Module 4 – TEST SYSTEM – Part 1
SHAKING TABLE – TECHNOLOGY
ACTUATORS – PUMPS PERFORMANCES

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The principal methods are:

- Quasi-static loading test method,
- Shaking table testing method,
- Effective force method,
- Pseudo-dynamic testing method,
- Real time pseudo-dynamic testing method,
- Real time dynamic hybrid testing method,
- Centrifuge tests
Quasi-static loading test method
The test specimen is subjected to slowly changing prescribed forces or deformations by means of hydraulic actuators.

Effective force method (EFT)
The method consists to apply dynamic forces to a test specimen that is anchored rigidly to an immobile ground and to perform real-time earthquake simulation.
Pseudo-dynamic testing method (PDT)
That method consists to apply slowly varying forces to a structural model. The motions and deformations observed in the test specimens are used to infer the inertial forces that the model would have been exposed to during the actual earthquake. The method uses substructure techniques.

Real time pseudo-dynamic testing method
This method is the same as the pseudo-dynamic test except that it is conducted in the real time. This method introduces problem in control, such as delay caused by numerical simulation and actuators.
Shaking table testing method
The test structures may be subjected to actual earthquake acceleration records to investigate dynamic effects. The inertial effects and structure assembly issues are well represented but the size of the structures are limited or scaled by the size and capacity of the shake table.
Real time dynamic hybrid testing method
That method allows to combine shaking table tests and real time substructure techniques. For large structure, which cannot be test on shaking table, a part of the structure is represented by a mockup tested on the shaking table and the other part of the structure is modeled and theirs effects are applied by additional actuators using substructure techniques.

Centrifuges
For soil tests and soil-structure interaction, tests can be performed on reduced scale mockup with centrifuges.
Some large shakers allow providing static load support up to 5000 kg. The addition of a slip table extends the capabilities. The biggest performances are about:
Useful frequency range for vibration control from 5 to 2500 Hz
Up to ±25 mm for displacement available
Maximum vibration force rating: 160 kN.
Excitation mono axial only
Advantages
Large frequency range of excitation and specially at very high frequency (up to 2000 Hz), Low distortion.

Disadvantages
Very low stroke (1 or 2 inches), Does not run at very low frequency (under 2 or 5 Hz), Important volume or size, Very expensive, Limited forces, Limited static load compensation.
Hydraulic actuators

**Advantages**
Long stroke (200 mm and over),
Important force or power,
Multi axial excitations are possible,
Low volume or size,
Limited cost.

**Disadvantages**
Frequency range limited to 100 Hz or 300 Hz,
Important distortion
Low velocity.
For seismic tests, all laboratories use hydraulic actuators because it is necessary to have important stroke, important forces at low frequency (lower than 35 Hz).
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Shake Table System

Shaking Table
Transfer Functions
Servo-hydraulic system
Three-stage Servovalve
Servovalve Actuator
Payload
Components of a shaking table

- the plate,
- actuator(s),
- servo valves,
- accumulators,
- hydraulic pumps,
- piping system,
- cooling system,
- controllers and associated sensors.
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- a cylinder with hydrostatic bearings [Servotest] or special bearings with very low friction coefficient [MTS],
- a piston,
- two swivels (one at each extremity),
- one or several servo valves,
- a LVDT transducer in the piston,
- a small LVDT in the servo valve,
- a pressure sensor,
- some time a load cell.

several types of linear actuator:
- Single-acting (A)
- Double-acting, single rod (B),
- Double-acting, double-rod (C).
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**Servovalve**

The servo valve is the heart of the system. It is a kind of hydraulic amplifier which gives oil to the actuator as function of a low level signal.
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*The voice coil servo valve
The Flapper nozzle valves servo valve
 Operating Principle

- **Working Parts**

  - Pilot or First Stage

  - Power or Second Stage

Transformation: electric signal (low power) in hydraulic force (high power)
Operating Principle

- **Pilot Stage Hydraulic Amplifier**
  - Armature and Flapper are rigidly joined and supported by a thin wall Flexure tube.
  - Fluid continuously flows from the supply pressure “P” through both inlet orifices, through the nozzle flapper chamber then to return “R”.
  - The rocking motion of the armature/flapper throttle flows through one nozzle or the other.
  - This diverts flow to “A” or “B” or builds up pressure if “A” or “B” are blocked.
Operating Principle

- **Power Stage valve spool**
  - 4 way Spool slides within the Bushing or Sleeve.
  - The bushing contains holes that connect to supply pressure “P” and return “R”.

