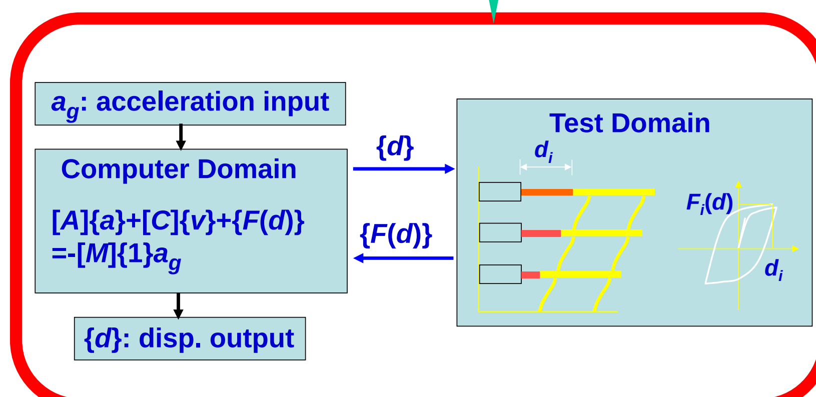


Hybrid Simulation (Pseudo Dynamic Test) for Full-Scale Six Story Steel Braced Frames



Loading by seven actuators synchronized with "hybrid simulation control.





My engagement in Large-Scale Hybrid Simulation

➔ Working for hybrid simulation of six-story steel frame, as a most junior member of BRI

A summary is given in Earthquakes Engineering and Structural Dynamics, Wiley (2020)

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REVIEW ARTICLE

WILEY

Hybrid simulation: An early history

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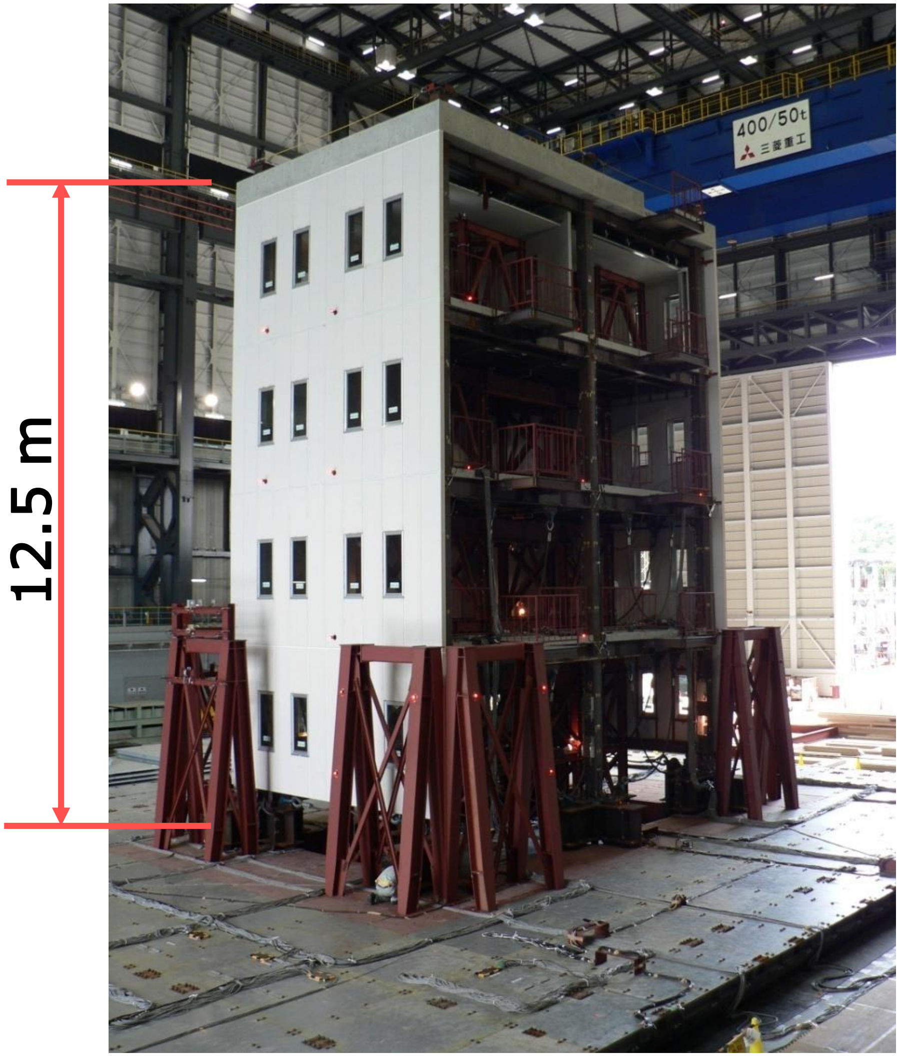
Summary

