EXPERIMENTAL SETUP FOR DYNAMIC TESTING

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Presentation Outline

- Introduction
- Types of dynamic testing
  - Real earthquake experience
  - In-situ test
  - Cyclic loading test
  - Shaking table test
  - Pseudo-dynamic test
- Summary

Introduction

- Testing and experimentation are important for seismic evaluation.
- Laboratory testing is most applicable to experimental analysis.
- Experimental analysis can be performed on either **un-scaled prototypes** or **scaled models** of elements.
- Developments in **computer** and electronics industries have made experimentation a **competitive proposition**, especially for the study of **complex behavior**.

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Objective

- To easily understand the structures' **response** to an earthquake.
- To **observe** how **stable** the structure is during earthquakes.
- Qualification of a structure under seismic loads, to make sure that it will be "**functional**" **during** or **after** the earthquake.

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Objective

- The output of the test is to provide qualitative or quantitative data to assess the seismic behavior of a structure.
- For validation and calibration of analytical models of the structure on the “whole” model or part of the structure.
- To **accelerate** the development of **seismic isolation equipments** and **minimize** the **damage** caused by an earthquake.
- Validation of specific design principles for special construction, especially when the standards are lacking .

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Experimental test setup includes:

- Test object
- Excitation system
- Control system
- Signal acquisition and modification system

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Different Categories of Seismic Tests

- Real earthquake experience
- In-situ tests
- Cyclic loading test
- Shaking table test
- Pseudo-dynamic test

Real Earthquake Experience

- Feedback from real EQ used to check and calibrate seismic design and construction practices.
- It is the basis of determination of the intensity correlating damage to vulnerability and losses predictions.
- Drawbacks are: unpredictiveness of the occurrence time, type of input signals, amplitude, lack of control of the situations, …etc

In-situ tests

- The actual prototype is excited by ambient vibration or by artificial excitation with centrifuge or hydraulic exciter, explosion …
- It is employed to validate frequencies and mode shapes of the construction and to give some information on damping.
- Advantage: Real structure in actual condition is tested.
- But it is not possible to apply strong input energy, if the structure to be used after

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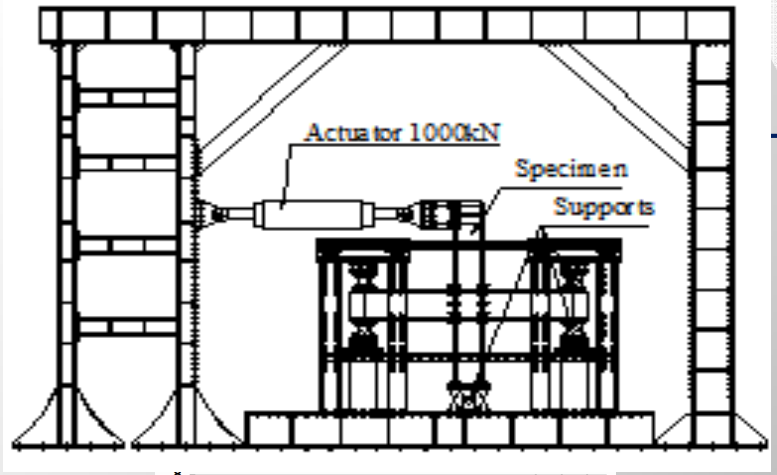
CYCLIC LOADING TEST

Cyclic loading test

- Cyclic test is a type of test in which a product, material, or object of interest is subjected to **repeated cyclic testing**, instead of a single test cycle.
- It involves loading and unloading, to recheck **product performance** at **various intervals**.
- The cyclic testing consists of a **slow application of the load** with **deflection control**. The application of the load under deflection control allows for the **evaluation** of **structural performance** in the post elastic range.
- The cyclic testing, generally performed at **progressively increasing amplitudes**, have as purpose to **simulate** the **alternating character of the seismic load.**

Cyclic loading test

- This test method can show not only the capacity of a product when new, but also the **performance over time**, looking at how issues like **wear** and **corrosion interact** with the product over its **lifetime**.
- The cyclic testing is generally used to **evaluate individual elements performances** (beams, columns) or small assemblies (as beam-to-column connections).
- Cyclic testing is performed with the assistance of a variety of test equipments.
- Reaction walls are commonly used.
- Largest reaction wall is in USC at San Diego with an area of 946 square meters and 15 m height.



