USE OF NEW AND MODIFICATION OF TRADITIONAL STRUCTURAL COMPONENTS CAN ADD TO BRIDGE SEISMIC RESILIENCY

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ABSTRACT :

Modifiying traditional structural accessories such as expansion joints and bearings can add to the structural anti-seismic resiliency by sharing horizontal loads and by eliminating component wear and post-seismic event replacement or repair. Adding Lock Up Devices (LUDs) to existing structures can increase the horizontal load capacity of an existing structure by increasing the efficiency of the existing structural design to maximize its potential capability. The results can be significant improvement in the overall structural performance with improvements of 30-50% beyond the original capacity of the structure.

KEYWORDS:
anti-seismic;load sharing;structural efficiency;quantification;

1. WHAT IS NEW IN BRIDGE STRUCTURAL COMPONENT USAGE?

Shock Transmission Units (STU)/Lock Up Devices (LUD)

A shock transmission unit (STU) is a simple device which provides the engineer a method of temporarily creating a fixed connection, when desirable, which would during normal operations remain as a moveable connection. The device is sometimes referred to as a Lock-Up Device (LUD). The unit is connected between adjoining separate structures or between elements of structures and has a benign effect on the bridge during normal periods of time. Upon receipt of a sudden short duration shock (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 when the sudden load is applied, affording the possibility of sharing the load throughout the structure. However, once the shock load is removed the device again reverts to its benign influence and the structure behaves in a normal manner.

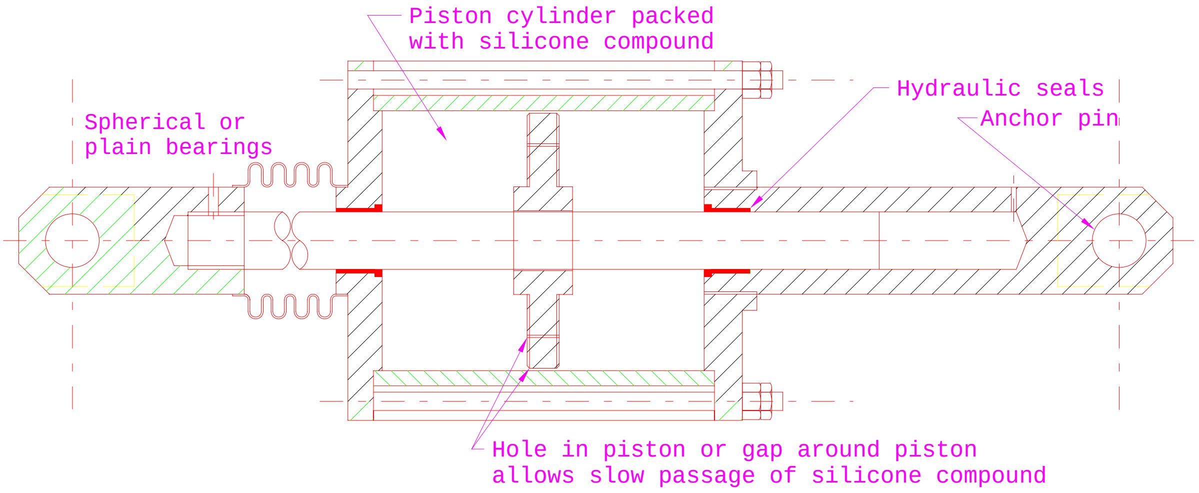


Fig. 1

In Fig. 1, the mechanism is detailed. The unique characteristics of the unit are achieved by migration of the medium around the piston when very slow movements occur. Therefore, slow structure movements such as temperature change, creep, shrinkage, post tensioning effects and settlement are adequately permitted as the medium will slowly squeeze past the piston and the side wall of the cylinder. However, the medium has a very special characteristic, when stationary it acts as a solid, but will flow very slowly under a constant pressure of slow velocity, but will react again as a solid upon a sudden impact of high velocity. TechStar developed a special silicone compound which flows between the piston and cylinder for these slow movements, but is unable to pass between the piston and cylinder during the impact loading due to the thixotropic characteristics.

