

Draft Australian Bridge Design Code AS-5100 Section 4 - Bearings & Expansion Joints. Trends in rehabilitation of deck joints and design developments of modular joints

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SYNOPSIS

The Draft of Australian Standard AS-5100 released for public comment is the intended replacement for the current Austroads Bridge Design Code 1996. Section 4 of AS-5100 addresses the important structural bearings and deck expansion joint components of bridge structures. This paper will review the key changes in specification requirements of expansion joints between the current Austroads BDC and draft AS-5100 (released for public comment).

In further review of bridge deck expansion joints this paper will discuss recent trends in the approach to the rehabilitation of single element deck expansion joint systems with movement range up to 100mm. The paper will highlight the need for assessment by the specifying engineer of correct process control of the rehabilitation methodology.

Larger movement multi seal element “modular” expansion joints have recently been the subject of significant review by Road Authorities with respect to their requirements to the design approach of the product. Such reviews have been driven by the in-service failure of some proprietary systems. This paper will summarise the principal areas addressed in current design of new generation modular expansion joints arising from these more demanding specifications.

A case history of the replacement of one such failed modular joint will be reviewed at the conference presentation and is not referenced in this actual paper, as the replacement event will occur in early 2004 and after the writing of this paper.

1 DECK EXPANSION JOINTS

The Preface of the draft AS 5100 Standard states the significant differences between AS 5100 and the 1996 Australian Bridge Design Code. Anchorages are listed as one of five major changes. Viz “*Anchorages* The rules for anchorage of pot bearings and deck joints have been revised”

The 1996 Australian Bridge Design Code does not adequately address the now common use of ‘tensioned bolt’ retention mode for stripseal type single element deck expansion joint systems –refer Figures 1 & 2 for diagrammatic of this retention mode. This type of anchorage achieves significant advantages over conventional welded ligatures or studs to metal protection angles, in that the tensioned fixing is not subjected to load reversal, is always in tension and avoids the ravages of fatigue induced failure.

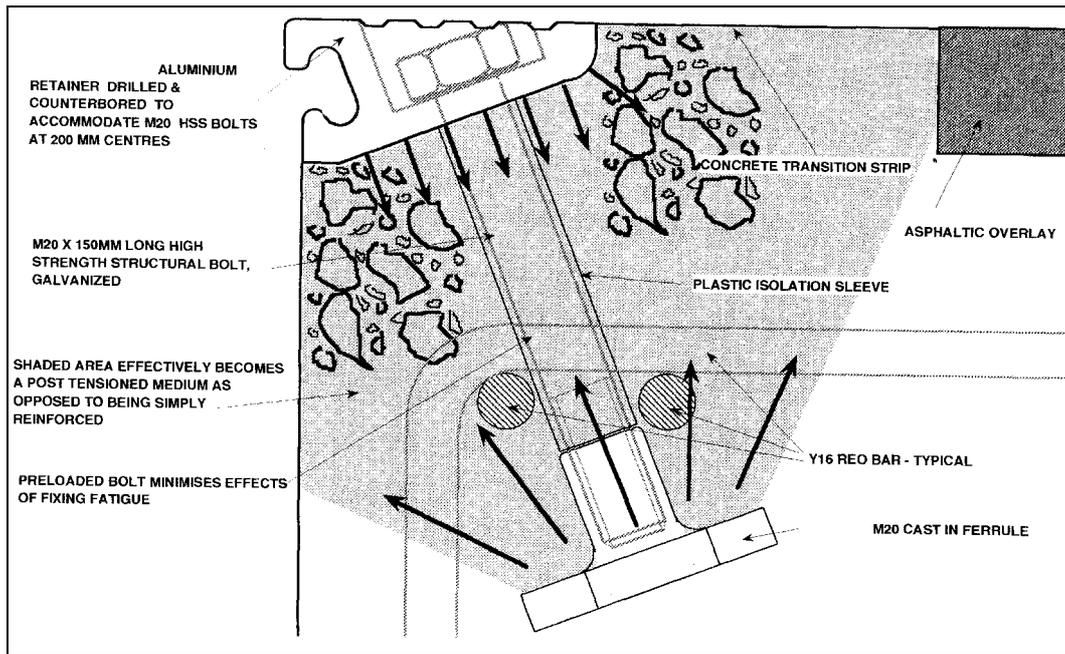


Figure 1: Section of "tensioned bolt" system (one side only shown)