This historical note reports on the early days of the development of an experimental method called "hybrid simulation." As background, the seeds of this concept, initiated in the early 1970s by Japanese researchers, are presented first, followed by initial efforts (regarded as Stage I) to realize the concept of hybrid simulation and its first applications to explore the seismic performance

Complete Collapse Test of Four-Story Steel Moment Frame



My engagement in Large-Scale Shaking Table Test ➔ Served as Founding Director of E-Defense

A summary is given in English Journal of Architectural Institute of Japan (AIJ), named Japan Architectural Review (2019).

Japan Architectural Review Open Access

Architectural Institute of Japan

Review Paper

Experiences, accomplishments, lessons, and challenges of E-defense—Tests using world's largest shaking table

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Correspondence

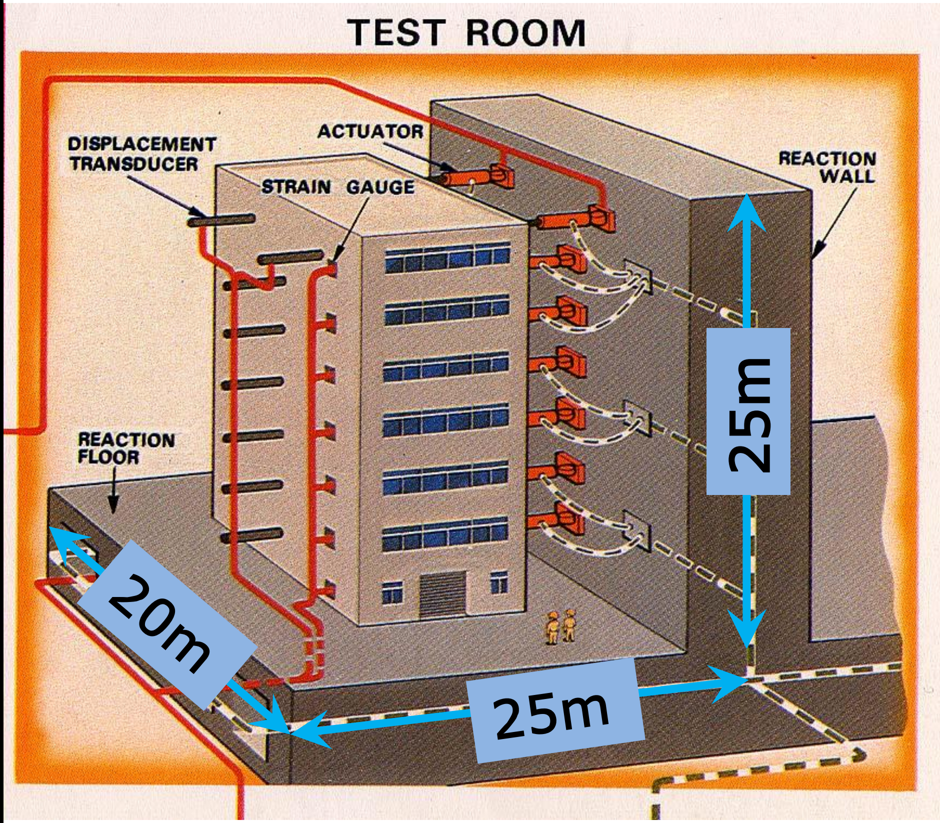
Masayoshi Nakashima, Kobori Research Complex Inc. and Professor Emeritus, Kyoto University, Minato-Ku, Japan.

