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BRIDGE STRENGTHENING WITH SHOCK TRANSMISSION UNITS

D. Stephen Brown

TechStar, Inc., 532 Sutton Place, Findlay, Ohio, USA 45840

ABSTRACT

The Shock Transmission Unit, STU, provides an unique method of strengthening bridges by sharing load through all substructure components. The bridge under normal operating conditions continues to move as designed for thermal, creep and shrinkage, but upon a sudden impact the STU locks the structure creating momentary fixed condition at all expansion locations. Therefore, briefly, the bridge is fixed and the loads from seismic events are shared reducing the loads on typical fixed locations.

KEYWORDS

Shock Transmission Unit, STU, Lock Up Device, silicone compound, thixotropic, sharing of load, transmission rod

WHAT IS A SHOCK TRANSMISSION UNIT (STU)?

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.** 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.

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, in that it is reverse thixotropic. The material when stationary 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. The medium used in the STU is 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.

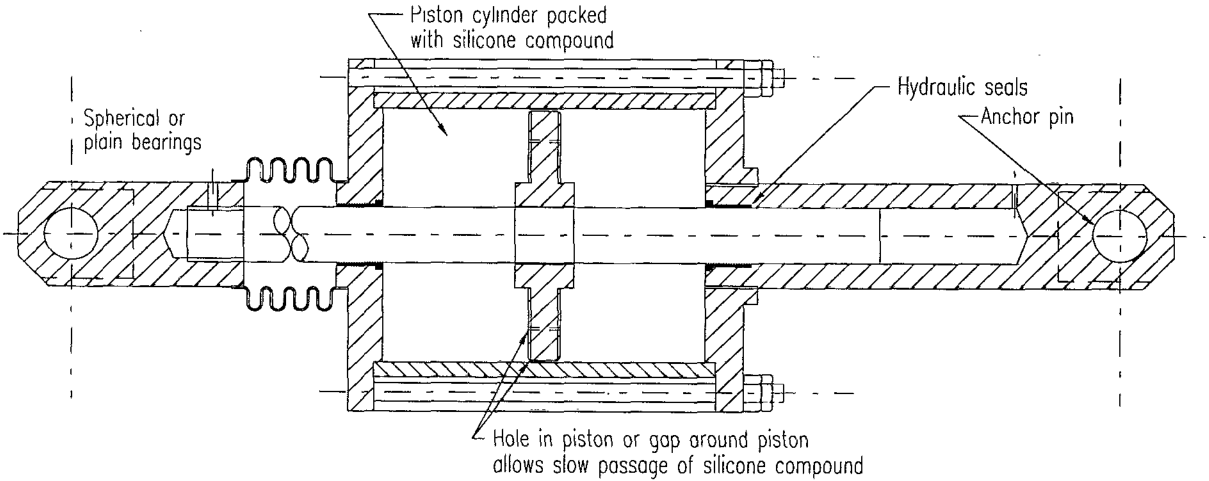


Fig. 1

The advantages of this device 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 STU 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. A series of structures or elements of structures which are subject to long term separation movements such as temperature expansion and contraction are now rigidly linked together with STUs to form a continuous structure during any short term dynamic loading. As an example, five equal-stiffness structures connected with STUs would share a dynamic load upon any one structure with all the others. This "sharing" of load offers a reduction of up to 80% of the loading on the support system of the bridge.

The STU 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.