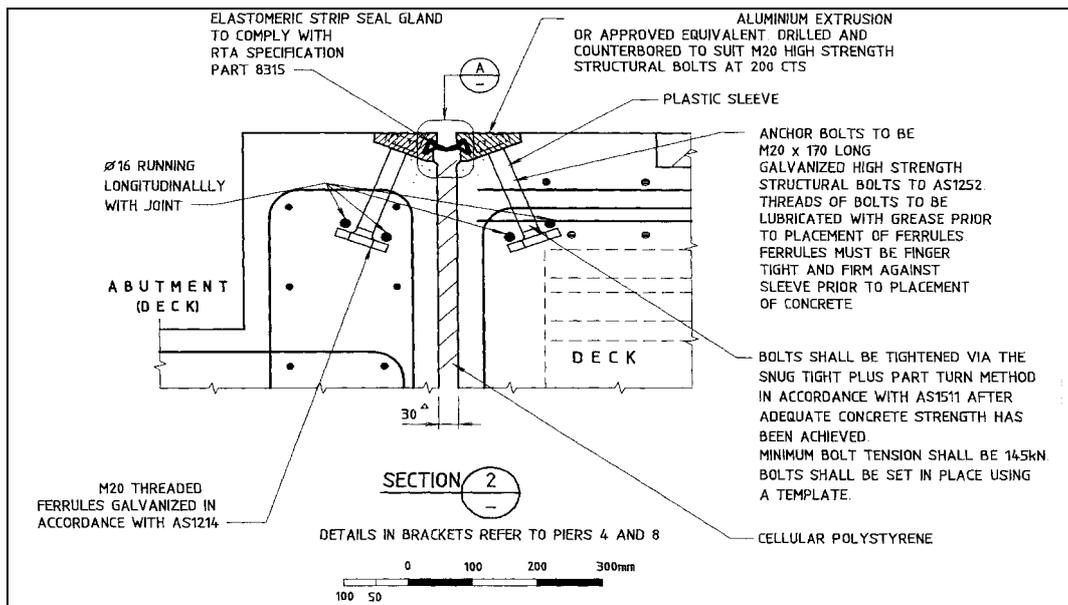


Figure 2: extract of design drawing showing details of 'tensioned bolt' Stripseal system

Draft of AS 5100, section 17.4 paragraph two provides a required outcome for such tensioned fixings with respect to the required design axial capacity of the bolts at ultimate limit state. AS 5100 requires that the axial capacity generated is not less than 500 kN/m of each side of the joint.

The following calculations demonstrate that such retention force can be achieved by using either M16 fully tensioned high tensile bolts at 200mm c-c spacings or alternatively by M20 (or larger) at the maximum permissible spacing of 300mm between bolt fixings.

M16 High Strength Structural bolt (AS1252 or AS-1110 class 8.8) fixity as a fully tensioned system

Retention / factored axial resistance per M16 bolt is

$$800 \text{ kN / mm}^2 \quad \times \quad 0.8 \quad \times \quad 157 \text{ mm}^2 \quad = 100.5 \text{ kN}$$

(Tensile Strength) (Factor) (Tensile Stress Area of thread) (Per Bolt)

Thus

$$500 \text{ kN per metre requirement} / 100.5 \text{ kN} = 4.98 \text{ number bolt fixings per metre of joint retainer}$$

THUS M16 HSS fixings at 200mm c-c comply with draft issue AS 5100 anchorage requirements.

M20 High Strength Structural bolt (AS1252 or AS-1110 class 8.8) fixity as a fully tensioned system

Retention / factored axial resistance per M20 bolt is

$$830 \text{ kN / mm}^2 \quad \times \quad 0.8 \quad \times \quad 245 \text{ mm}^2 \quad = 162.7 \text{ kN}$$

(Tensile Strength) (Factor) (Tensile Stress Area of thread) (Per Bolt)

Thus

$$500 \text{ kN per metre requirement} / 162.7 \text{ kN} = 3.07 \text{ number bolt fixings per metre of joint retainer}$$

THUS M20 HSS fixings at 325mm c-c will provide the required factored axial resistance of 500 kN / metre; HOWEVER it is a requirement that fixings cannot be spaced at greater than 300mm centres

THUS M20 HSS fixings at 300mm c-c comply with draft issue with AS5100 anchor requirements.

