Shock transmission units for bridge strengthening

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Unités de transmission de chocs pour le renforcement des ponts

Stossübertragungselemente zur Erdbebensicherung von Brücken

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SUMMARY
The paper introduces a shock transmission unit which has been developed to meet some of the challenges of designing new bridges to resist earthquake effects and the strengthening of existing bridges. The unit and some recent applications are described.

RÉSUMÉ
L'article présente une unité de transmission de chocs qui a été développée pour répondre à certaines des exigences de conception des nouveaux ponts devant résister aux effets des tremblements de terre et pour le renforcement de ponts existants. L'unité et certaines applications récentes sont décrites.

ZUSAMMENFASSUNG
Der Beitrag stellt ein Stoß-Uebertragungselement vor, das entwickelt wurde, um einigen Herausforderungen im Hinblick auf Erdbebensicherheit bei der Konstruktion neuer und der Verstärkung bestehender Brücken zu begegnen. Das Element und einige Anwendungen werden beschrieben.

1. INTRODUCTION

Shock Transmission Units (STUs) capable of acting as a rigid member under impact loading whilst permitting slow axial movement without resistance have found important applications in all types of engineering over the years. However, their use to date in bridge engineering has been very limited. This had probably arisen because, hitherto, the STU has been a relatively complex device with a high initial cost and a need for regular maintenance and adjustment.

A special bridge STU, developed some years ago in the UK offers a new design with several advantages. It is the purpose of this paper to describe the unit and some recent successful uses in meeting the challenges of designing new earthquake resistant bridges and the strengthening of existing bridges by inducing beneficial load sharing in the bridge substructures.

2. THE 'NEW' STU FOR BRIDGING

The special bridge STU was developed in the UK some years ago and is only referred to as 'new' because it has taken some time for its benefits to be recognised sufficient to actually using it in several recent bridge structures.

The new STU introduces a simpler approach to the design of shock transmission units, sometimes erroneously referred to as dampers. Hitherto these units have been complex precision hydraulic devices but the new unit, with only a single moving part, is much simpler, more economical, robust & virtually maintenance-free.

Instead of oil the STU utilises the peculiar properties of "bouncing putty", a silicone compound which will readily deform under slow pressure but becomes rigid under impact. For all practical purposes the viscosity of the material remains constant throughout a wide temperature range. Thus the new STU can be relied upon to perform consistently under most climatic conditions.

The unit, Figures 1 & 2, is of extremely simple construction, consisting of a steel body or cylinder containing a loose fitting piston fixed to a transmission rod, the void round the piston being filled with the bouncing putty. Under slow movement this putty is squeezed slowly around the piston and displaced from one end of the cylinder to the other. The transmission rod passes through the entire length of the cylinder so that the volume of the cylinder remains constant at all positions of the piston.

The new STU has been designed primarily to function in a horizontal position but it can be adapted for vertical movement by incorporating an internal spring to return the piston to the neutral position.

The bridge units are made to resist impacts ranging between 10 & 120 tonnes, with larger requirements satisfied by increasing the number of units. Movement rates are controlled by the clearance around the piston, the usual 50 tonne unit giving a typical rate of extension of some 10mm/minute, more than adequate to meet the zero resistance slow movement demands of bridge decks arising from temperature, shrinkage & creep. Typical impact resistance/time behaviour for such a unit requires that the extension or compression shall not exceed 2mm in the first ten seconds nor 4mm in the first 20 seconds after the impact application.

3. BRIDGE STUs IN EARTHQUAKE ZONES

3.1 General

Bridge STUs have found a good application in resisting earthquake effects on the substructures of bridges located in such zones. The following sections describe the ideal substructure articulation for a typical multispan flyover and the assistance provided by STUs in adding earthquake resistance to the articulation. A large flyover using STUs for this purpose and recently built in Kuwait is described.

3.2 Ideal Multispan Bridge Deck Articulation

Multispan bridge decks or flyovers are best designed as continuous, offering not only deck & substructure economy plus ride quality but also eliminating trouble-prone movement joints over piers.

The substructure articulation is generally arranged as shown in Figure 3, less the STUs, to provide economical minimum resistance to longitudinal deck movement. A fixed rotation bearing is located at the central pier and rotation/moving rubber, sliding or roller bearings at the remaining piers and the end abutments, where the only deck joints are located.

