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Fuse enabled modular expansion joints for bridges subject to seismic damage potential - A life saving innovation

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ABSTRACT

Integrated FUSE system protects the modular expansion joint and the connecting structure from earthquake damage. Should a regular expansion joint, during an earthquake, close by more than what is allowed by its design, severe damage can be caused to the joint and to the bridge. Such damage can be avoided by the use of FUSE-Element, which acts as a predetermined break point, allowing failure to occur in a controlled, designed manner. The design of the FUSE-ELEMENT also allows the expansion joint to be returned to its original position after the earthquake with relatively little effort, enabling emergency vehicles to use the bridge. The use of the integrated FUSE-Element is recommended for bridges in seismic regions, and can often lead to an optimisation of the design of the expansion joint and the structure itself, with fewer gaps than would otherwise be required.

This paper will look into two bridges where this joint is used for the first time in New Zealand, to provide recommendations for bridge designers and asset owners considering the challenges and benefits in using such innovative and potentially lifesaving technology on their bridges.

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1 INTRODUCTION

Millennial design techniques resulting in very demanding structures that also imply ever greater demands on Bridge expansion joints. Such demands include greater seismic durability and restoring desire of quick replace ability or reparability along with higher traffic loading and greater tri-axial movements and rotations. Continuous evolution of Expansion joint technology is a must to keep up with these ever increasing demands, and the quest of bridge owners and operators to significantly reduce life-cycle costs associated with expansion joints. The minimisation of the traffic disruption caused during repair and replacement work is on top of their wish list too. Bridge designers, asset owners/managers and end users must be made aware of ever improving expansion joint technology and manufactures' capabilities, to enable them benefit from the better functionality reliability and durability offered by the latest generation of expansion joints. It is very important that Bridge designers and owners to be aware of these advancements to ensure that they specify appropriate level of durability, testing regime and serviceability/reparability in case of occurrence of seismic event, so that proper selection of optimised joint system can be made and informed decisions can be made to ensure that expansion joint life-cycle performance and costs are optimized, resulting in less maintenance and replacement effort, greatly reduced owner and operator costs, and less impact on bridge users and the environment. An expansion joint that can be, at least temporarily, restored immediately after the seismic event, provide that rest of the structure is safe enough, can facilitate the safe movement of emergency and repair vehicles allowing potentially lifesaving operations to continue when it is critically required, i.e. immediately after the occurrence of seismic event. This is demonstrated below with reference to the modular expansion joint with a unique fuse-element, which is widely used all around the world to accommodate greater overall movements and rotations than other types, and is thus arguably the most versatile type of expansion joint available today.

2 THE MODULAR JOINT WITH UNIQUE FUSE ELEMENT – TENSA MODULAR LR-FE

Thanks to their ability and great flexibility of accommodating most diverse range of tri-axial movements, and multi axial rotations – that no other the modular expansion joints can provide, Modular Expansion joints offer great deal of flexibility to the designers and contractors. Due to their increasing popularity as preferred type of expansion joints for many of the world's largest/most complex and highly demanding bridges in recent years. Emphasis on performance standards, testing requirements is hence also increasing.

Modular expansion joints divide the total movement requirement of the superstructure among individual, smaller gaps. The gaps are separated by centre beams, which create the driving surface and which are supported at regular intervals by support bars underneath.

The modular expansion joints divide the total bridge gap at the end of the bridge deck into smaller individual gaps by horizontal centre beams. This enables deck movements of well over 2'000 mm to be accommodated. Rotations around all axes can also be facilitated. The individual gaps are sealed watertight by elastomeric profiles, enabling the joint to be completely drained at the deck surface.

TENSA®MODULAR is a modular expansion joint of the single support bar type (with every support bar supporting all centre beams), with pre-stressed, free-sliding, bolted stirrup connections between centre beams and support bars (see Figures 2 to 4). The support bars themselves are supported by a similar system in the joist boxes at each end. Elastomeric control springs, positioned in sets below the centre beams, coordinate the movements of the centre beams. This elastic system avoids constraint forces and reduces the effects of loading on the joint and on the main structure, extending the life of the entire system.