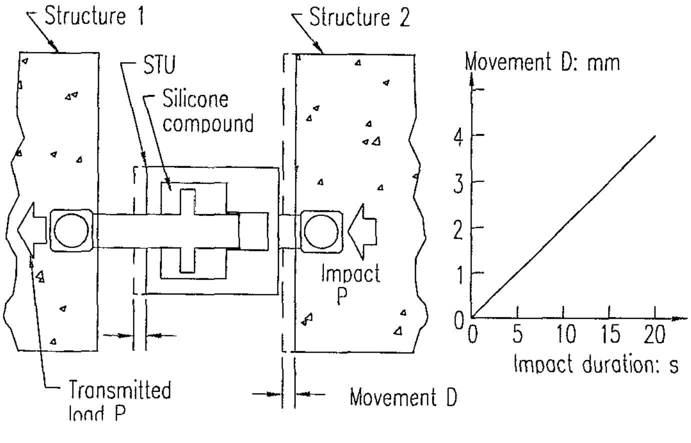


Fig. 2

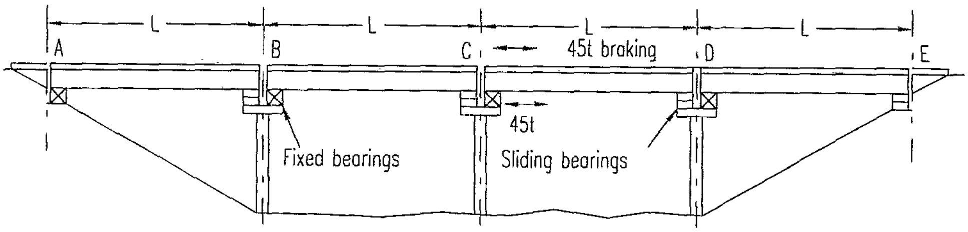
When a short term dynamic load is applied through the transmission rod the impact tensile or compression force is passed along the load path of the transmission rod / piston head / silicone medium / cylinder to the adjacent structure or structure element. The rating of the STU unit defines the maximum 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 STU 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 STU during the slow movement of the bridge.

USE OF STUs IN BRIDGE APPLICATIONS

The STU permits the bridge engineer the to design a 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 STU is perhaps best applied. When a bridge has a series of abutments and piers, column or bents, the STU 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 STU can in effect reduce the amount of load on any given part of the structure.

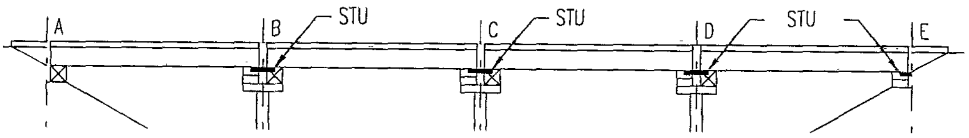
In *Fig. 4*, a typical simple span bridge is illustrated. The design calls for each span to have an expansion bearing and a fixed bearing. The breaking forces and longitudinal acceleration forces must be taken by the fixed bearing and the substructure below. The friction of the expansion bearing is normally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