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Experimental setup

Constant axial load

Reversed cyclic lateral loading

Test specimen

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Advantages of Cyclic Loading

- To show how a structure performs over time in a variety of environments.
- It is also beneficial to know how far they can be pushed before they will start to **experience problems**. This information may be used to address issues like **maintenance scheduling .**
- To evaluate individual elements performances (beams, columns)

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Drawbacks of Cyclic Loading

- The cyclic loading requires relatively **high investment.**
- It is **not able** to **reproduce** two of the most important structural features under seismic action.
  - Strain rate- much lower in the experimental case than in reality, and which is neglecting the dynamic effect of the seismic action.
  - Deflection history- which in case of a real earthquake has a random character (aspect) and does not increase following a progressive predetermined pattern.

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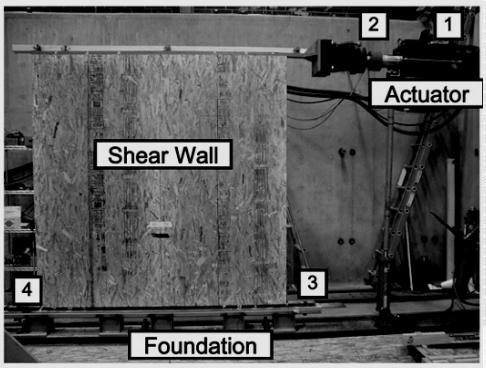
Example of Cyclic Loading

- Cyclic Load testing of Partially and Fully anchored Wood-Frame Shear Walls
- (Oregon State University)



1. Internal LVDT – Displacement at top of wall
2. Load Cell – Applied load at top of wall
3. LVDT – Uplift (inboard end)
4. LVDT – Uplift (outboard end)

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Example of Cyclic Loading

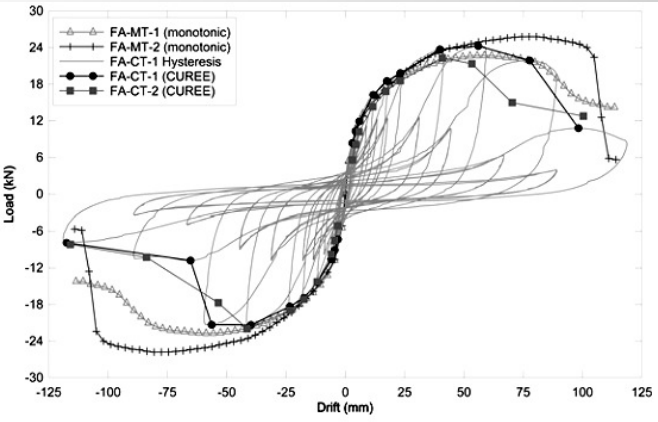

Figure 6. Backbone curves of fully anchored monotonic and cyclic tests.

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SHAKING TABLE TEST

Historical background of ST

- **First shaking tables** appeared in the **30s** with a very limited capacity. **Largest** tables appeared in the **60s** in USA (UC Berkeley), Japan, France (in 1968 in Saclay) and Italy.
- Largest table is in Japan at National Institute for Earth Science and Disaster Prevention (NIED) with a 6 DOF, payload of 1200 tons and 300 m^2 (20m x 15m) area.

Shaking Table Tests

- The shaking table is an experimental device built of a platform, moved by **actuators**, which are able to **induce** a **movement** similar to that observed during earthquakes, including reproductions of **recorded** earthquake time-histories.
- Test specimens are **fixed** to the platform and **shaken**, often to the **point of failure.**
- Using **video records** and data from transducers, it is possible to interpret the **dynamic behavior of the specimen.**

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Shaking Table Tests

- Devices differ by **physical dimensions** and the number of degrees of freedom for which deflections or rotations may be imposed.
- The shaking table is able to reproduce most accurately the loading conditions on structures during earthquakes.
- They are subjected to conditions **representative** of **true earthquake ground motions.**

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Main parts of Shaking Table

- **A rigid table** - must have a high rigidity and a large capacity of displacement with limited distortions.
- **Actuators** -composed of a cylinder with bearings, a piston, one or several servo-valves and displacement transducers
  - Electro-dynamic shaker
  - Hydraulic actuator