Note: Tensile strength figures and Tensile stress area of thread figures are provided by Ajax Fasteners publication Fastener Handbook – issue 99 – tables 29 and 31 (2)

1.1 Other Changes in Draft AS 5100 to Austroads BDC 1996

Draft AS 5100, section 17.3.5. Paragraph 3, advises some definitive rules with respect to gap clearances for Finger Joints. It requires that the maximum open gap between adjacent fingers on the same side of the joint shall be 50mm and that the minimum overlap of fingers on the opposite side of the joint shall be 15mm. Figure 3 below shows these requirements diagrammatically

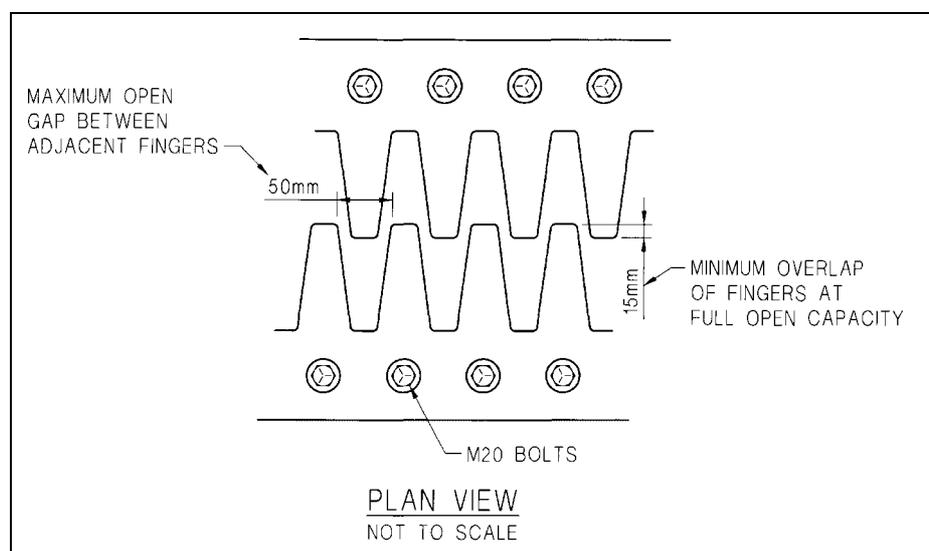


Figure 3: Plan view of "Finger" joint showing required gap clearances

Draft AS 5100, section 17.3.2. Design Loads, provides a requirement that joints be designed for concurrent vertical and horizontal live loads. It further provides rules for load factors with dynamic load allowances, when designing for serviceability limit state, ultimate limit state and fatigue.

Section 17.6 of AS 5100 makes an additional requirement from those stated in Austroads BDC 1996, that Modular expansion joints must be demonstrated to have complied with the fatigue test specification of NCHRP 402. This is recognition of the need to address the design of modular expansion joint systems as a dynamically designed component, rather than a quasi-static design with load factors added.

2 TRENDS IN REHABILITATION SYSTEMS FOR SINGLE ELEMENT BRIDGE EXPANSION JOINTS

2.1 Introduction

The late 1960's saw the beginning of the use of proprietary expansion joint systems into Bridge construction, and Australia was no exception to this trend. The success of these proprietary designed systems varied not only from product to product, but also varied within product groups largely due to variations in the integrity of the installation practices.

Some Bridge industry participants, contractors, designers and Road Authorities have been scathing in their view of the adequacy of such proprietary designed systems and in some respects perhaps correctly so.

Martin P. Burke in his paper Flawed Assumptions and the Failure of Bridge Deck Joints and Bearings (1) presented at the Third World Congress on Joint Sealing and Bearing Systems for Concrete Structures in 1991, commented as follows when comparing the relative success of the aero space industry in achieving its goal of getting man to the moon compared to the Transportation Industries goal of achieving effective and durable sealing systems for deck joints.

“The relative difficulty of their tasks cannot be used as an explanation since it must be conceded that the space engineers’ goals were extraordinarily greater than the bridge engineers’ One obvious reason for their success is that the space industry was centrally organized and directed for specific goals, while the transportation industry was not. Another reason is that the various tasks of a complex space goal were assigned to specialists in various fields to achieve the most reliable solutions. On the other hand, all tasks of the bridge engineers’ goal were given to elastomer industry volunteers to achieve the most cost-competitive solutions – not the most durable solutions.”

It is the opinion of the writer that the above observation whilst generally true of the past is less applicable to the current industry approach. Years of in service evaluations of systems have resulted in the evolution of more durable expansion joint systems for use into new structures.

2.1 Failure mode of ‘older’ bridge joints

Some of the more frequently used and specified single element joint systems used on bridges built during the late 60's, the 70's and 80's and now showing signs of failure can be summarised as follows:

- Compression Seals – refer Figure 4
 - Such seals were extensively used in 1960's and 70's structures, either between concrete faced gaps but more commonly between cast-in steel angles and/or plates. Performance of such seal elements varied, but where failure occurred in most cases it was shown to be directly attributable to factors such as long term age hardening of the elastomer and/or the seal loosing its “compression set” characteristics (i.e. its ability to recover from a closure compression). Often structure opening or closure movements beyond the capacity of the seal resulted in failure – refer Figure 5
 - Failure of the cast-in steel retainers is also often encountered. Such failures principally due to either inadequate concrete compaction behind the steel angle and / or lack of connected area ligatures or stud connectors resulting in fatigue induced connection failure.
- Elastomer Steel ‘slab’ type expansion joints such as Transflex Waboflex SR and Felspan – refer Figures 6 & 7
 - Such systems where either monolithic across the joint gap (Figure 6) or adopted the use of a flexible low force membrane retained under rubber / steel moulded retainer blocks (Figure 7). The usual failure mode of such systems is shown to be attributable to inadequacy of retention strength of fixings. These fixings were not of the tensioned type, but rather cast-in or grouted anchors, relatively small in diameter size and in most proprietary designs, spaced too far apart at nominal 12” centres. Such fixing failures are potential cause for complete system modules to become loose and create a major traffic hazard; cause for vehicle damage and potential loss of life (Figure 8). For this reason most Road Authorities have banned future use of these types of joints and have in place a programmed removal and rehabilitation of all such expansion joints.
- Aluminium retainer stripseal joints – refer Figure 9
 - Whilst Aluminium Stripseal expansion joints are the major current use joint, these are now detailed with ‘tensioned bolt’ fixings. Some early versions (shown in Figure 9) were installed with grouted bolt fixings and these early types are exhibiting similar classic failure mode of the above Transflex / Felspan type joints. I.e. inadequate fixing retention strength and failure of bedding grouts etc.

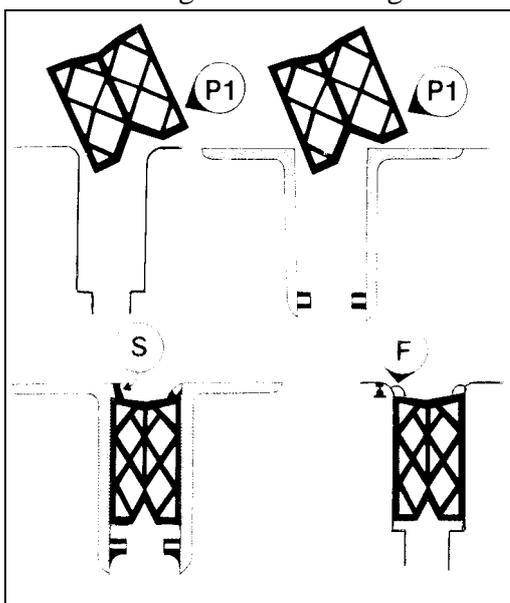


Figure 4: Typical “Compression Seal” Expansion joints into concrete or Steel moulded recess.



Figure 5: Often encountered failure of cast-in steel retainers. Fatigue of retention ligatures or concrete failure behind angles

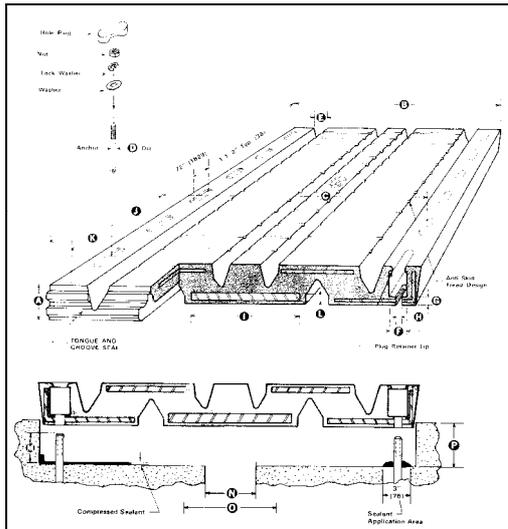


Figure 6: Elastomer Steel composite “Slab” type joints – Transflex / Waboflex

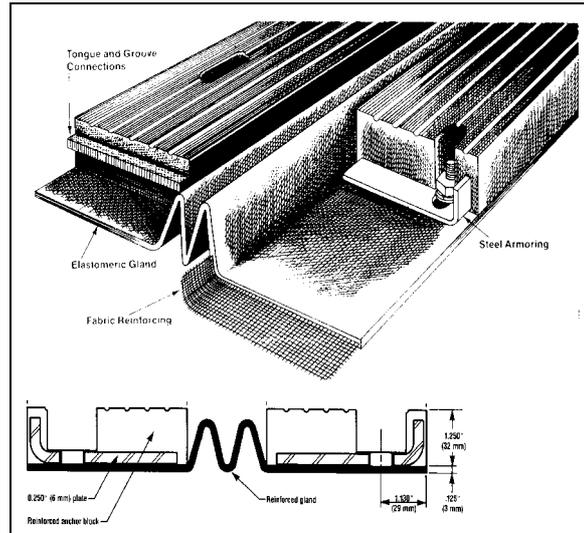


Figure 7: Elastomeric membrane with rubber steel block retention blocks – Felspan / Elastoflex