Abstract

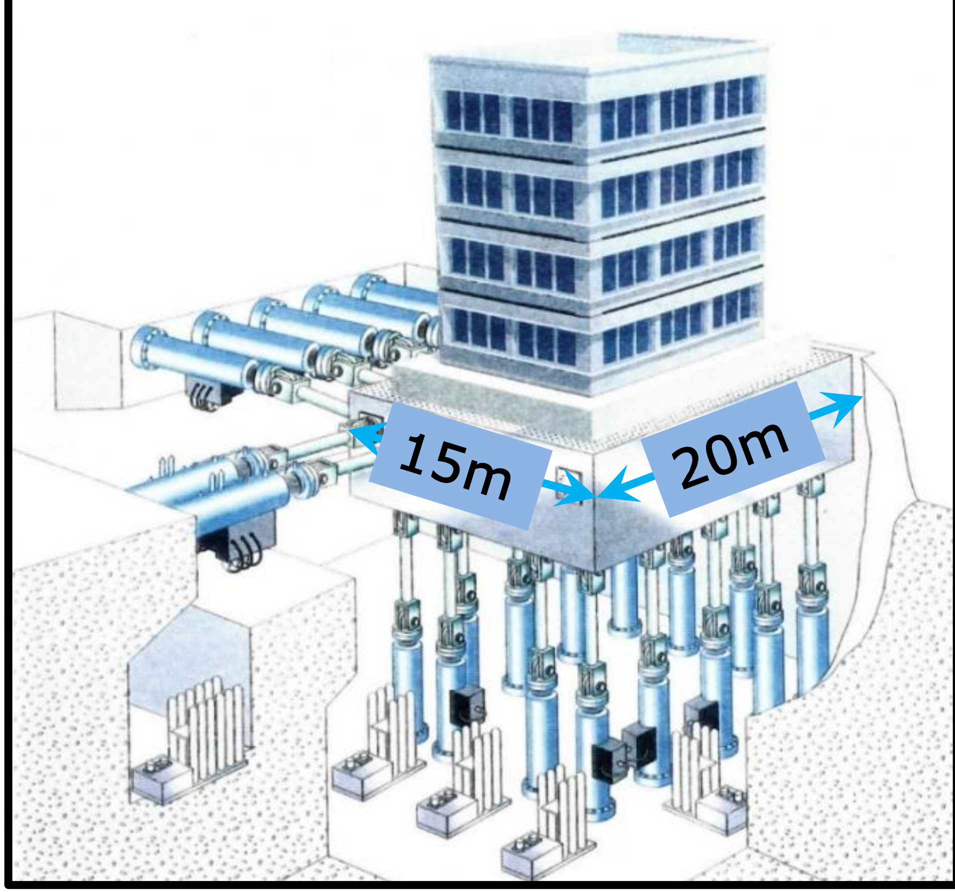
E-Defense, which is operated by the Japanese National Research Institute for Earth

Suppose you agree with me about the roles of experiment and the need for large-scale testing. Suppose one day, a person come to you and offer to donate one of the two test systems below. ➔ ***Which one of the two will you take?***