A fuse element is then integrated between the centre beams as per movement requirements.

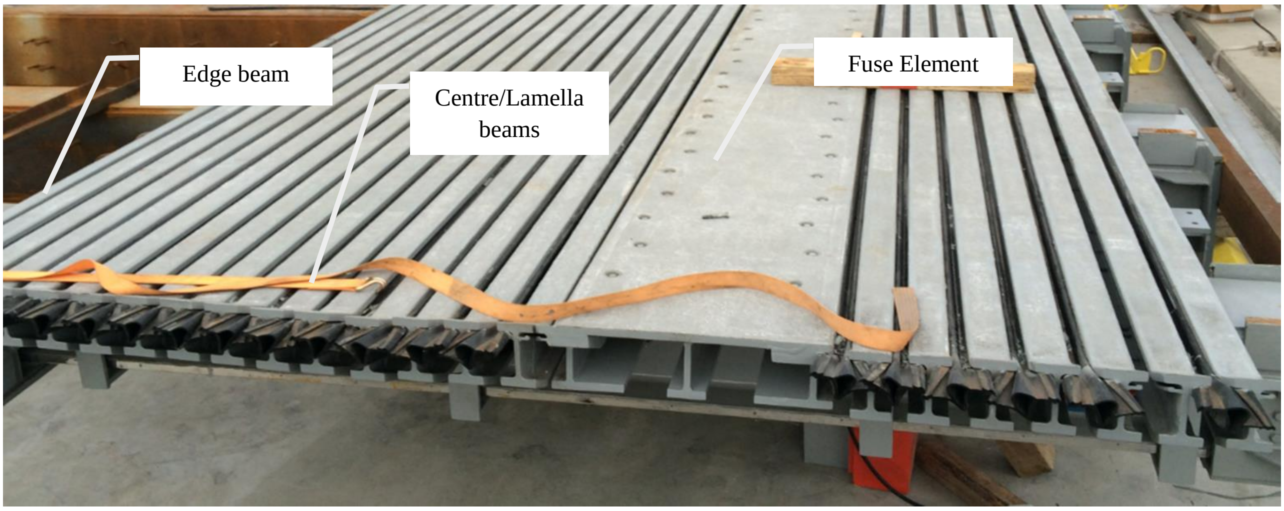

Figure 1: A modular expansion joint, viewed from above, showing the centre beams, Fuse element and edge beams that form its driving surface.