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

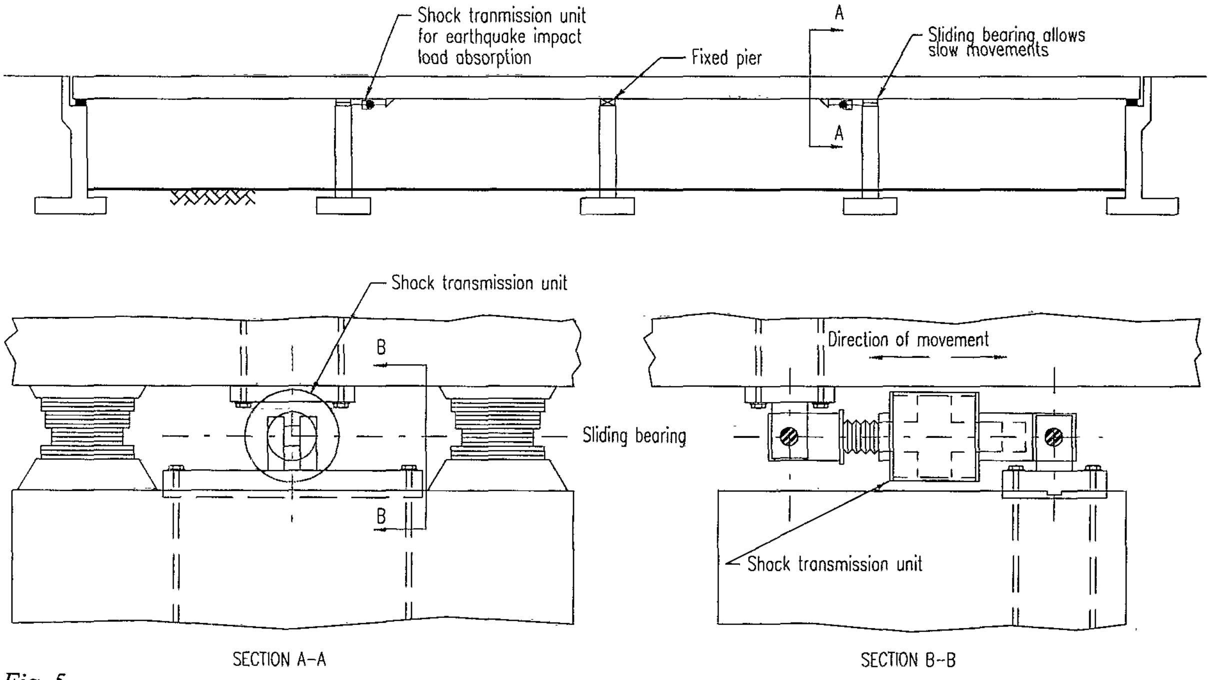


Fig. 5

By placing STUs 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 this approach braking forces are 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 to 25% of the original design at all fixed locations due to the temporary fixing of the expansion locations by the STU. The STU locks up and the load is shared at all points. This is a significant reduction in force and may dictate that the bridge might not have to be replaced.

The structure does not have to be simply supported to benefit from the STU. The STU 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 STUs 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 STUs at all sliding connections as illustrated in *Fig. 5*, the load is distributed between all piers, not just the fixed pier. This design concept is a significant advantage when the design criteria dictates an overload of the fixed pier.

The STU utilization would be similar in the Caltrans concrete box girder design, with integral columns and hinge expansion joints. The placement of STUs within the hinge would create 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 STU at the hinge the load is transmitted through 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 STU prohibits the banging of expansion joints during less severe seismic events. The STU works in compression as well as tension. The current Caltrans practice of tying the spans together with cables only prohibits the span from falling from the bearing seat. The cables offer no resistance to the compression of the expansion joint and spalling is often seen on all joints from this occurrence. The STU would totally eliminate this problem..

Another application similar to the concept of *Fig 5*, would be in light rail elevated structures. With the inclusion of STUs a light rail structure might be able to carry a heavier train (i.e. more cars) and take the increase braking forces associated with the load increase without a change to the substructure. This has been done in the past with great success. At the London Docklands Light Railway STUs attached at the expansion piers permitted the sharing of the braking forces between all piers of a seven span continuous structure. This meant that the train could be increased by two cars, double the previous total. The braking forces were shared and no changes to the substructure were necessary. This resulted in great savings over the conventional approach of strengthening the substructure of the central fixed pier.

CABLE STAYED OR SUSPENSION BRIDGE APPLICATIONS

In cable stayed bridges the deck is often connected to the tower so that the large displacement of the deck during a seismic event can be eliminated. However, in a concrete girder cable stayed bridge the tower is influenced tremendously by the forces of creep and shrinkage of the deck. In many cases this results in a large increase in the structural capacity of the tower. The question up to now has been how to connect the deck for seismic considerations and yet not have the shrinkage and creep forces acting upon the tower for the life of the structure.

In a steel cable stayed bridge the thermal movement can be quite extreme during the temperature differentials of any given day. In this application the stresses which build up due to this gradient movement are eliminated by use of the STU. The STU handles the most severe thermal movements possible and has been realized up to 8 mm per hour in some cases. The advantage again is that the deck and tower for sudden loads is temporarily fixed when the sudden load is applied.

Today engineers in every seismic zone of the world are designing STUs into both steel and concrete cable stayed bridges to eliminate the large displacement of the deck during an earthquake. The STUs are placed between the tower and the deck so as to distribute the load throughout the deck as much as possible. While STUs can be made to handle a very large capacity (up to 1000 tons have been contemplated to this date), the devices are normally used in series and/or parallel so that the distribution of the load is achieved throughout the structure without overloading a particular element. In such cases as Fig. 6 the tower is free from the deck during the normal operations of the bridge but during a seismic event, the STUs between the tower and the deck lock up and create a fixed connection so that the forces associated with the displacement of the deck are absorbed into the tower. During normal operations, the deck is free to shrink, to creep, to expand and contract with temperature differentials without these forces acting upon the tower. This is a great benefit to the bridge engineer and can realize a great saving in the design of the tower. In some cases the engineer elects to retain one tower in a normal configuration and allow the STUs to function at the other, while at other times the engineer deems it beneficial to have both towers connected with the STUs. There is great deal to be achieved with this simple robust device once an engineer sets his mind to exploit its potential.