Lock-Up Devices are really nothing new, and has been adopted by AASHTO for use in its design/construction. First introduced in the 1930s and then reintroduced by TechStar to growing acceptance starting in 1990. The advantages of LUDs are numerous and offer the bridge engineer many applications which will result in a less expensive bridge design. The concept of “sharing” the load throughout the structure is the most obvious. By connecting the device to normal expansion areas of a bridge, the structure during the normal course of operation will behave in a normal manner (i.e. the bridge would move as if the device were not present). However, at the first instant of a sudden load applied to the expansion area, the device creates a temporary fixed connection. The LUD should be considered a tension / compression bar in its capacity to transmit the load across the expansion joint or from the superstructure into the substructure. Since the 1990 re-introduction, TechStar has produced LUDs for many project including the largest capacity LUDs ever utilized. These 25,000 kN (ULS) LUDs were used on the San Francisco-Carquinez Bridge retrofit completed in 1997. Most applications use smaller devices on the scale of 100-450 kips (450- 2000 kN).

The LUD is connected by brackets and pins to the superstructure and/or substructure, which permits the normal translation of movement. The transmission rod (piston) passes through the entire length of the cylinder so that the volume of the silicone medium remains constant at all piston positions. Under slow movement between the structures the medium flows around the piston and is displaced from one end of the cylinder to the other. The faster the piston is made to move in the cylinder, the greater the force required to do so due to the increasing resistance of the compound until a point is reached when flow of the compound ceases and the unit locks.

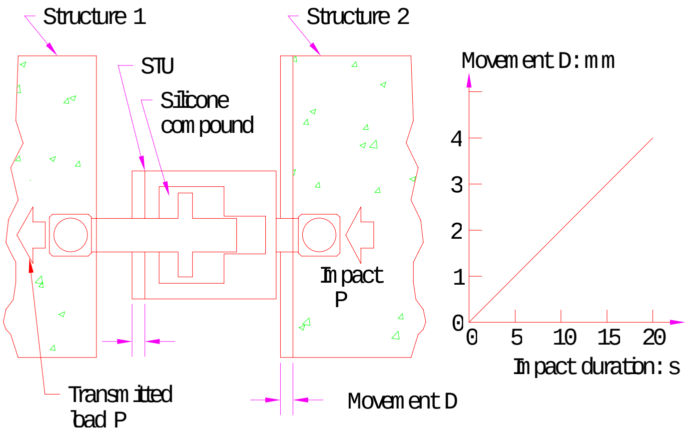


Fig. 2

When a short term dynamic load if applied through the transmission rod the impact tensile or compression force is passed along the load path of the transmission rod / piston head / silicone medium / cylinder to the adjacent structure or structure element. The rating of the LUD unit defines the maximum impact force which is to be transmitted. The length of the transmission rod is designed to meet the expectations of the normal movement of the bridge at that location, while resisting the axial forces of the specified shock design load. The unique thixotropic characteristics of the silicone medium are present through a wide range of temperatures, therefore, the LUD can be relied upon to perform consistently under all climatic conditions. In Fig. 3 the normal operation is shown and the graph depicts resistance typical of what might be applied by a LUD during the slow movement of the bridge.

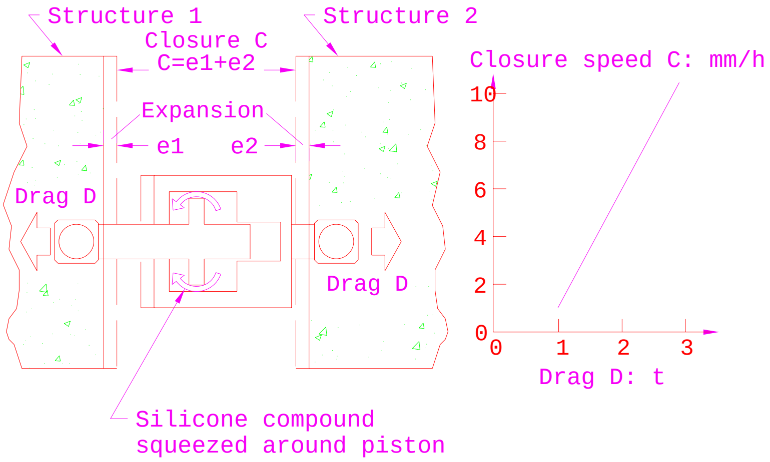
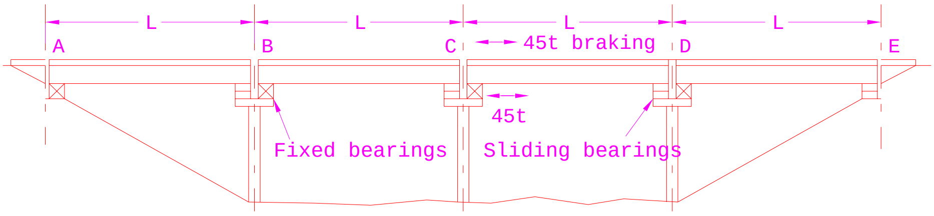