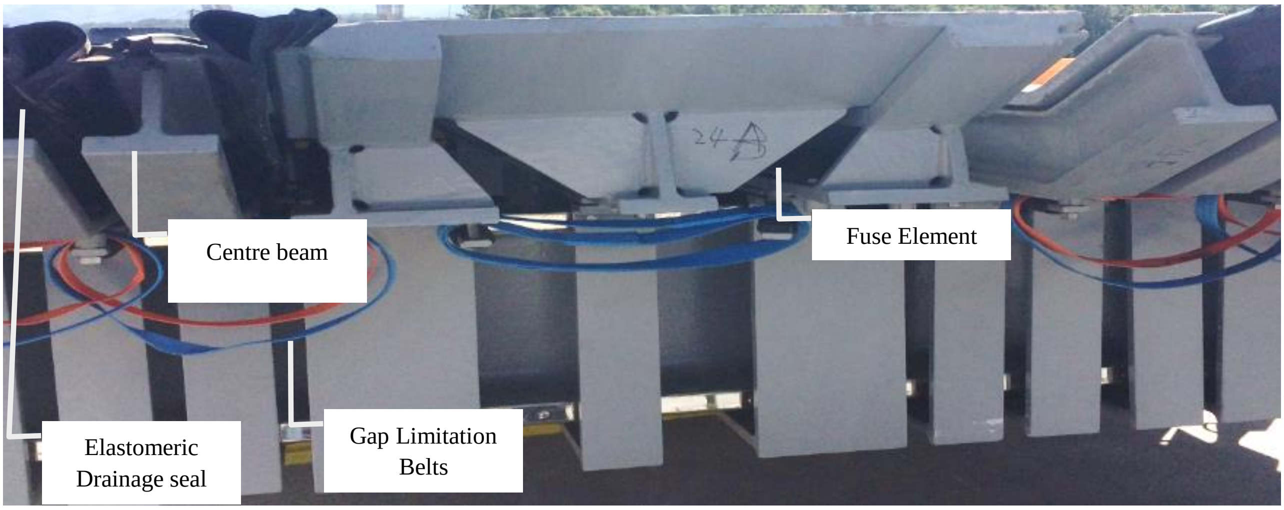

Figure 2: A TENSA®MODULAR LR-FE expansion joint (cross section at a support bar), showing stirrup connections to centre beams.

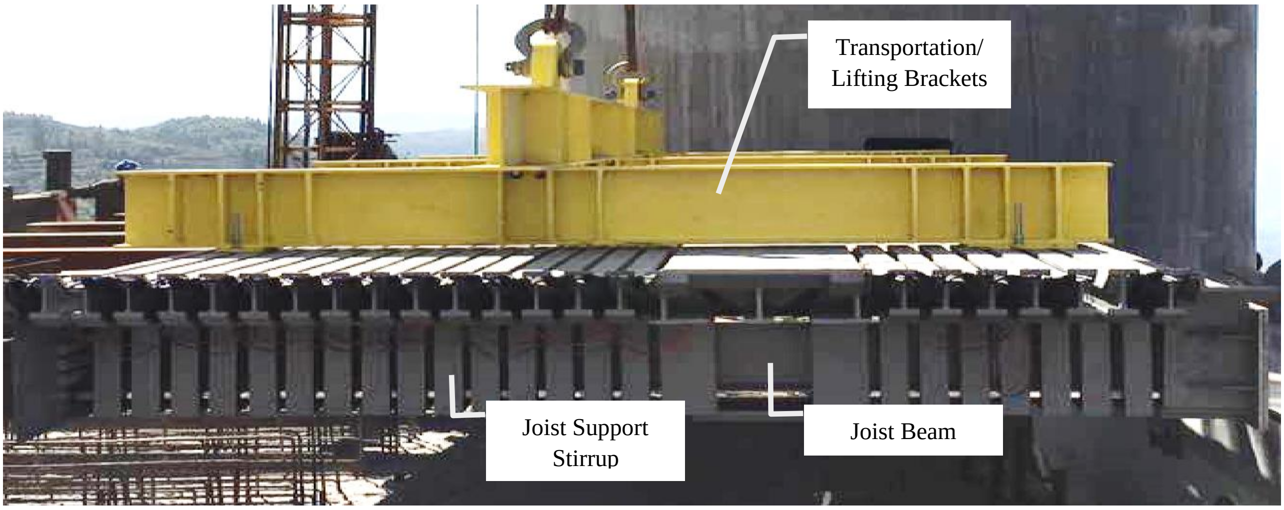

Figure 3: Installation of a TENSA®MODULAR LR26-FE expansion joint in a concrete bridge deck

3 SPECIAL MATERIALS AND DESIGN FEATURES

In order to be able to optimally meet the widely varying needs of different structures, it should be possible to tailor a modern modular expansion joint to suit any particular set of demands and circumstances, with the selection of appropriate design features. A number of these, appropriate to the above mentioned TENSA®MODULAR joint, are presented below.

3.1 Materials

Of course, all materials used in the manufacture of a high-quality expansion joint should be of appropriately high quality and performance level. This is particularly true of the sliding materials that are used, typically paired with a stainless steel sliding partner, at each of the joint's sliding interfaces. PTFE is no longer the sliding material of choice in many cases, with modern UHMWPE alternatives such as ROBO®SLIDE offering far greater strength and resistance to wear, and very often, lower friction (Spuler et al., 2009). Considering that an expansion joint's sliding materials are generally much more susceptible to damage and wear than the rest of the joint, the use of the best sliding materials available has great potential to minimize expansion joint maintenance and replacement work. The joint comprises of several specially rolled wide flange H beams from Europe to provide highest quality to the end users.