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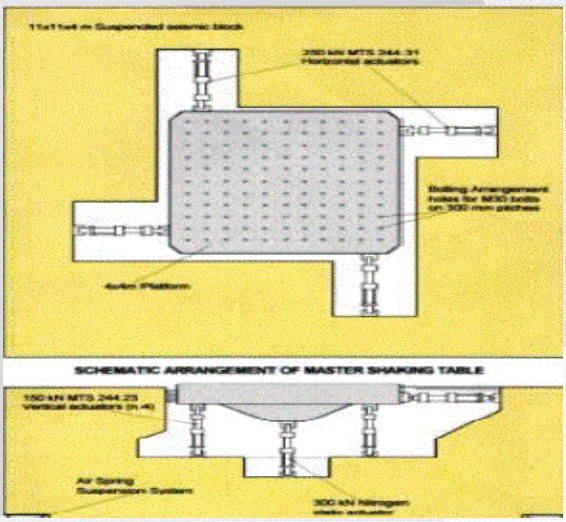
Main parts (continued)

- **A concrete "reaction" mass** – supports the table
- **Control system** - control of the table input motion
- A computer to generate the program signal



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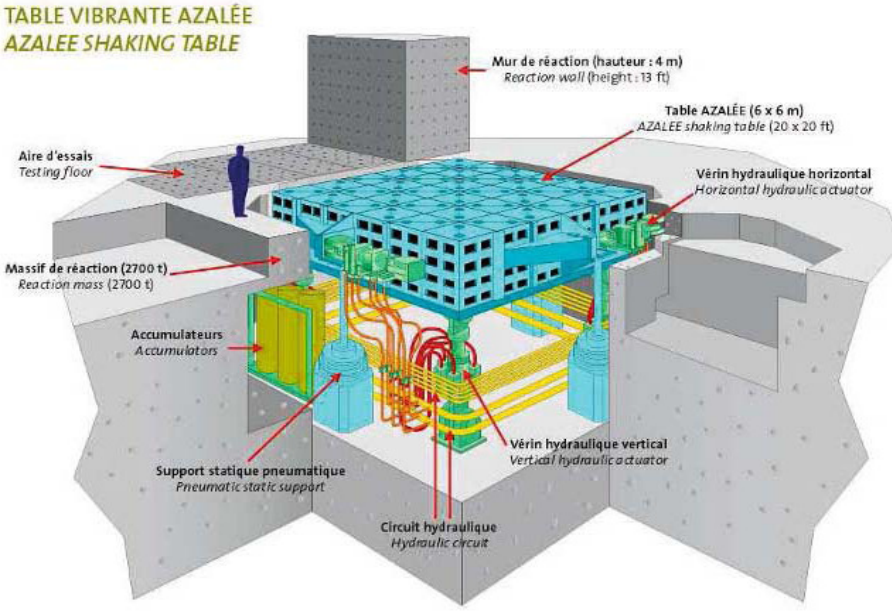

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Types of input motion for ST

- Square wave
- Sinusoidal wave
- Narrow band signal with several distinct frequency components
- White noise, modified by high and low-pass filtering
- Actual earthquake time histories with various model scaling factors

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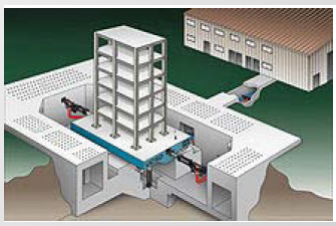
Example of Shaking Table Test Models (Tongji University, Shanghai)

Test model on the 4 X 4 meter shaking table

Examples of Shaking Table



Examples of Shaking Table

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Drawbacks of Shaking Table

- The required **cost** to built such a device is particularly **high**, requiring significant material resources for the initial construction and maintenance.
- Do not allow for **natural scale** testing.
- The **short time** required to perform this testing makes it difficult to make **accurate observation** of structural response.

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PSEUDO-DYNAMIC (PSD) TESTING

PSD HISTORICAL BACKGROUND

- The concept was proposed for the first time by Hakuno et al (1969) and Takanashi et al. (1974).
- Some developments of the techniques were implemented in USA at UC at Berkeley and the algorithms and overall control significantly improved

Pseudo-Dynamic Testing

- PsD test can be used to assess the seismic response of structures at **natural scale** in a **better** way**.**
- The PsD is a hybrid technique, coupling test and computer analysis.
- The desire to test large model pushed the development of PsD together with the improvement of **numerical** and **computer techniques**.
- Describes the dynamic response of a structure based on a model with a finite number of dynamic degrees of freedom.