This arrangement allows the deck to move longitudinally with minimum restraint to take up the effects of temperature, and where appropriate,. concrete shrinkage and creep. Any longitudinal deck forces arising from traction, braking or wind are resisted by the central fixed pier, assisted by friction or shear generated by deck movements at the other piers and the abutments. If the longitudinal restraint force at the central fixed pier is too much in excess of the friction or shear forces on the other piers, economy would dictate size differentials between the central & other piers. This is aesthetically undesirable and pier sizing equality can often be obtained by sharing the restraint force among two or three central piers, depending upon the extra forces generated in those piers by restrained temperature, shrinkage or creep movement.

3.3 Adding Earthquake Resistance using STUs

The longitudinal forces generated in a bridge deck subjected to earthquake, a function of the deck mass and usually well in excess of any traffic braking or traction, require the development of considerable longitudinal restraint from the substructure at bearing level. For the typical viaduct described in 3.2 this restraint would overload the central fixed pier. Ideally this effect, hopefully rare, should be resisted equally by all the supports. However, they cannot be designed to be fixed like the central fixed pier because of the considerable deck movement forces which would arise in normal service.

This is where the STU comes into its own, offering no resistance to normal service deck movement but providing a fixed pier connection during earthquake impact. Figure 3 shows the typical arrangement of STUs at the 'free' piers which temporarily convert the piers to 'fixed' to permit beneficial load sharing during earthquakes. If necessary, additional STUs can be mounted at the abutments to add further load sharing.

3.4 Interchange 3 Viaduct, Outer Bypass, Kuwait

This large viaduct, Figure 4, recently built for the Ministry of Public Works in Kuwait, is designed to resist earthquake forces in accordance with the 1973 AASHTO code with an equivalent lateral force coefficient of 4%.

It is some 800m long and curved in plan with 13 spans of 55.1m and 2 end spans of 41m. The continuous prestressed insitu concrete deck is of 5 cell hollow box construction, 2.75m deep and 15.12m wide. The elliptical piers are of reinforced concrete construction 5m wide and 1.75m maximum thickness.

Pier bearings are twin fixed at central pier 8 and twin PTFE sliding at all other piers. Longitudinal earthquake forces are resisted at pier 8 and also at piers 6, 7, 9 & 10 by twin 120 tonne STUs, Figure 5.

4. STUs FOR STRENGTHENING EXISTING VIADUCTS

4.1 General

A large number of our existing stock of viaducts feature long sequences of simply supported deck spans, often supported on a series of high & substantial piers. This is particularly evident in major river crossings where high navigation clearances require long approach viaducts.

The piers under each simply supported span inevitably carry fixed bearings for one span alongside free bearings for the adjacent span. This means that the design longitudinal traction & braking forces must be individually applied to each deck span throughout the viaduct. Main resistance is offered by the pier carrying the fixed bearings of that particular span, with generally a small additional resistance from friction generated at the free bearings carrying that span, located over the next pier. This means that a substructure of this type with, say, 10 equal height piers has a total resistance capacity of 10 times the deck design traction & braking longitudinal loads, a capacity unfortunately not available because of the simply supported articulation.

This large extra resistance capacity can be realised by placing the new bridge STUs across the joints between the simply supported spans, either at deck or bearing level.

Current integrity assessments of a number of these multi simply supported span viaducts often indicate that the piers are understrength due to increases in the traction & braking loading since original design, often accompanied by damage generated by limited road salt, carbonation or ASR. STUs placed across the joints will immediately mobilise load sharing between piers, usually sufficient to reduce pier loading to a level not requiring strengthening.

Even with existing continuous deck spans, which automatically produce similar load sharing action at the piers without resort to STUs, further beneficial load sharing can be gained by placing STUs at the expansion joint ends of the continuous span sequence.

4.2 Strengthening Viaducts on the London Docklands Light Railway

The newly completed viaducts carrying London's Docklands Light Railway, Figure 6, were designed for a train service which, due to a breathtaking increase in adjacent development, will now require considerable expansion. This will mean heavier & more frequent trains, which will add braking & traction effects in excess of those originally catered for.

Figure 7 shows a typical seven span deck unit, continuous between expansion joints. Train traction and braking loads are currently shared among the slender piers, which generally support the deck via rubber bearings. It is proposed to install STUs, Figure 8, at rail level between joints such that, when the new increased longitudinal traction & braking loading is applied to one particular seven span unit, load is beneficially transmitted and shared with adjacent seven span decks sufficient to require no pier and foundation strengthening.