3.2 Fuse Element

A fuse element is fabricated with the same materials as used for the other key components of the expansion joints and integrated between the centre beams to cater for;

- Creating additional closing movement for a selected movement case. Typically in a range of min. 250mm and max. 600mm per one Fuse Element.
- Generating defined/controlled release forces. Can be selected in min. / max. range due to different diameter and distance of the bolts.
- Allow to reduce the pre-setting per single gap due to reduced closing movement range for load cases with fuse release.

Limitations of the Fuse Element;

- Cannot create any additional opening movement capacity.
- Cannot reduce the total joint dimension in noticeable size compared to a standard expansion joint (with the same movement capacity)
- Cannot be always cheaper compared to a standard design with the same movement capacity.

3.3 Functioning of Fuse Element

Functioning of Fuse element is illustrated with Figures 4 to 7 below;

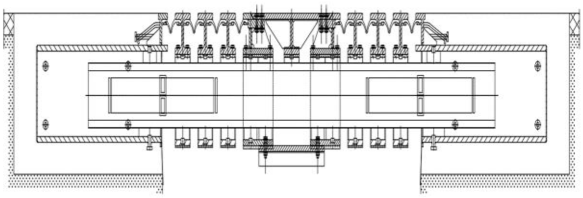

Figure 4: Fuse Element in neutral/central position

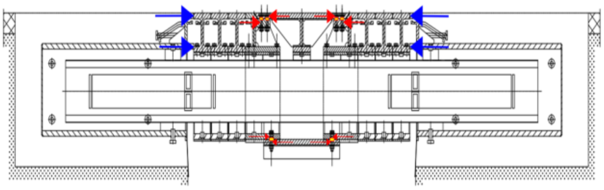

Figure 5: Fuse Element in fully closed position- blue arrows represent forces applied on fuse element and red arrows represent internal stresses generated into fuse element components that activate the fuse action

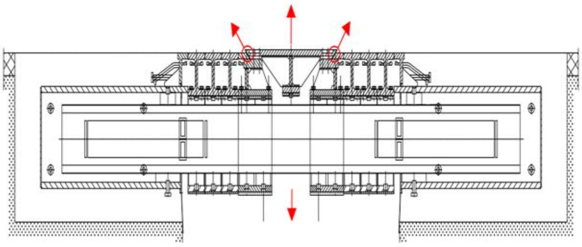

Figure 6: Further closing results in failure of bolted connection in fuse element components and disconnects fuse from centre beams pushes it out. T profile at the bottom of fuse falls in the bridge gap.

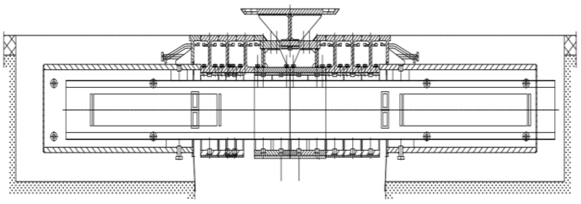

Figure 7: At minimum possible closing position, the fuse element is at its highest position, until this point there is no damage to the expansion joint. Further closing will damage other joint components.

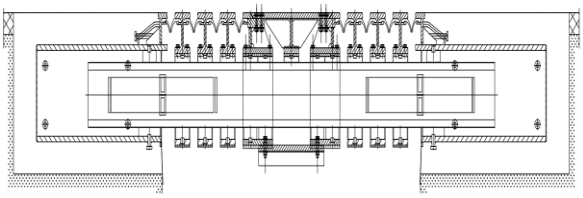

Figure 8: After Occurrence of Seismic even the Fuse element reactivates and generally drops back in the original position or can be pushed down with relative ease and repaired so that bridge can be immediately used by emergency vehicles. Extraction of sheared bolts for repair is a standard fabrication practise.

