Seismic Devices
DEFINITION
A Lock Up Device (LUD) is a plasto-elastic unit that provides the engineer a simple method of temporarily creating a fixed connection, when desirable, that otherwise would remain as a moveable connection. The device is sometimes referred to as a shock transmission unit or STU. The device is connected to either side of adjoining structures or between elements of structures, where expansion and contraction occur. Upon a sudden dynamic load, the device locks up and transmits the load through the structure. In effect, the device creates a rigid link within a fraction of a second and is modeled as a fixed connection during the shock loading. Once the shock load is removed, the device reverts to its benign influence and the structure behaves in a normal manner. The LUD does accommodate all slow movements associated with a bridge structure such as thermal movement, shrinkage, and creep.

DESCRIPTION
The mechanism consists of a machined cylinder with a transmission rod that is connected at one end to the structure and at the other end to the piston inside the cylinder. The medium within the cylinder is a specially formulated silicone compound, precisely designed for the performance characteristics of a specific project. The silicone material is reverse thixotropic. During slow movements caused by temperature change in the structure or shrinkage and long-term creep of concrete, the silicone is able to squeeze through the gap between the piston and cylinder wall. By tuning the desired clearance between the piston and the cylinder wall, different characteristics can be achieved.

A sudden load causes the transmission rod to accelerate through the silicone compound within the cylinder. The acceleration quickly creates a velocity where the silicone cannot pass fast enough around the piston. At this point the device locks up, usually within a half second.

Seismic forces are cyclic. The device is designed to perform in either tension or compression. As the reversal in motion occurs during an earthquake, the device locks almost instantaneously in each direction. All sudden shock loadings affect the LUD. These would also include wind loads and breaking forces.

LUD PRINCIPLE
LUD APPLICATIONS

SINGLE SPAN BRIDGE
The simple span bridge is an ideal bridge where the LUD can create strengthening through the sharing of load. As detailed below, the simple span bridge has a sliding (expansion) bearing and a fixed bearing at each pier. Any load that occurs at mid span must be accommodated by the fixed bearing. If LUDs span the expansion joints, deck to deck, the LUD locks the sliding bearing during the loading. This creates great redundancy within the structure. The applications below suggest a remedy for large brake loads. During the braking action, the LUD locks, creating a bridge that, during this shock loading, has nothing but fixed connections. Therefore, all piers and abutments are sharing the load, greatly reducing the forces of any single pier. This reduces the horizontal forces acting upon any single pier to 25% of the original design. When considering the cost of bridge replacement, this cost-effective method of strengthening the bridge should be considered.

CONTINUOUS GIRDER BRIDGE
A steel or concrete continuous girder can also be greatly strengthened the case of the four-span continuous girder below. There is only one fixed pier which must take all loads. In many bridges designed before the current AASHTO guidelines for seismic reactions, the fixed pier is unable to withstand the theoretical forces of an earthquake. A simple solution is to add the LUDs at the expansion piers so that all three piers and abutments share the seismic load. The adding of the LUDs is quite cost effective as compared to strengthening the fixed pier.
CABLE STAYED BRIDGE
Large span bridges often have extremely large displacements due to seismic reactions. The ideal large span design would have the tower integral with the deck to reduce these large displacements. However, when the tower is integral with the deck, the forces of shrinkage and creep, as well as thermal gradients, greatly affect the tower. It is a much simpler design to connect the deck and tower with LUDs, creating the fixed connection when desired but permitting the deck to move freely during normal operations. This reduces the cost of the tower and yet, due to the LUDs, eliminates the large displacements. Recently, all major structures with long spans are utilizing the LUD. These projects include the Cape Girardeau Bridge in Missouri, the Sidney Lanier Bridge in Georgia, and the Maysville Bridge in Kentucky.

RETROFIT
In the United States, the focus of bridge engineering is on the retrofitting of our nation’s bridges and highways. A major contributor to the retrofit of bridges centers on the seismic upgrading of our current bridges to the 1994 AASHTO Code. The LUD can play a significant role in assisting the engineer in upgrading the structure at a minimum cost. In addition, bridges can be strengthened against wind loads, acceleration, and braking forces. The LUD can also be used in bascule bridges, elevated light rail structures, or pipelines. The LUD can be used in both the longitudinal direction and in the transverse, acting as a shear key.