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PsD Laboratory Equipment

- The laboratory must be equipped with:
  - Displacement transducers
  - Force transducers
  - Servo-hydraulic actuators
  - Reaction walls- The reaction wall serves to support actuators which apply load on the structure.
  - A strong floor - serves to support the structure itself.
  - Computers

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Steps in PsD Testing

- Numerical model is analyzed under the action of an accelerogram representing the seismic motion to which the structure is subjected.
- Displacements are obtained.
- Displacements are applied to the test structure by servo-controlled hydraulic actuators connected to the reaction wall.
- The force transducers record the forces caused by the displacements.
- Information is transmitted to the computer with the purpose of integrating the equation of motion in the next step.

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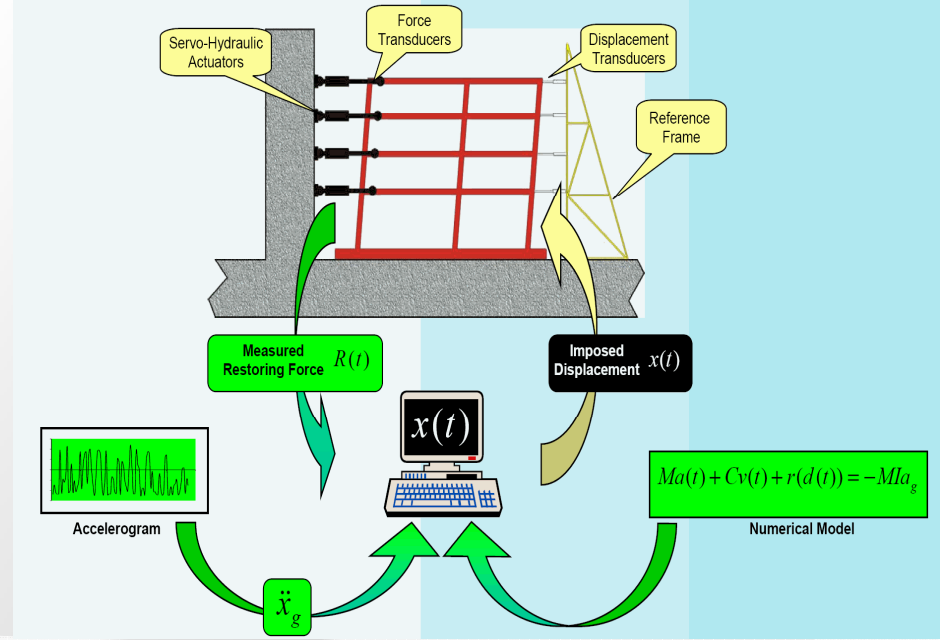

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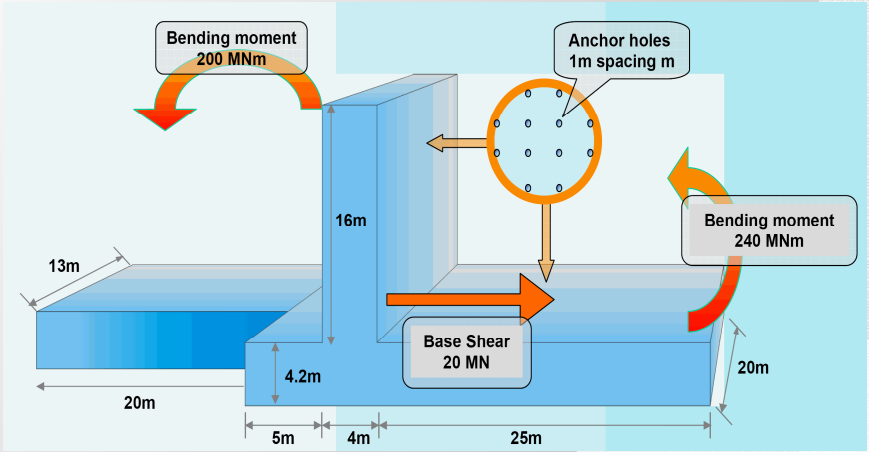
Reaction Wall at ELSA (Italy)



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Advantage of PsD

- Can be performed at **real scale**:
- Test can be done **slowly**:
  - **highest quality** in the measurements
  - **continuous observation** and monitoring
  - full control of **collapse point**
  - possible modification of measurement set-up

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Disadvantage of PsD

- Tests are performed at **"reduced" velocity**: some visco-elastic materials, with a low damping depending on velocity, are not well represented.
- Force application at a few nodal points or DOFs→ **inadequate** for structure with **highly distributed mass** since masses are assumed to be concentrated.
- The **vertical excitation** is usually **not considered**, which may cause some troubles. Usually **limited** to **horizontal** component of seismic excitation.