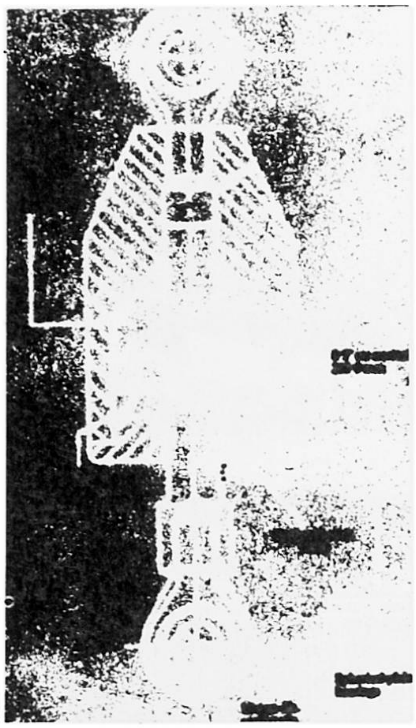


Fig. 1 Arrangement of STU

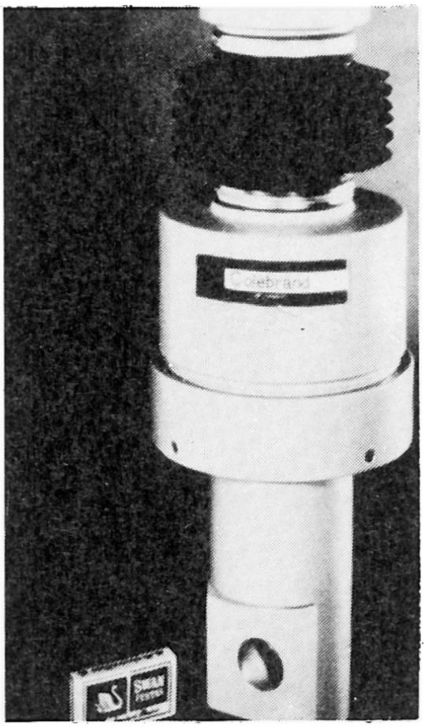


Fig. 2 50 Tonne STU

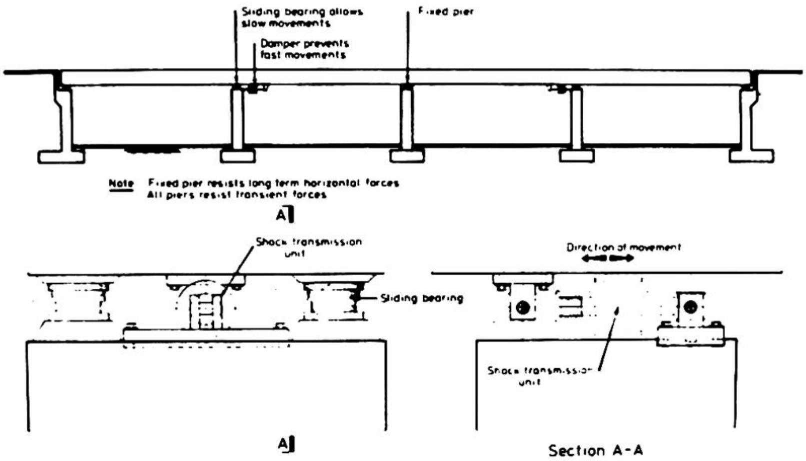


Fig. 3 Flyover Articulation with STUs

Fig. 4 Kuwait Flyover

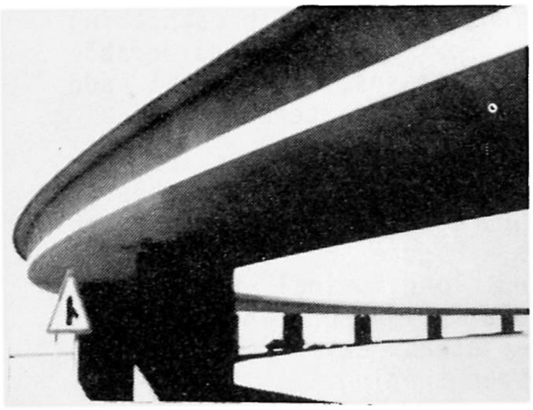


Fig. 5 Pier STUs

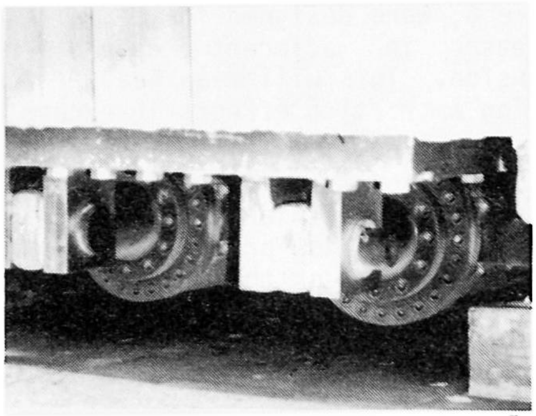


Fig. 6 Docklands Light Railway (DLR)