Fig. 3

2. STRENGTHENING AND ADDED RESILIENCY IN BRIDGE APPLICATIONS

The LUD permits the bridge engineer the to design a traditional bridge with a virtually maintenance free device that has no effects on the normal bridge operations. The device expands and contracts freely in response to all the long term movements which can be anticipated. The device does act as a temporary rigid bar connection and can be modeled as a fixed connection during impact loads such as seismic loads, road or rail braking and acceleration forces, ship collisions and in retrofit applications to upgrade the load rating of a bridge.

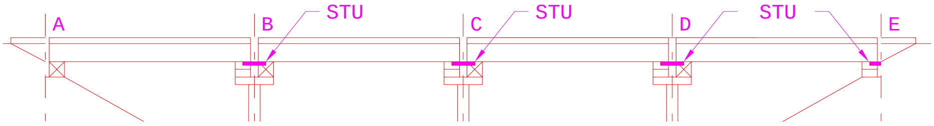
In multi-span structures the LUD is perhaps best applied. When a bridge has a series of abutments and piers, column or bents, the LUD can be used to connect all of these locations and create a continuous structure for an event which would apply a dynamic load to the structure. The bridge engineer has always wished he could tie the structure together but has been unable till now to do so because a bridge must be permitted to move. The LUD can in effect reduce the amount of load on any given part of the structure.



Typical 4 span, simply supported bridge

45t traction/braking in span	Horizontal load on support: t				
	A	B	C	D	E
AB	45	-	-	-	-
BC	-	45	-	-	-
CD	-	-	45	-	-
DE	-	-	-	45	-

Total support horizontal support capacity required for traction/braking =
= 45t + 45t + 45t + 45t = 180t



Addition of 4 STUs
(for simplicity assume equal stiffness at all supports)

45t traction/braking in span	Horizontal load on support: t				
	A	B	C	D	E
AB	9	9	9	9	9
BC	9	9	9	9	9
CD	9	9	9	9	9
DE	9	9	9	9	9