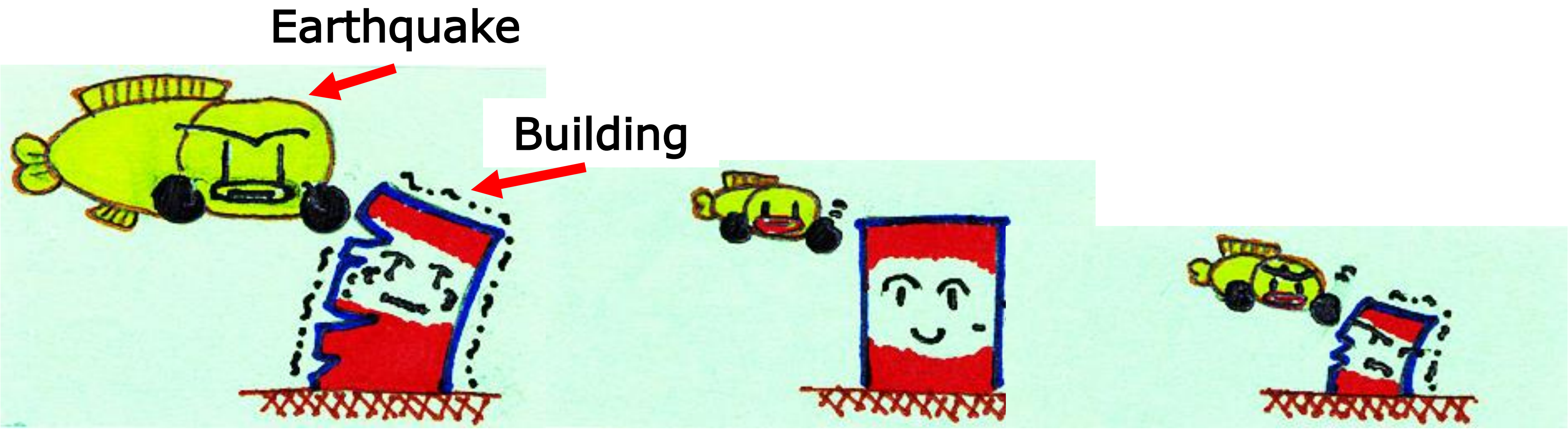
Strong Floor/Wall System



Shaking Table System



Seismic Performance - Safe and Unsafe

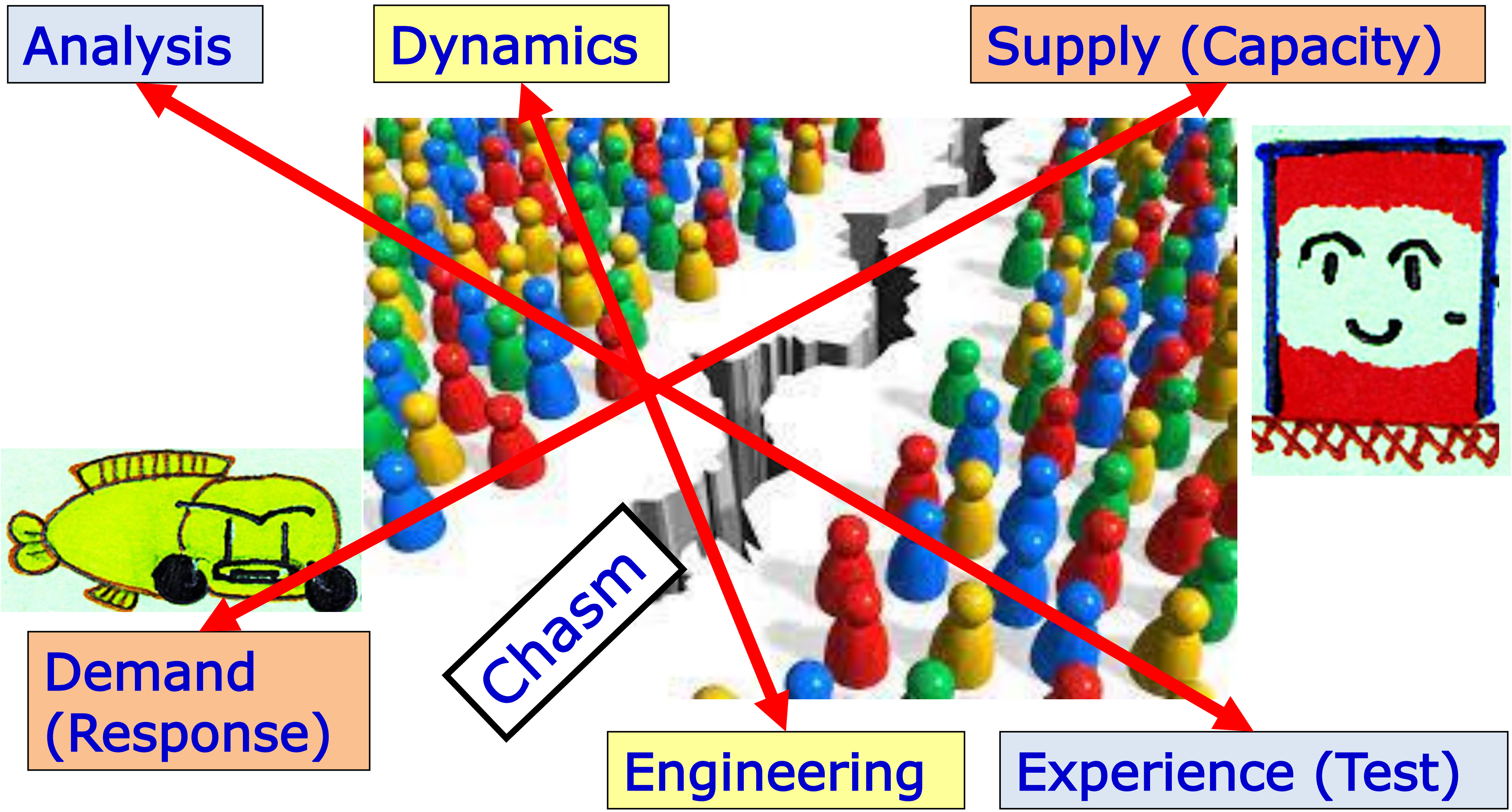


Too large a quake	Properly designed	Too small a resistance
Unsafe	**Safe**	**Unsafe**