At “Null”, the spool is centred in the bushing; spool lands cover “P” and “R” openings.

- Spool motion to either side of null allows fluid to flow from “P” to one of the control port and from other control port “R”.
Operating Principle

- Power Stage valve spool
Operating Principle

- **Torque motor & Spool operation**

  - The electrical current in the torque motor coils creates magnetic forces on the ends of the armature.
  - The armature and flapper assembly rotates about the flexure tube support.
  - The Flapper closes-off one of the nozzles and diverts the flow to the spool end.
  - The spool then moves to open P to control port C2 and opens C1 to R
  - The spool pushes the Ball end of the Feed Back Spring, thus creating a restoring Torque on the Armature/Flapper.
Operating Principle

- Torque motor & Spool operation

- As the feedback torque becomes equal to the torque from the magnetic forces, the armature/flapper moves back to the centre position.

- The spool stops at the position where the feedback spring torque equals the torque due to the input current.

- Therefore the spool position is proportional to the input current.

- With the constant pressure, Flow to load is proportional to spool position.
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The plate

By the past, some plates were built in reinforced concrete
The plate

The majority of the plates is made in steel. To increase the performance in acceleration, a solution is reducing the mass of the plate. For this reason, some plates have been made in aluminum alloy (for example AZALEE shaking table). The advantage is to decrease the mass, by this solution is more expensive, and the plates are more brittle and there are some problems for welding.

The AZALEE shaking table has a 6 m x 6 m plate made in AG7 (aluminum alloy). The plate weights about 24 tons.
To have a good control of the table and to not overload the mockup fixed to the plate, the natural frequencies of the plate must be over the frequency range of the time history.
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<table>
<thead>
<tr>
<th></th>
<th>Mode 1</th>
<th>Mode 2</th>
<th>Mode 3</th>
<th>Mode 4</th>
<th>Mode 5</th>
<th>Mode 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test results free-free</td>
<td>80.5 Hz</td>
<td>95.7 Hz</td>
<td>116.2 Hz</td>
<td>129.2 Hz</td>
<td>129.3 Hz</td>
<td>151.1 Hz</td>
</tr>
<tr>
<td>CAST3M – free-free</td>
<td>82.4 Hz</td>
<td>100 Hz</td>
<td>120 Hz</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>SAP - free-free</td>
<td>80 Hz</td>
<td>95 Hz</td>
<td>117 Hz</td>
<td>134.5 Hz</td>
<td>134.5 Hz</td>
<td>162.5 Hz</td>
</tr>
<tr>
<td>Mode 1’</td>
<td>54.3 Hz</td>
<td>54.3 Hz</td>
<td>65.7 Hz</td>
<td>73.5 Hz</td>
<td>73.5 Hz</td>
<td>99 Hz</td>
</tr>
<tr>
<td>SAP plate fixed</td>
<td>54.3 Hz</td>
<td>54.3 Hz</td>
<td>65.7 Hz</td>
<td>73.5 Hz</td>
<td>73.5 Hz</td>
<td>99 Hz</td>
</tr>
</tbody>
</table>
Moment en pied de structure (t.m) = masse modale x hauteur du centre de masse modale

Abaque pour les modes de flexion de la maquette

Fréquence de la maquette encastrée au sol

Chute de fréquence (%)
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Accumulators

The aims of these accumulators are: to increase the performances of the actuator (distortion and velocity) accumulator pressurized at 125 bars, to decrease hydraulic shocks in the piping (return line, accumulators pressurized at 3 bars).

Discharge of the accumulator

Accumulator Charging

Flow Averaging Accumulators

\[ Q_{\text{average}} = Q_{\text{peak}} \times \frac{\pi}{2} \]

Maximum accumulator requirements are at intersection of maximum velocity and displacement limits.
Some others accumulators can be placed directly on the hydraulic line to increase the power or the global flow of the testing facility. The accumulators are pressurized when the pumps starts and they give flow for a short duration when the testing facility needs oil.
**Bladder accumulators** consist of a pressure vessel and an internal elastomeric bladder that contains the gas. The bladder is charged through a gas valve at the top of the accumulator, while a poppet valve at the bottom prevents the bladder from being ejected with the outflowing fluid. The poppet valve is sized so that maximum volumetric flow (typically to 15 liter/sec, but up to 140 liter/sec for high-flow designs) cannot be exceeded. The bladder can be replaced, usually through the fluid end of the vessel.