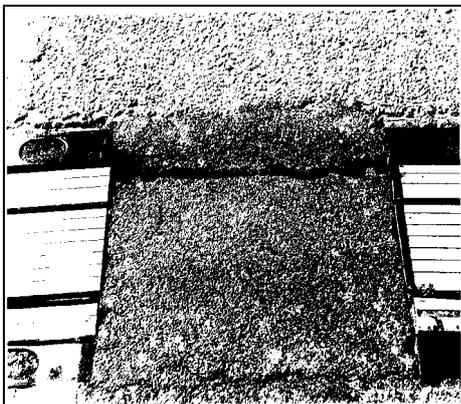


Figure 8: Photo showing missing Waboflex segment

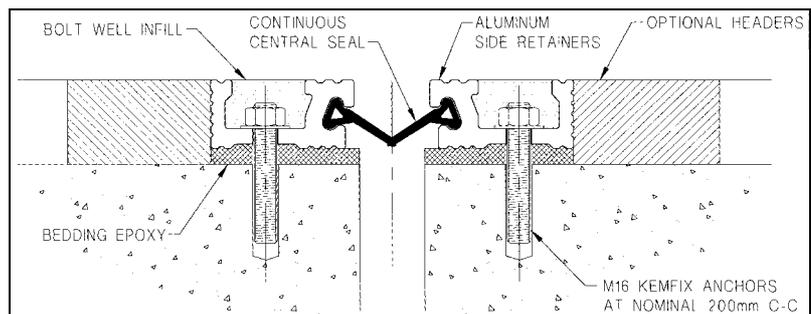


Figure 9: Aluminium retainer Stripseal joint system with grouted bolt connection mode

2.2 Current use rehabilitation systems

Failed bridge deck expansion joint systems need to be rehabilitated or fully replaced with minimal disruption to the normal traffic flows and with minimal physical impact on the bridge superstructure or deck. Freeway bridge structures necessarily demand night shift or weekend works to facilitate such outcomes requiring the section of joint being worked on to be open and fully operational at the end of the shift suitable for normal traffic loads and speeds.

The late 1980's early 90's saw an escalation of need for rehabilitation systems and outcomes due to the acceleration of structures presenting with joint systems (per those nominated above), which had reached the end of their serviceable life cycle.

Developments in Europe and USA has seen the evolution and introduction of composite systems using rapid cure synthetic resin, urethane, polymer and epoxy based materials coupled with inset seal retainers or rapid cure silicone and urethane sealants as the central sealing medium.

Typical details of such systems are shown in Figures 10, 11 & 12. The evolution of such systems was driven by the Road Authorities need to limit the amount of breakout and intrusion into the bridge structure and to achieve a rapid rehabilitation process with limited traffic interruptions.

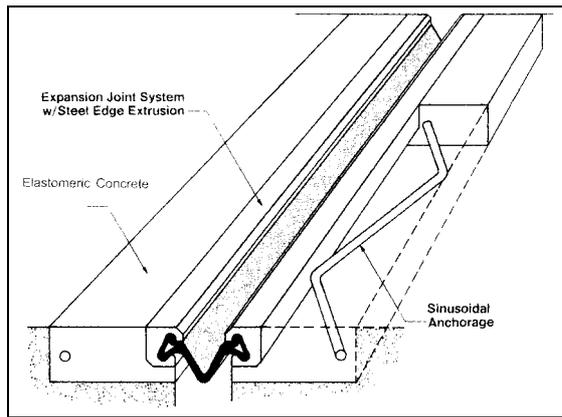


Figure 10: Steel retainer Stripseal Inset into “Elastomeric Concrete” Headers

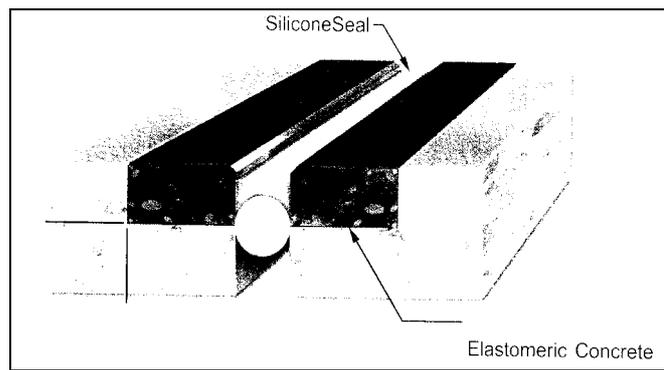


Figure 11: Composite system using “Elastomeric Concrete” and central rapid Cure Silicone Sealant.