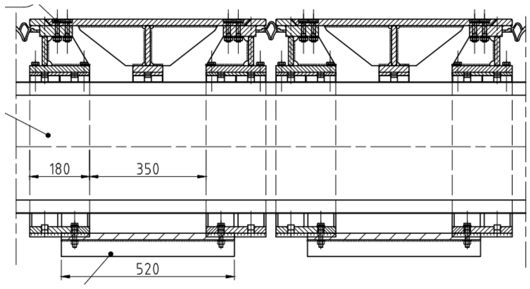

Figure 9: Multiple fuse boxes can be combined to increase closing movements more than 600mm.

4 WHIROKINO AND MANAWATU BRIDGES AND FUSE ELEMENT MODULAR JOINT

The New Zealand Transport Agency (NZTA) initiated the project “Whirokino Trestle and Manawatu River Bridge” to improve safety, efficiency and resilience of SH-1. Neither the existing Whirokino Trestle nor Manawatu River bridges currently allow high productivity motor vehicle (HPMV) loads and Whirokino Trestle is approaching the end of its structural and economic serviceable life.

The Whirokino Trestle and Manawatu River bridges are located between Foxton and Levin in the Horowhenua region of the lower North Island. The site is approximately 6km inland from the Tasman Sea.

The project includes 2 bridges, the Moutoa Floodway and the new Manawatu River Bridge, and an Agricultural Underpass.

The Moutoa Floodway is an overflow floodplain of the Manawatu River and is confined by 4-5m high stop banks constructed on each side. The new Moutoa Floodway Bridge will span the floodway west of the existing Whirokino Trestle Bridge. The total bridge length is 609.4m between the centre lines of the abutment piers.

The proposed bridge structure consists of 17 spans, divided into 3 sections. The first and third sections consist of 6 spans (end spans of 33.6m and 33.8m and 4 intermediate spans of 37m). The total section length is 215.4m. The second section is 178.6m long and consists of 5 spans (2 end spans of 33.8m each and 3 intermediate spans of 37m). The modular joint is located on Pier 7 & 12 (total 18 piers) of the bridge which are 215.4m away from North and South Abutment respectively. To accommodate for the movements, the spans are made simply supported at Abutments and Piers 7 & 12 by adopting bearings and road joints.

The Manawatu River bridge runs over the Manawatu River which is confined by stop banks constructed on each side. The new Manawatu River Bridge will span beyond these stop banks and will be approximately 10m longer than the existing bridge total span length. It will be located downstream and to the west of the existing bridge. The total bridge length is 192.3m between the centre lines of the abutment piers.

The proposed bridge structure consists of 6 spans, with three 36m spans, two spans of 34m and one span of 16.3m (DHC span) which makes the combined total span of the bridge to be 192.3m between the centre lines of abutment piers.

To accommodate creep, shrinkage and thermal movements, the spans at section ends and abutments have been made simply supported by adopting bearings and road joints with sufficient displacement capabilities.

Under ULS seismic event, there will be significant movement of the superstructure relative to the piers with longitudinal sliding bearings. The movements are summarised in the Table below:

Movement			
Moutoa Floodway Bridge		Manawatu River Bridge	
Closing	Opening	Closing	Opening
600mm	700mm	400mm	400mm

The ground at site is of poor quality and prone to liquefaction. In a ULS seismic event, the design bridge movements are of the order of 1.0 m longitudinally, though superstructure displacements relative to the pier foundations are limited by a loose linkage system. The modular joint provides an efficient system to accommodate such high movements. No transverse displacement is accounted for as Transverse seismic restraint is provided by shear keys. However, the joint itself is capable of accommodating transverse movements almost as much as it longitudinal capacity.