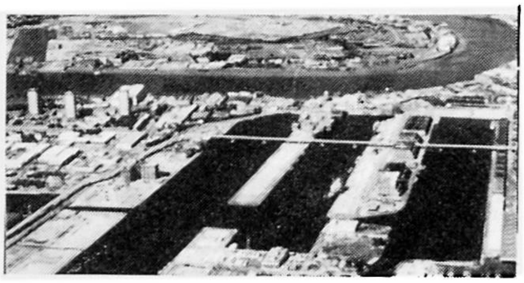
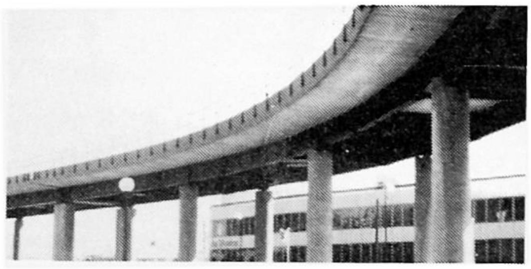


Fig. 7 DLR Viaduct



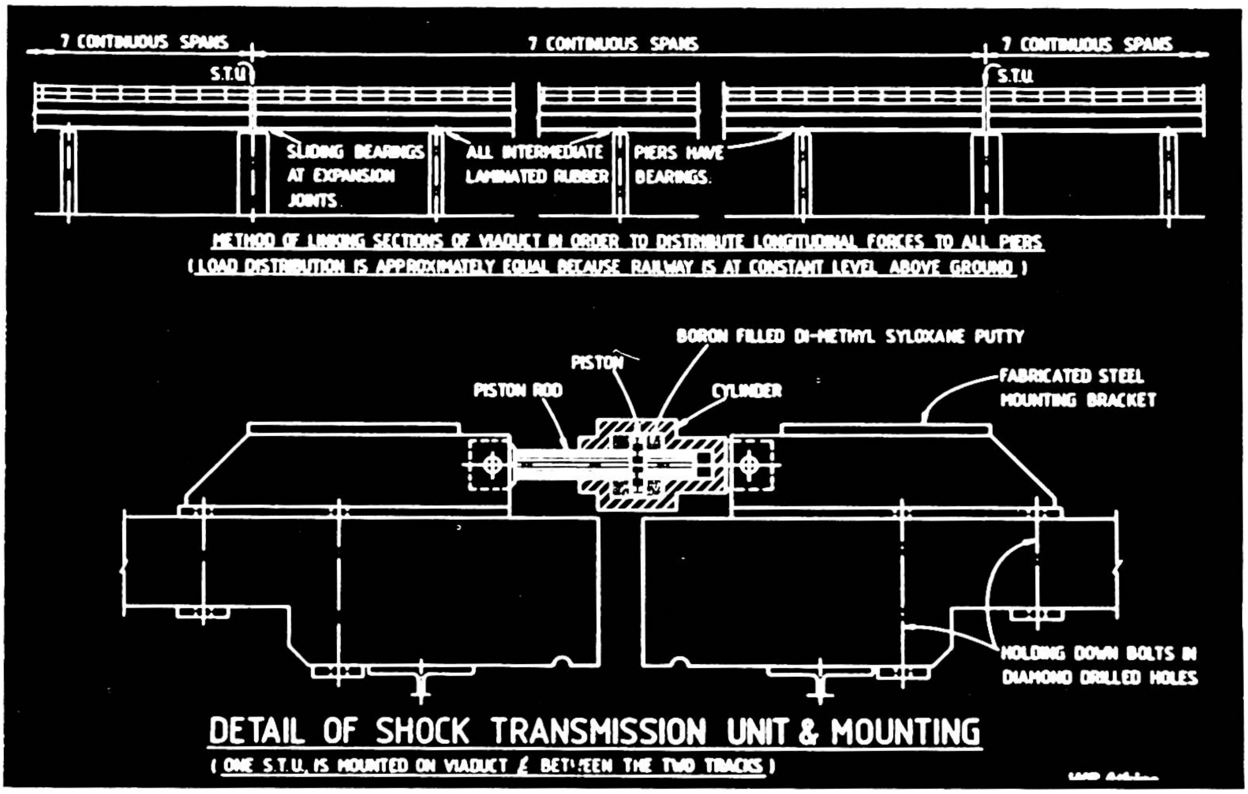


Fig. 8 Docklands STUs