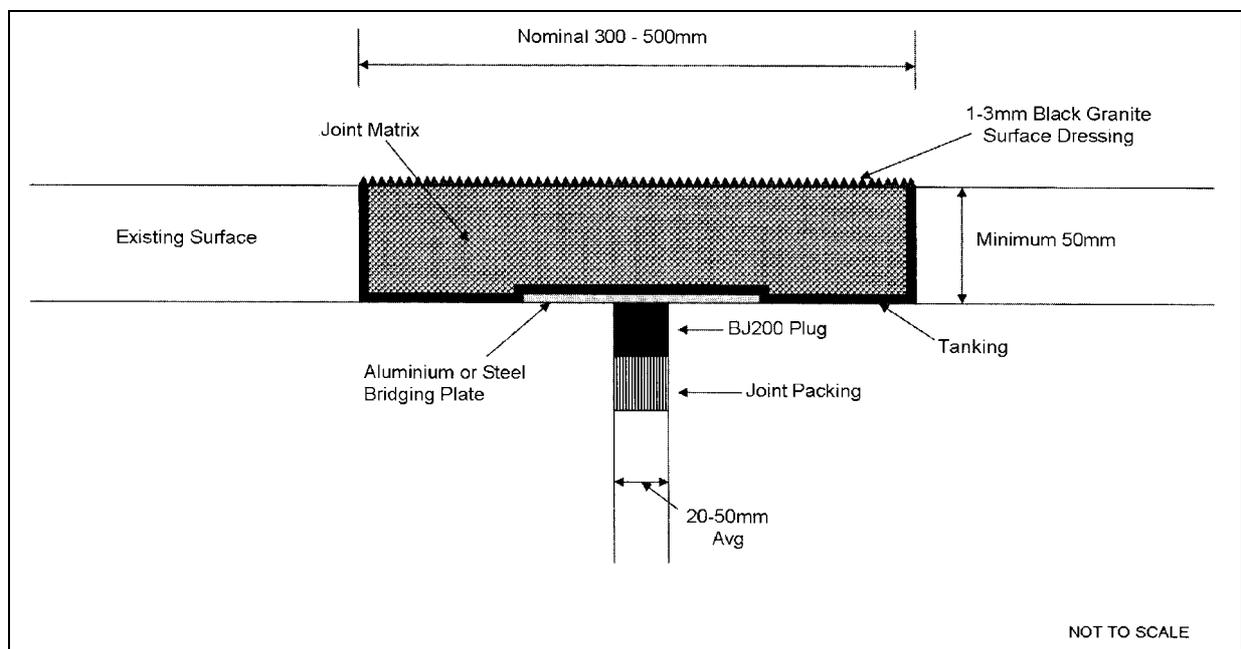


Figure 12: Typical “Asphaltic Plug”, or “Buried” joint system, monolithic binder and Aggregate composite

The common features of such systems are:

- The geometry of the replacement systems is usually accommodated within the confines of that provided by the removed failed expansion joint and with little or no intrusion into the deck slabs.
- They consist of rapid curing composites that allow lane at a time replacement and provide for normal vehicle traffic access upon the completion of the shift.

Some Road Authorities in the absence of definitive available means of controlling quality of such joint systems via specification have carried out field evaluation trials of joints to establish a relative comparison of performance ranking and outcomes. One such evaluation was carried out by the Florida Department of Transportation, the results of which were presented as a paper by Moussa Issa, Brenda Robinson and Mohsen Shahawy (3) at the Forth World Congress on Joint Sealing and Bearing Systems for Concrete Structures Conference in 1996.

The Florida D of T study evaluated the as installed performance over a 2 year period of a range of the above described composite rehabilitation systems developed by a number of USA and European manufacturers, with systems being installed by the manufacturers approved and trained installers.

The evaluation / study provides an insight into the relationship between installation technique, the care and attention placed on surface preparation of the exposed concrete substrates prior to the placement of the rehabilitation system and also to design integrity of the system. It was obvious that each of these factors played an equally important role in the ultimate performance of the evaluated system. It is clear that failure to achieve both sound installation practices and a design with integrity resulted in a system that failed to provide durability. This is demonstrated by the ultimate conclusion drawn by the writers of the above paper (3) and as follows:

“The solution appears to have many factors starting from the design to the installation and maintenance phases of the expansion joint system. The manufacturers should provide clear and detailed installation procedure for the expansion joint system.

It is recommended that the expansion joint system or seal be installed by the joint manufacturer or a contractor who is certified by the specific joint manufacturer. A technical engineer from the joint manufacturer is to be present during all phases of joint installation and construction.”