To operate, the bladder is charged with nitrogen to a pressure specified by the manufacturer according to the operating conditions. When system pressure exceeds gas-precharge pressure of the accumulator, the poppet valve opens and hydraulic fluid enters the accumulator. The change in gas volume in the bladder between minimum and maximum operating pressure determines the useful fluid capacity.

**Piston accumulators** have an outer cylinder tube, end caps, a piston element, and sealing system. The cylinder holds fluid pressure and guides the piston, which forms the separating element between gas and fluid. Charging the gas side forces the piston against the end cover at the fluid end. As system pressure exceeds the minimum operating level for the accumulator, the piston moves and compresses gas in the cylinder.

Each type of separated, hydropneumatic accumulator has advantages, but bladder designs are generally considered the most versatile. For shock and pulsation, for example, bladder models are ideal. Piston units are not recommended because they are too slow to react to shock waves.
Oil pressure in a bladder accumulator (or Floating piston accumulator)
Open view of accumulators (hydro-pneumatic) bladder accumulator
Open view of Floating piston accumulator
Hydraulic power system

The principal parts of a hydraulic power system are:
- a motor,
- a pump,
- a pressure regulator,
- a tank,
- a filtration system,
- an oil cooler.
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Several types of pump: Gear pumps - Vane pumps - Radial-piston pumps - Axial-piston swash-plate pump

![](image)

Gear pumps

Output: Pressurized oil

Oil Input
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Several types of pump: Gear pumps - Vane pumps - Radial-piston pumps - Axial-piston swash-plate pump

Vane pumps
Radial-piston pumps

1. Pressure compensator
2. Stroke ring
3. Drain port
4. Body
5. SAE piping connections
6. Slipper pads
7. Pistons without non-ferrous metal guides
8. Rolling bearing
9. Coupling
Radial-piston pumps

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Radial-piston pumps
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Axial-piston swash-plate pump
Axial-piston swash-plate pump
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Axial-piston swash-plate pump
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Axial-piston swash-plate pump
Variation of the output pressure/flow
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- Piston
- Cylinder block
- Suction kidney
- Pressure kidney
- Valve plate
10 cm³ trapped volume
0.3 cm³ compression volume
compression starts

angle 1°

10 cm³ trapped volume
0.3 cm³ compression volume
compression ends

angle 12°

Standard pump
0.3 cm³
11° angle
1.22 ms
14.73 l/min
~21% of 69 l/min
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- Piston
- Cylinder block
- Suction kidney
- Valve plate
- Pressure kidney
- Precompression volume
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- **11 cm³ trapped volume**
- **0.3 cm³ compression volume**

### Angle 1°
- Compression starts

### Angle 12°
- Compression ends
- Chamber refill starts

### Angle 35°
- Chamber refill ends

- PVplus
- 0.3 cm³
- 23° angle
- 2.56 ms
- 7.04 l/min
- 10% of 69 l/min

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Pump Housing Optimization reduces pump noise
- absolute reduction in noise emission
- frequency shift to better “sound”

Precompression Volume Reduces Flow and Pressure Pulsation by 40 - 60%
- no extra cost: additional casting core is offset by material saving
- minor effect on pump noise
- major effect on system noise
Several type of regulation

**Bypass regulated constant pressure hydraulic power supply**

**Stroke regulated constant pressure hydraulic power supply**

**Constant pressure hydraulic power supply with servo load**
The oil

Generally these oils are used: Shell TELLUS 46 or Mobil DTE 25
- Class of pollution ISO
  The ISO class of the oil is characterized by a code with 2 numbers relative to the number of particles with diameter > 5 microns/milliliter and with diameter > 15 microns /milliliter
  Example:
  Required Class ISO 13/9
  13 = 400 to 800 particles size 5 microns
  9 = 250 to 500 particles size 15 microns
  Limit Class: ISO15/11
  - Bulk modulus (Compressibility) = 15500 à 18000 kg/cm²
  - Flash Point (temperature) = 236 °C
  - Viscosity at 40°C = 46 mm²/s
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