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Comparison of ST &PSD Testing

Shaking Table Testing	Pseudo-Dynamic Testing
Very expensive	Relatively cheaper
Physical dimension of the model is limited	Allows for natural scale testing
Loading rate is taken into consideration	Effect of loading rate not directly considered
Can be applied to structures with distributed mass	Not appropriate for distributed mass structures
Short duration → detailed observation of response is difficult	Long duration → detailed observation of response is possible

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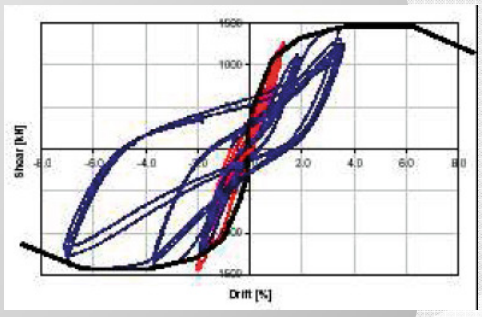
Examples (ELSA Laboratory, Italy)



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Examples (Lehigh Laboratory, USA)

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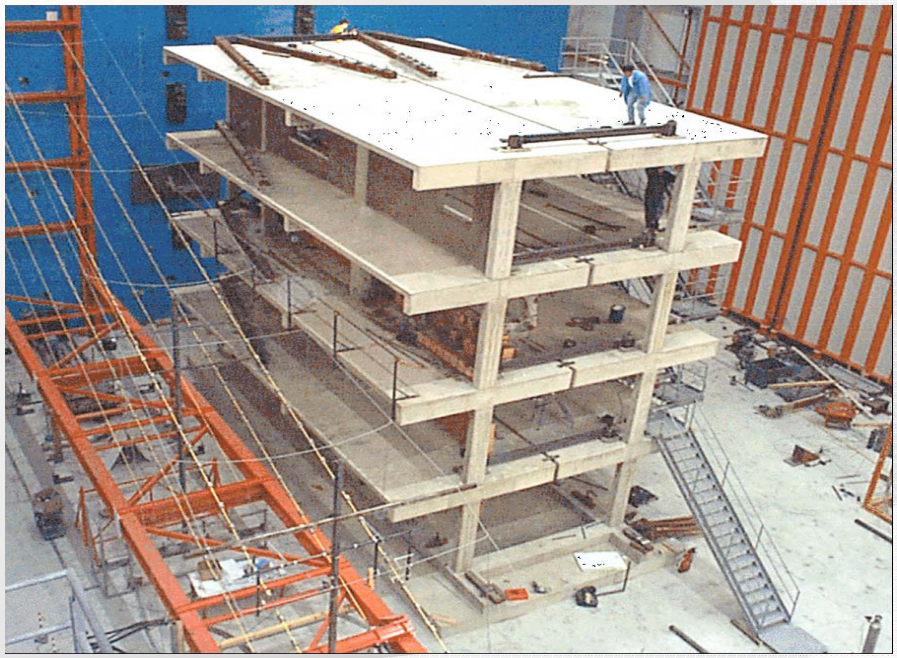

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FLATSLAB FRAME TESTING SET-UP AT ELSA LABORATORY

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Summary

- Even though, experimental set up for dynamic testing is an expensive procedure, it must not be ignored.
- The new method like the internet based pseudo-dynamic test method gives **effective results .**
- It helps to exchange information between different laboratories around the world.
- By doing these experiments, the structures' response to an earthquake can be understood. The results will show how stable the structure is during earthquakes.
- The outcome of the dynamic testing can be used for development of seismic controls and minimize the damage caused by an earthquake since a structure must be able to sustain its main functions of **safety** and **serviceability**, during and after an earthquake exposure.

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THAT IS ALL FOR TODAY!

Please read the books

"*Advanced Earthquake Analysis*" edited by Alain Pecker, and "*Seismic Design, Assessment and Retrofitting of Concrete Buildings*" by Michael N. Fardis

for additional information.