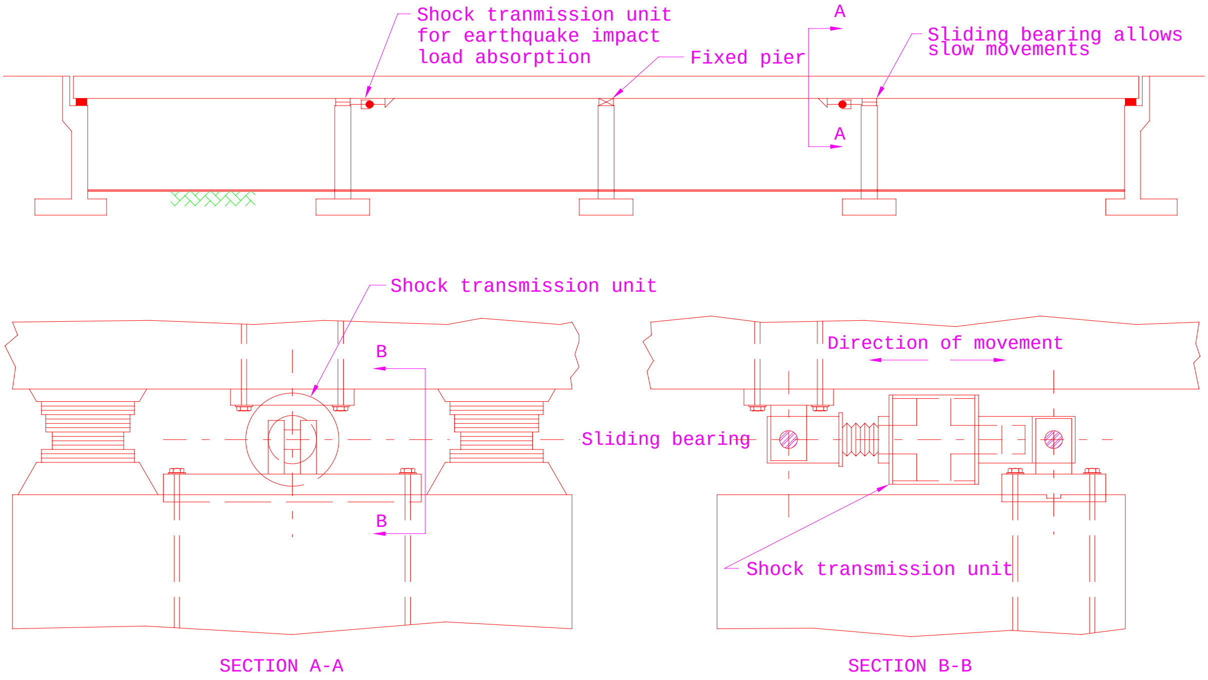
Total support horizontal support capacity required for traction/braking =
= 9t + 9t + 9t + 9t + 9t = 45t

Fig. 4

In Fig. 4, a typical simple span bridge is illustrated. The design calls for each span to have an expansion bearing and a fixed bearing. The breaking forces and longitudinal acceleration forces must be taken by the fixed bearing and the substructure below. Regardless of the number of spans the effect of placing the LUDs to work in series does not change.

By placing LUDs between all the simple support spans, the bridge in effect is made continuous for the purpose of any force which would act upon any individual part of the bridge. The forces affecting one span would now be shared by all fixed bearing locations and the abutment with the braking forces distributed throughout the entire bridge. The first table indicates the actual forces applied to the fixed piers for a braking force of 45 tons. The second table indicates the reduction in force of 20% of the original design at all fixed locations due to the temporary fixing of the expansion locations by the LUD. This is a significant reduction in force and may dictate that the bridge might not have to be replaced.

The LUD can also be applied to a continuous structure. A typical viaduct having a central fixed pier or a fixed abutment and sliding, rocker, or elastomeric bearings at all other locations can benefit from the application of LUDs as well. Consider the seismic loading criteria, the lone fixed pier must withstand all the forces associated with the seismic event. However, by placing the LUDs at all sliding connections as illustrated in Fig. 5, the load is distributed between all piers, not just the fixed pier. This concept is a significant advantage when the design criteria dictates an overload of the fixed pier.



SECTION A-A

SECTION B-B

Fig. 5

The LUD utilization on a concrete box girder design, such as in California, with integral columns and hinge expansion joints is shown. The placement of LUDs creates a fixed connection during an earthquake, thus sharing the seismic load with all columns. A hinge joint is often located adjacent to a short column which lacks the ductility to resist the earthquake forces by itself. By placing the LUD at the hinge the load is transmitted across the hinge to the next span and a much taller column which shares the load, reducing the forces applied to the shorter column. This can save a bridge from disaster. In addition, the LUDs prohibits the banging of expansion joints during less severe seismic events.

3. ASIAN LUD APPLICATIONS

Lock Up Devices have been used on bridge applications within Asia for the past ten years. One of the first applications was on the Jamuna Bridge located in Bangladesh. For this application, the LUDs were coupled within the shear keys of the structure. Following the success of this application, Bangladesh has used LUDs on several large structures (Figure 6). India has also used LUDs on bridge structures. Perhaps more than any other Asian country, South Korea has used LUDs often within the bridge bearings. These have been installed on several prominent long-span structures and on the high-speed rail test section. In this regard, South Korea was one of the first users of the technology. Taiwan has used LUDs extensively within their High Speed Rail Sytem. Hong Kong structures have used this technology and China continues to consider the product for further potential regional applications.