Fuse Box Modular Expansion joints have been designed with a pre-determined fuse box element. The joint is designed to perform without damage under normal SLS expansion and contraction movements, including thermal, creep, shrinkage and seismic $R_u/4$ movement demands of the superstructure each side of piers. This type of joint incorporates a fuse element that protects the concrete either side from significant damage in a major seismic event. The fuse element is design to ‘pop up’ and provide more displacement capability for the superstructure with less damage to repair.

Post-earthquake, the joint is designed to be usable by emergency traffic even without any temporary repair. Also, the joint is designed to be reinstated relatively quickly as the typical damage is limited only seals and fixings

In ULS seismic events where the adjacent superstructures move apart (out of phase), the expansion joint has capacity to prevent loss of support of the modular joint components.

In ULS seismic events where the adjacent superstructures move together (out of phase), the fuse box at the centre of modular joint is forced upward when displacement exceeds the SLS capacity limits. The fuse box slides up over the angled section of modular joint, whilst retaining the modular joint system, protecting both the bridge superstructure and modular joint from damage.

After a ULS seismic event, the joint returns to the original position with the fuse box section moving down to its pre earthquake level. Local damage to the wearing course and seals in the modular joint can be expected but the joint provides for emergency vehicles passage over. This is a requirement in the NZTA Bridge Manual that post-earthquake, the bridge shall be usable by emergency traffic.

Major concerns on this project were large longitudinal movements and reinstatement post-earthquake. The fuse element in the modular joint helps accommodating large movements and at the same time prevents any damage to the concrete elements. Damage is limited to rubber seals and fasteners that connect the fuse element to rest of the joint during normal SLS movements, all of which are easily replaceable, thereby allowing easy post-earthquake repairs. A cross section of Pier with the modular joint on Moutoa Floodway Bridge and Manawatu River Bridge is shown in Figure 9 & 10 respectively below.