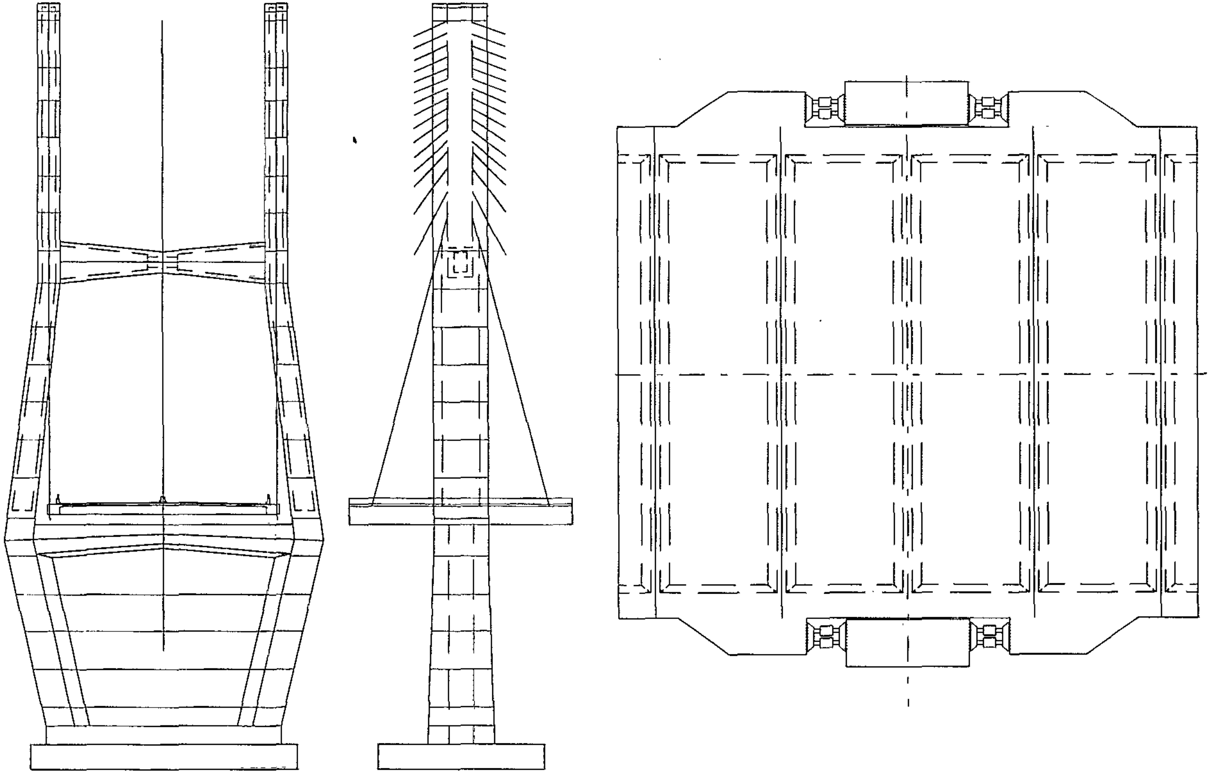


Fig 6

Front View *Side View* *Plan View*

The STUs are clustered about the tower to provide the optimum distribution of the seismic load into the tower.. In the case presented above the STUs would work in tension and compression at the same time, creating the rigid link necessary to transmit the load into the tower.

RETROFIT APPLICATIONS

In many instances it is possible to apply the STUs while the bridge is under traffic. This in itself is quite a saving over the expense that a disruptive closure of a bridge can bring about. The STU is attached and is working immediately. The principle decision making involves how to attach the STU to the structure. In many instances brackets must be built to strengthen the girders or abutments. In some applications external post tensioning of pier caps is required to produced a design suitable for the attachment of the STU. Most applications however, require simple brackets and a pin connection.