Fig. 6

4. LOCK UP DEVICES COMBINED WITH BEARINGS

Lock Up Devices can be combined into the structural bearings of a bridge to provide a single multi-functional load transmitter and movement device. In this application that bearing can be designed with its anchorage to accept the seismic loading. The addition of Lock Up Devices to Spherical Bearings has minimal impact on the bearings overall height, depending on load. Yielding elements which absorb load can be added to the bearing if either a Seismic-Fuse or Bearing Damping property are desired beyond the load transfer of a LUD/Rotational Bearing device through the structure. (Fig. 7)

Fig. 7

5.USE OF ANTI-SEISMIC "SWIVELING CAPABLE" MODULAR EXPANSION JOINTS FOR ADDED SECURITY ASSURANCE

A growing trend in anti-seismic bridge design is to minimize any potential damage at the expansion joints from earthquake displacements. Often these anticipated seismic displacements are beyond the normal thermal longitudinal movement capacity of the expansion joint and also anticipate transverse movements (sideways) and vertical rotations. By utilizing "swiveling-capable" modular expansion joints, designers are able to mitigate these problems (Figure 8). The overall goal in selecting such a multi-directional movement expansion joint for the anti-seismic application is that the expansion joint remains functional for emergency vehicles use immediately after the earthquake event. Overall damage to the expansion joint is minimized and any required cosmetic repair can take place without removing the expansion joint or closing the bridge.

Fig. 8 (swiveling capable boxes to permit both longitudinal and transverse movements)

Use of these type of anti-seismic modular expansion joints have been used extensively in Asia on long suspension and cable-stayed bridges in Hong Kong and China, are used in California on box-girder structures and elsewhere within the world. These have been used in Shandong Province, China on bridge rehabilitations undertaken there (Figure 9). Modifications needed by these designs from normal modern modular expansion joint systems are realitively minor. Any "Single Bar" modular expansion joint is capable of swiveling. Several manufacturers currently make such systems with sufficient experience to merit consideration. The extent of the swiveling (pivoting) and rotating of an expansion joint is a function of the geometry of the support bar boxes which permit movement of the support bars, trumpeting them to permit the required additional movements, and use of spherical bearings for vertical rotations. Extra-long support bars which extend beyond the normal thermal movement requirements are used to accommodate any longitudinal seismic movements. TechStar modular joints of this type have been used on several key bridges within the "high earthquake zone" around San Francisco, California including, the San Francisco Airport Interchanges, the Benicia-Martinez Bridge, the Carquinez Bridge, the San Francisco-Oakland Bay Bridge, and several structures in the Los Angeles freeway system. TechStar "Swiveling Capable" Modular Joints have been manufactured in China and exported for use to projects in Banglasdesh, Dubai, and to Africa.

The Rupsa Bridge in Bangladesh, a box girder bridge, was one of the first application to use these modular expansion joints in Southern Asia in the late-1990s required two TechStar expansion joints with 800 mm longitudinal and 150 mm transverse movements.

In Dubai, UAE, a large land reclamation project called Palm Jumeirah which is a large man-made island shaped like a giant palm tree extends out into the Arabian Sea. The privately developed Palm Jumeirah Island is a gateway to ultra-high luxury housing, hotels, and other tourist attractions on the palm. Connecting the stalk of the tree to the mainland is a large bridge known as the Gateway Bridge. Four large-scale TechStar modular expansion joints, each with 700 mm of longitudinal movement and 300 mm transverse movement are used.

Fig. 9 (Shandong China Installation)

There have been several attempts to validate manufacturer's capability to withstand earthquake motions while providing assurance that the expansion joint is capable of long-term performance under normal traffic. We have found that the best assurance can be realized by utilizing a very conservative loading (a high loading factor) in the expansion joint design. We recommend using a 2X (two times) AASHTO loading factor for any such applications as a minimum, irrespective of any long-term Fatigue Testing or other supporting evidence of a manufacturers' performance claims. By using 2X AASHTO, this reduces the spacing between the support bar and gains overall structural integrity to the system. This is what is required in California and has been adopted elsewhere in Asia using TechStar Swiveling-Capable Modular Joints.