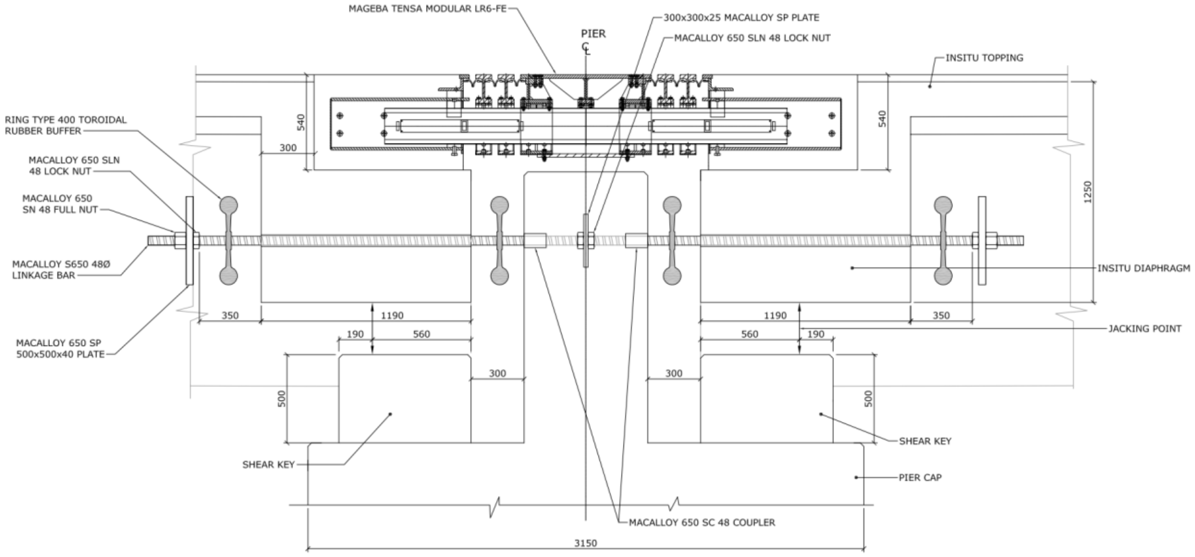

Figure 10: MAGEBA Tensa Modular LR6-FE on Moutoa Floodway Bridge

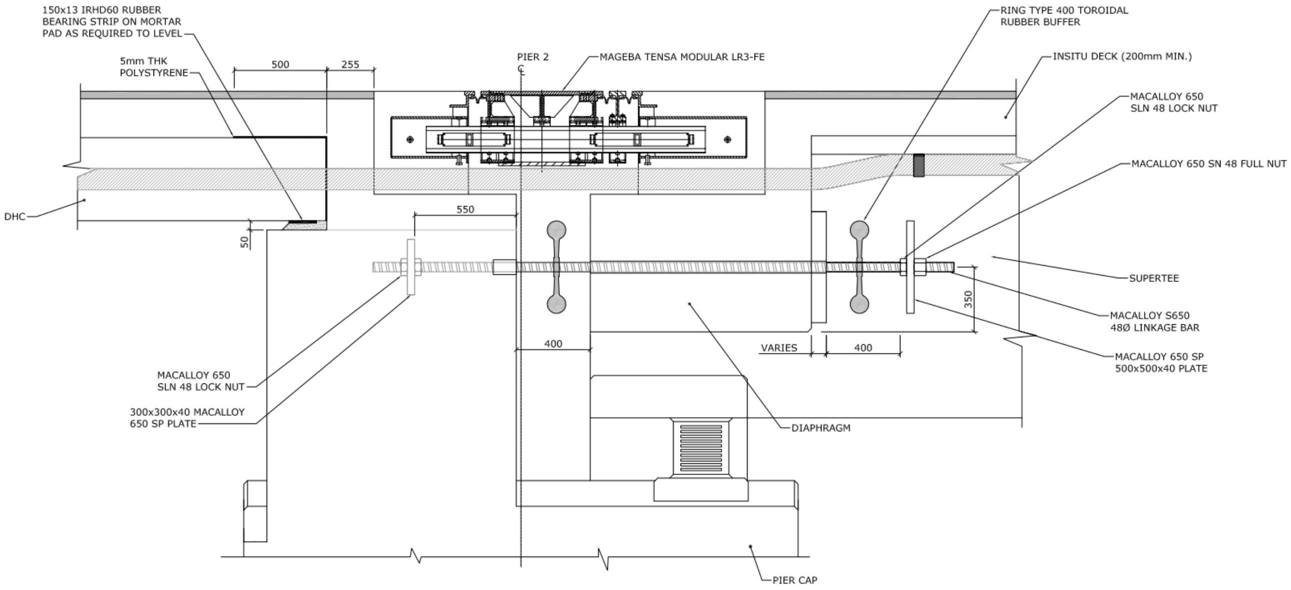

Figure 11: MAGEBA Tensa Modular LR3-FE on Manawatu River Bridge

5 ALTERNATIVES CONSIDERED

Another potential alternative could be using lock-up devices similar to Shock Absorber or Hydraulic dampers. However the project had progressed too far ahead to revisit any of these considering the additional time involved in testing the prototypes etc. in accordance with EN-15129 and still be able to deliver them within constructor's planned schedule.

6 CONCLUSION

The integration of sophisticated fuse element in the modular expansion joints of newly built bridges offered great benefits to their asset management programs. Such systems efficiently reduce structure's life cycle costs – e.g. to repair joint instead of full replacement after seismic event etc., with minimal and most usual maintenance requirements. The design of bridges, especially the knock off linkages and additional concrete structures is significantly optimised thus enabling reduce the construction cost and complexity. In spite of all other safety features in bridge design, the high ULS seismic opening movement would have left a huge gap between bridge deck and approach slabs thus limiting the accessibility for emergency vehicles. The fuse element integrated in modular joint hence will be potentially proven an equally lifesaving as of other design features that prevent bridge collapse and loss of life.

REFERENCES

Spuler, T., Moor, G. & Savioz, P. 2009. Special Requirements of Large Modular Expansion Joints, *Proc. 33rd IABSE Symposium, Bangkok, Thailand*.