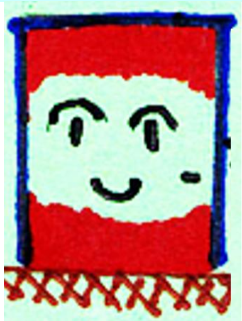
Safe → (Seismic Demand) < (Building Strength)

Unsafe → (Seismic Demand) > (Building Strength)

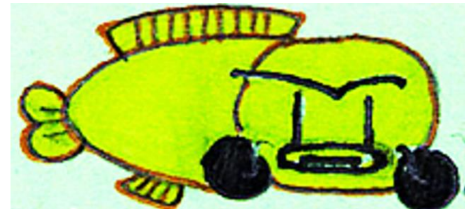
In our Earthquake Engineering Research, a "Chasm" exists between "Two Groups (demand/response and supply/capacity)" ➔ *Which group you belong to?*



Which one of the two do you take?

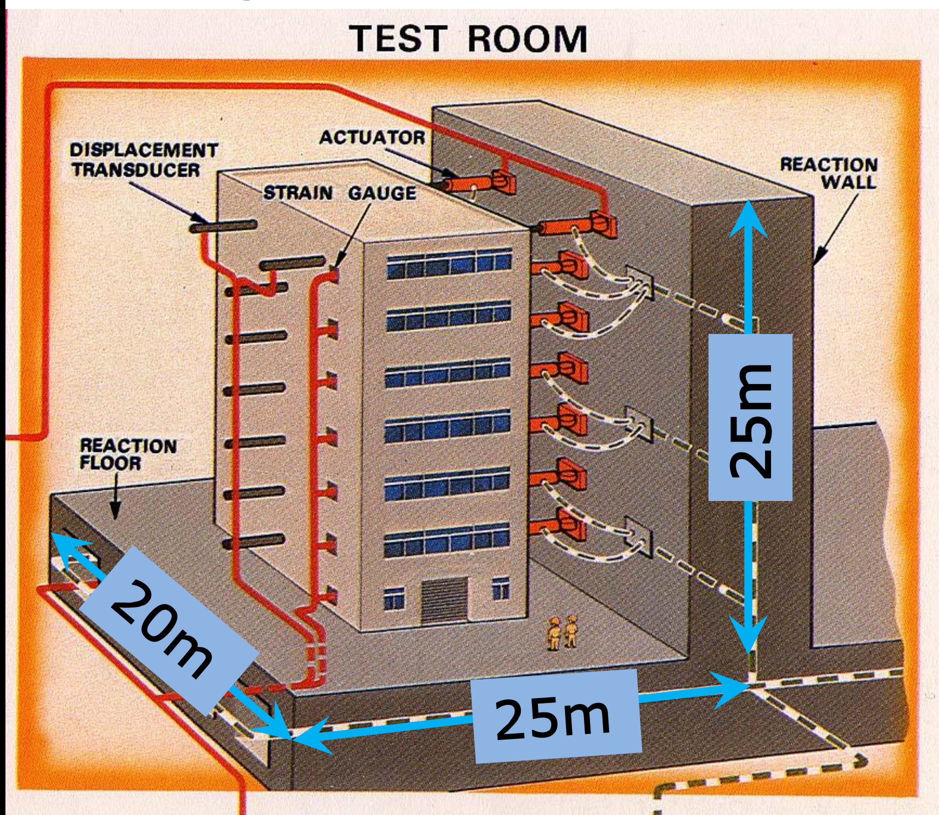


Supply (Capacity)