Certainly at the very least, the challenge for Road Authorities is to adequately assess the bona fides of such offered systems by:

- Insisting on documentary evidence (minimum of 5 years in-service) of successful performance of the system used as a replacement expansion joint. Failing such evidence, to require that the manufacturer of the system install a “trial or evaluation” joint on an appropriately trafficked structure, which should be evaluated for a 2 year in-service period prior to its approval for future ongoing use.
- Obtain documentary installation instructions complete with hold points and checklists and insist that these be used in any installation outcome.
- Insist that manufacturers “approved installers” carry out installations, or that a manufacturer’s representative be present during an installation outcome.

2 MODULAR MULTI SEAL ELEMENT DECK EXPANSION JOINTS

2.1 Introduction

Modular multi seal element deck expansion joints were developed in the late 1960’s. The system concept whilst probably well known to conference participants is shown in isometric in Figure 13.

Figure 13 depicts the multi support bar concept of a Modular system whereby each transverse seal retention beam is connected to a dedicated support arm. This multi-support arm system was developed by Maurer in Europe in the late 1960’s and the basic design / concept has been in continuous use by many worldwide manufacturers, initially under license ever since.

Single support arm systems – refer Figure 14, where larger section support arms support every seal beam are also a common use variant of the Modular Joint.

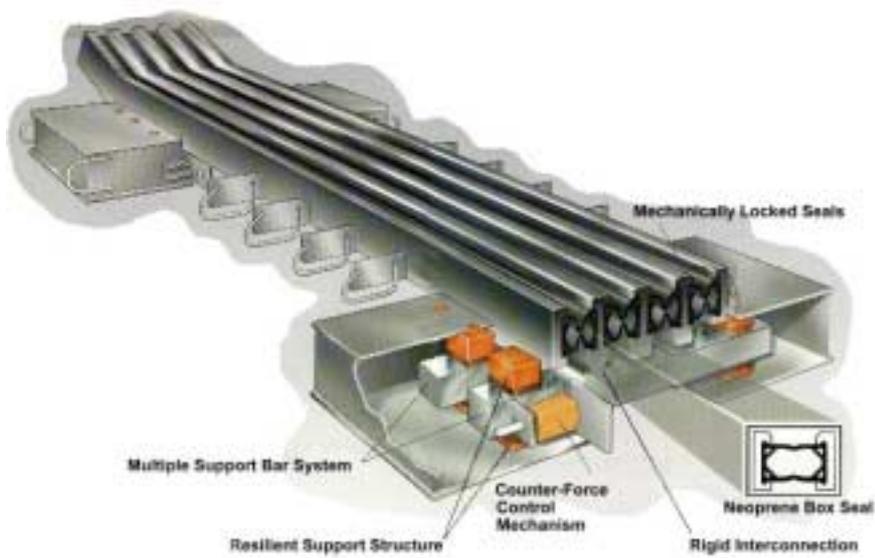


Figure 13: Multi support bars Modular Stripseal system

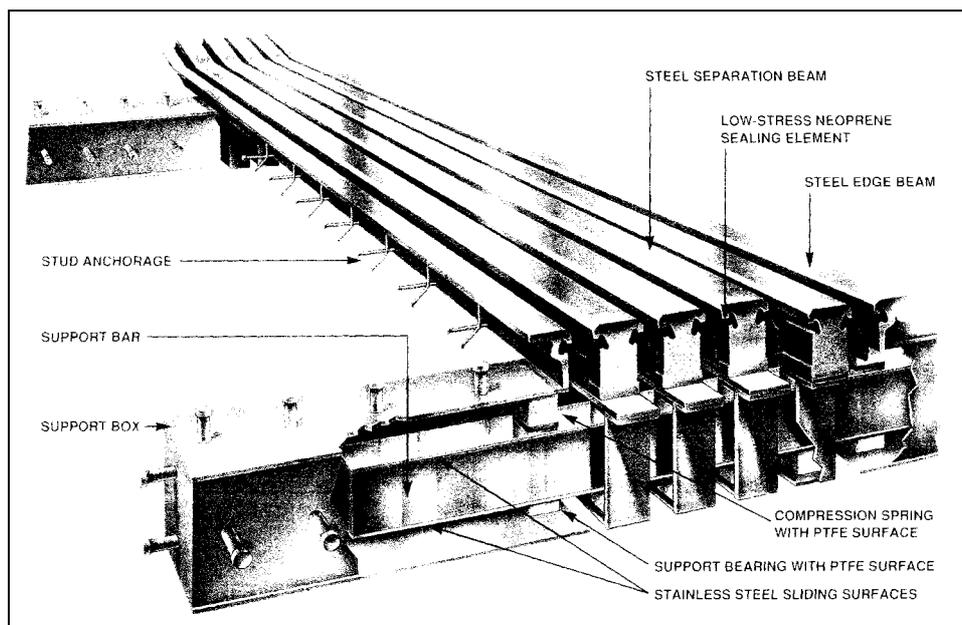


Figure 14: Single support bar Modular Stripseal system

The Modular concept of expansion joint has been a hot topic in Australia and other papers on the specific subject are being presented at this conference.