DESIGN CRITERIA
In order to design an LUD, it is necessary to know the following:

- Rate of expansion and contraction during normal operation
- Total stroke (mm, in.) of the transmission rod through full range of normal movement
- Ultimate design force to be transmitted through the LUD
- Geometry of the surrounding application
- Design code that is applicable
- Preference in corrosion protection

LUD APPLICATIONS (CONTINUED)
TechStar’s load testing capability is the largest structural bearing/dynamic STU testing facility in the USA. Statically, the testing frame has a vertical load capacity of 6 million pounds (28,000 kN). The hydraulic controls of the testing frame allow it to be dialed down for testing of small loads such as 100 kips. The horizontal capacity is 1.9 million pounds with a travel/stroke range of 15 inches (380 mm) with the same dial down capacity for light load testing. TechStar’s auxiliary STU testing hydraulic controls provide the same “in-triplet” mounted horizontal rams a dynamic capacity of 1.9 million pounds at 6.5-7.0 mm/second velocity in both tension and compression. The structural frame is rated above 2 million pounds. This is the largest dynamic load testing capability within the USA except for Caltran’s lab in San Diego. The TechStar facility is the only lab available on short notice for full dynamic testing with outside independent supervision.

TechStar has tested bearings up to 7 million pounds vertical load for State DOTs and has tested STUs for projects including for the government of South Korea.
TESTING

The LUD can be tested to determine if the desired performance is achieved. Full-scale testing of any unit is possible. Three tests are commonly required: 1) the Impressed Deflection Test, 2) the Simulated Dynamic Force Transfer Test, and 3) the Simulated Cyclical Force Transfer Test.

- The **Impressed Deflection Test**, or IDT, verifies the rate at which normal movements occur within the device. Every device must be tuned to the precise movement rate and range of the bridge application.
- The **Simulated Dynamic Force Transfer Test**, or SDFT, determines the ultimate force that the device will transfer upon lock up.
- The **Simulated Cyclical Force Transfer Test**, or SCFT, provides assurance that as the reverse cyclic movement occurs, the device locks up as intended.

Figure 4 - Schematic of Testing Press

TechStar LUD at Independent Laboratory
Note: The testing data in this section is for a 450 kip, ±6" stroke device.
1 Support bracket being readied for placement. Lifting support bracket into position.

2 Tightening bolts on support bracket. Bracket ready for LUD installation.

3 LUD attached to shipping bracket ready to be installed. Lifting LUD into position.

4 LUD attached at slide bearing. LUD has a 300 ton capacity.

5 Placing LUD into position — ready for pin placement. Stainless steel pins connecting LUD to brackets.

6 LUD attached at slide bearing. LUD has a 300 ton capacity.
LEAD RUBBER BEARINGS

Lead Core Rubber Bearings (LRB) consists of a laminated rubber and steel bearing with steel flange plates for mounting to the structure. Ninety percent of our isolators have an energy dissipating lead core. The rubber in the isolator acts as a spring. It is very soft laterally but very stiff vertically. The high vertical stiffness is achieved by having thin layers of rubber reinforced by steel shims. These two characteristics allow the isolator to move laterally with relatively low stiffness yet carry significant axial load due to their high vertical stiffness. The lead core provides damping by deforming plastically when the isolator moves laterally in an earthquake. The shims for isolators are cut to exacting tolerances by laser. The steel mounting plates are machined by computer-controlled milling machines that give high production throughput and accuracy. Molding each bearing takes 8 to 48 hours depending on the size of the bearing. The curing phase is continuously monitored to ensure that the rubber is uniformly cured throughout the bearing.
The TechStar HDRB isolators contain layers of rubber and reinforcing steel plates. These components let the HDRB isolate the bridge/building/structure due to the horizontal stiffness and they can dissipate energy up to 16% damping due to high damping rubber compound. A HDRB isolators fulfill the following requirements:

- Transmit the vertical loads due to permanent and accidental effects;
- Capacity to support horizontal loads due to service load conditions with very low displacements;
- Capacity of isolate the structure by shifting the fundamental vibration period to an optimal and safe level;
- Capacity to dissipate energy to reduce the horizontal displacement of the isolated structure with respect to the ground.

HDRB's do not damage the structure that remains due to the elastic response for high intensity earthquakes with no interruption of the structural function. This is a primary goal for strategic structures (hospitals, control rooms, etc.)
NOTABLE PROJECTS

1. Carquinez Bridge, California
2. Oakland Bay Rollout, California
3. Silver Jubilee Bridge, UK
4. Canadian National Railway, Canada
5. Geoje Bridge, South Korea