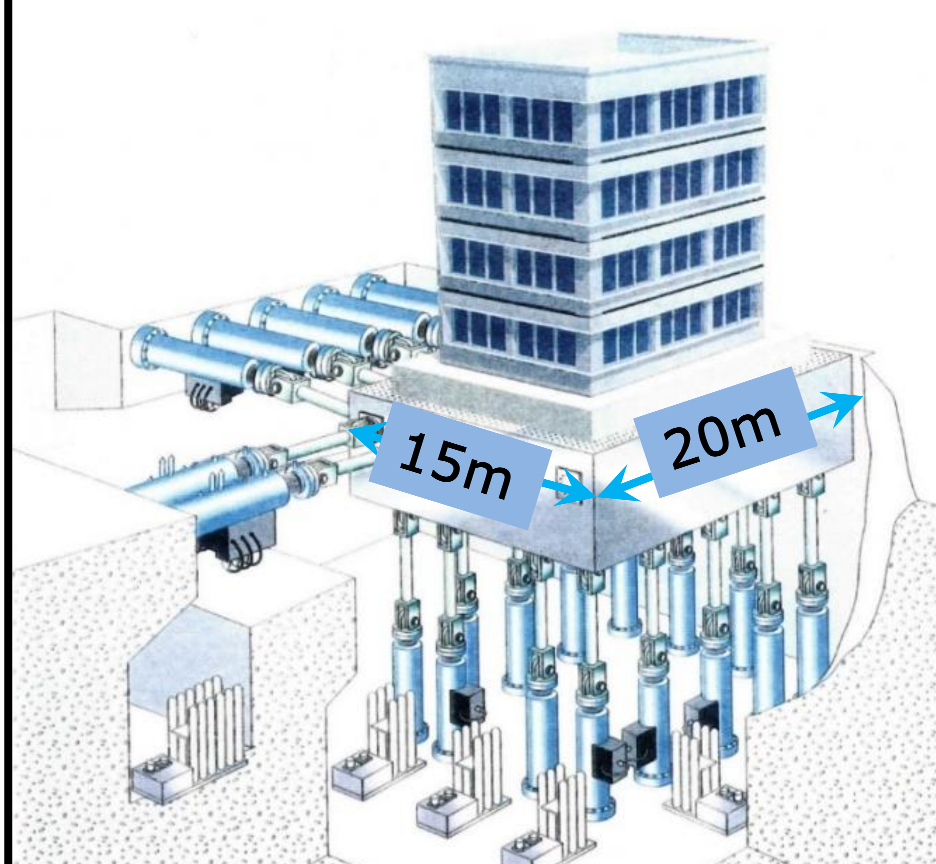


Demand (Response)

Strong Floor/Wall System



Shaking Table System



My View on Pros and Cons of Several Experimental Methods Used in Earthquake Engineering

A repertoire of experimental methods

* Quasi-static loading test (with predetermined loading histories)
* Classic hybrid simulation (based on quasi-static loading)
* Shaking table test
* Hybrid simulation combined with substructuring
* Real-time hybrid simulation

Quasi-static loading test is the center for research on capacity (supply) of structures subjected to earthquake loading.

Classic hybrid simulation can borrow the quasi-static loading test system (strong floor/wall systems with loading actuators), and the simulation can still reproduce the earthquake response behavior of tested structures (meaning very cost effective).

My View about shaking table test versus classic hybrid simulation

* Quasi-static loading test (with predetermined loading histories')

* Classic hybrid simulation (based on quasi-static loading)

* Shaking table test

* Hybrid simulation combined with substructuring

* Real-time hybrid simulation

Slow loading gives us an ample time to obverse damage evolution, which is beneficial from experimental perspective. Once dynamically loaded, everything goes too fast for us to contemplate the correlation between prediction and observation.

Rate-of-loading effect is likely to remain secondary at least for the most popular three structural materials, i.e., wood, concrete, and steel.

My View about hybrid simulation with substructuring versus classic hybrid simulation

* Quasi-static loading test (with predetermined loading histories')
* Classic hybrid simulation (based on quasi-static loading)
* Shaking table test
* Hybrid simulation combined with substructuring
* Real-time hybrid simulation

The idea sounds good, and some successful applications reported. However, in real structural systems with much redundancy and consisting of many members and elements, it is often hard to designate and extract the tested portion and treat the rest as the numerical substructures. Once such extraction is doubted as "too dubious," the entire test result will not be trusted.

We often encounter the situation such that the boundaries between the experimental and numerical portions become cumbersome and it is hard to realize the boundaries in the test.

My View about real-time hybrid simulation versus classic hybrid simulation

* Quasi-static loading test (with predetermined loading histories')
* Classic hybrid simulation (based on quasi-static loading)
* Shaking table test
* Hybrid simulation combined with substructuring
* Real-time hybrid simulation

The idea sounds good, too, and some successful applications reported. However, there is no real-time hybrid simulation ever reported in which realistic-size specimens were tested and multiple (say five or six or more) actuators controlled in the real time.