A typical retrofit utilizing the STU will take place on Pennsylvania S.R. 29 over the Schuylkill River in Montgomery County. The bridge consists of a four girder, five span continuous bridge with a central fixed pier. The retrofit design calls for placing two STUs on two of the four girders *(Fig. 7)* at the three expansion piers. The bridge can be updated for seismic considerations without any other type of construction retrofit. The seismic upgrade can be achieved while traffic remains on the bridge, avoiding costly detours. In this case the STUs are attached to either side of the internal girders, away from sight and to the pier cap. Thus the expansion pier is free to move for all slow movements but should an impact force from a seismic event take place the connection will temporarily be a fixed connection. Once the force is eliminated, the device will again have a benign influence on the bridge.

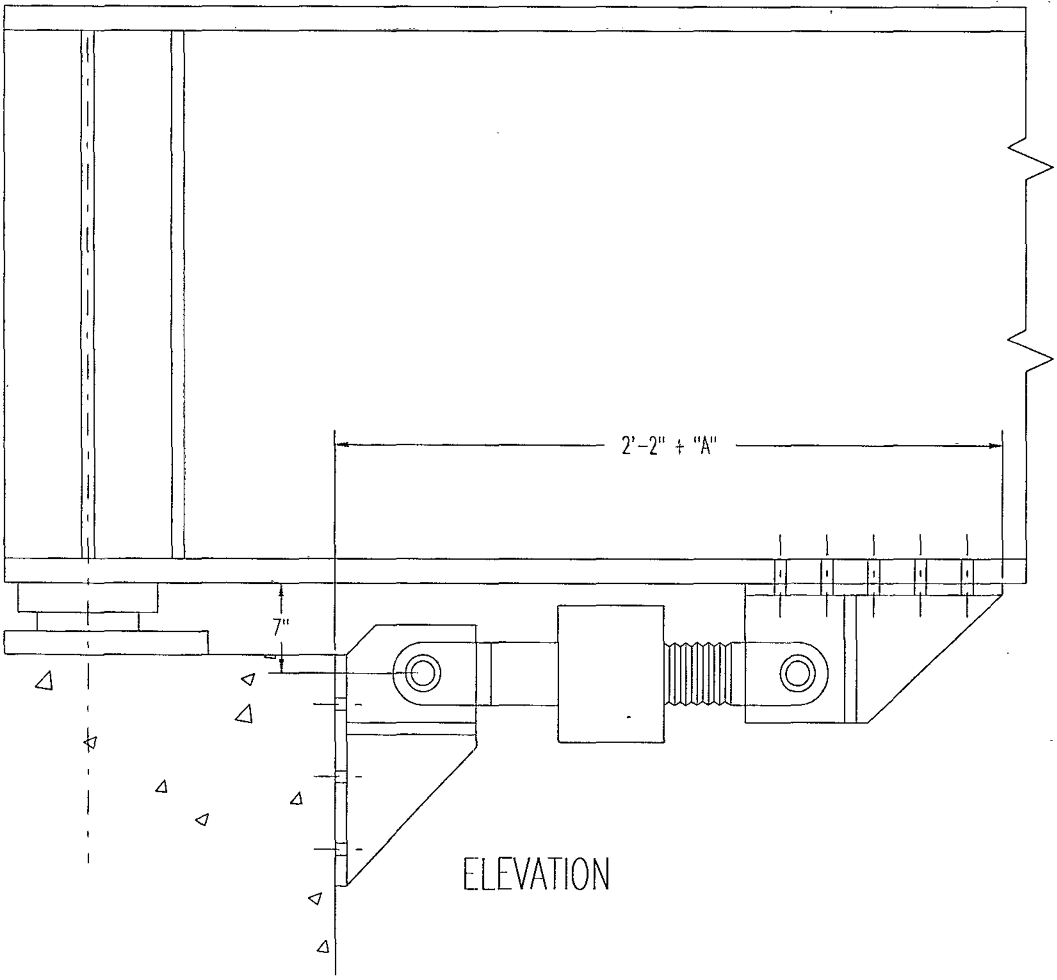


Fig. 8

A STU is anchored to each side of the bottom flange of girder and to pier wall