Actuator control in which individual actuators have to move larger and more differently to each other may be more difficult than actuator control to activate the shaking table in 3D.

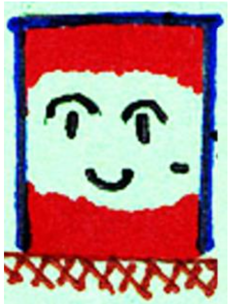
Quasi-static loading test VS Classic hybrid simulation: Classic hybrid simulation is part of the general concept of quasi-static loading test, needing no extra experimental facilities. It is a bonus as it serves as a tool to offer information on "demand."

Classic hybrid simulation VS Shaking table test: Slow loading gives us an ample time to obverse damage evolution. Once dynamically loaded, everything goes too fast. Rate-of-loading effect is likely to remain secondary at least for most popular structural materials, i.e., wood, concrete, and steel.

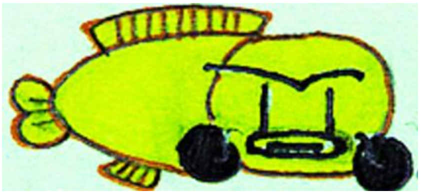
Classic hybrid simulation VS Hybrid simulation with substructuring: In real structural systems with much redundancy, it is often hard to designate and extract the tested portion and treat the rest as the numerical substructures. We also encounter cases when the boundaries between the experimental and numerical portions become very cumbersome to realize.

Quasi-static loading test VS Real-time hybrid simulation: There is no real-time hybrid simulation ever reported in which realistic-size specimens were tested and multiple (say five or more) actuators controlled in the real time.

Conclusion – Which one of the two do you take?

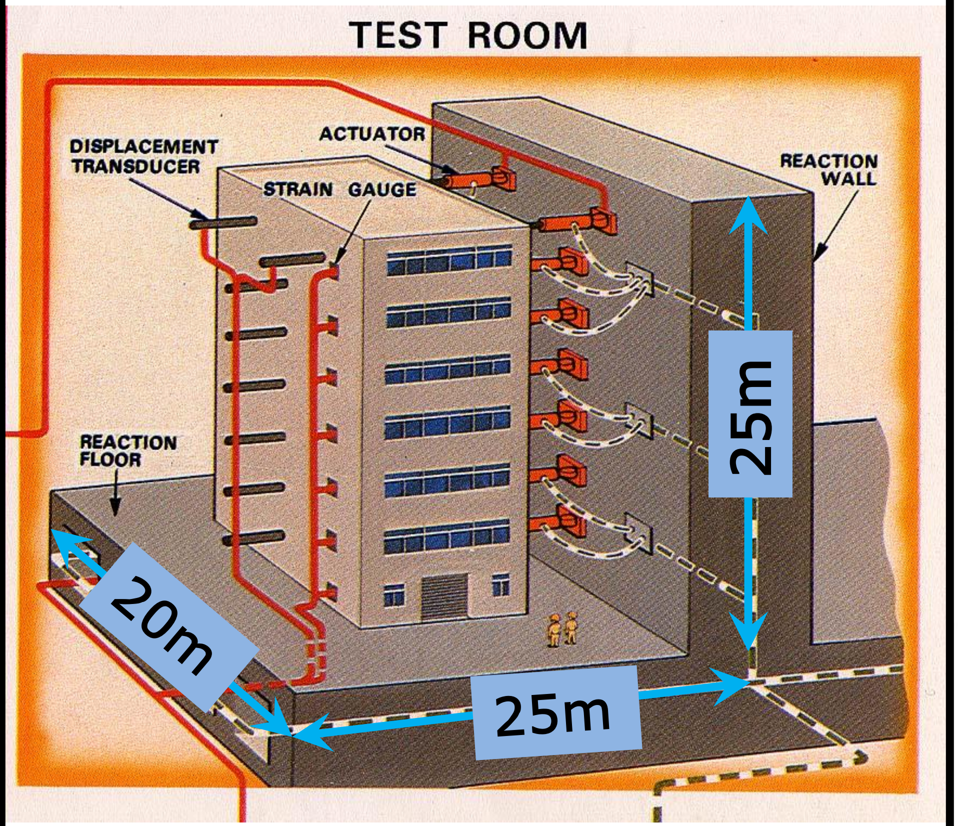


Supply
(Capacity)



Demand
(Response)

Strong Floor/Wall System



Shaking Table System