Performance of Modular expansion joints has been variable with many installations performing well after decades of service, however not withstanding the fact that installation quality and technique (as is the case with all expansion joints) does influence the ultimate durability and performance of Modular Expansion Joints, it is true to say that many proprietary design variants of the Maurer concept, indeed the Maurer concept joint itself have in some installations experienced an acceptable lack of durability and in-service failure.

Whilst the industry has undertaken investigations such as NCHRP 402 to progress the design of the product, it seems evident that some proprietary manufacturers are either not cognitive of or refuse to

recognise that such investigations clearly demonstrate that this deck expansion joint in particular must be designed as a dynamically loaded component. This is not a sudden revelation, evidenced by the findings of Tschemmernegg (4) who provided clear evidence of the need to refocus design approach away from quasi static analysis in his paper presented at the Third World Congress on Joint Sealing and Bearing Systems for Concrete Structures back in 1991, some 12 years ago.

Leading and responsible Modular joint manufacturers are now adopting such approaches as using full penetration weld connections at beam and support bar connections. Some USA State Road Authorities are placing conservative governing design requirements as simplistic as demanding that support arm spacings be a maximum of 1 metre apart, an empirical approach.

2.2 Current Design trends and Specification Requirements.

Recent revisions to the RTA of NSW specification B316 (5) – viz version for Mooney Mooney Creek Bridge Replacement Joint, demonstrates a structured and analytical approach to ensuring that the Modular Joint product achieves an infinite life cycle. Such approach is to be commended. This approach requires that the product becoming a “prime cost” component, resulting not in potential manufacturer / suppliers to compromise design and robustness of product in order to achieve commercial viability, but rather results in all parties aiming at a joint that will last the life of the structure with only occasion need to replace easily accessible bearing components

This revised RTA of NSW spec B316 requires potential manufacturers to show evidence of Experimental Modal Analysis (EMA) of the proposed Modular Joints, such that these results can be used to calibrate dynamic Finite Element (FE) models for the design of the joint to be supplied.

Figure 15 below shows such EMA undertaken by RTA on a 5 seal multi-support bar modular joint system on the bridges over the Manning River at Taree.

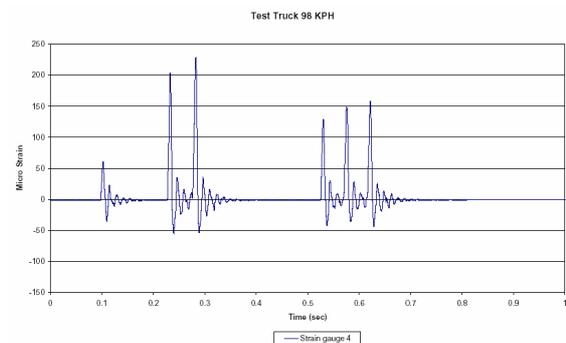


Figure 15: Experimental Modal Analysis of existing Multi Support arm Modular Joint at Taree.

The degree of damping of a Modular joint (facilitated by the support bearing pads) has a significant effect on the decay with time of the vibrations, with less influence on the initial vibration magnitude. The graph below (Figure 16) shows the differences in decay effect between 1.2% damping and 7% damping. High damping results in reducing the amplification effects that multiple axle trucks produce (one wheel hits at time t_0 , then a fraction later the next wheel hits at time t_1)

The analysis of the behaviour of modular joints under traffic can be complex. When a tyre strikes the joint, the joints beams want to bend and vibrate in different ways into a combination of a few different shapes, called mode shapes. Where the tyre strikes the joint dictates how much each mode shape contributes to the joints overall dynamic response. FEA reveals that all modular joints have common mode shapes. Such mode shapes include:

- Transverse “wagging” of the cantilever ends of the joints beams (Figure 17)
- Vertical “wagging” of the cantilever ends of the joints beams (Figure 18)
- Transverse Uniform mode – bending in a centrally pushed way (Figure 19)
- Vertical Uniform mode – bending down of beams (Figure 20)
- Axial Uniform mode (Figure 21)
- Complex Multiple wave modes (Figures 22 & 23)

Each of these vibrational modes has a modal (natural) frequency associated with it. Thus if the tyre pulse hits the joint beams at the same frequency, resonance effects occur. When designing dynamically (as opposed to static design), one can change these natural frequencies by changing dimensions so that they are above the tyre pulse frequencies, and hence will respond less.

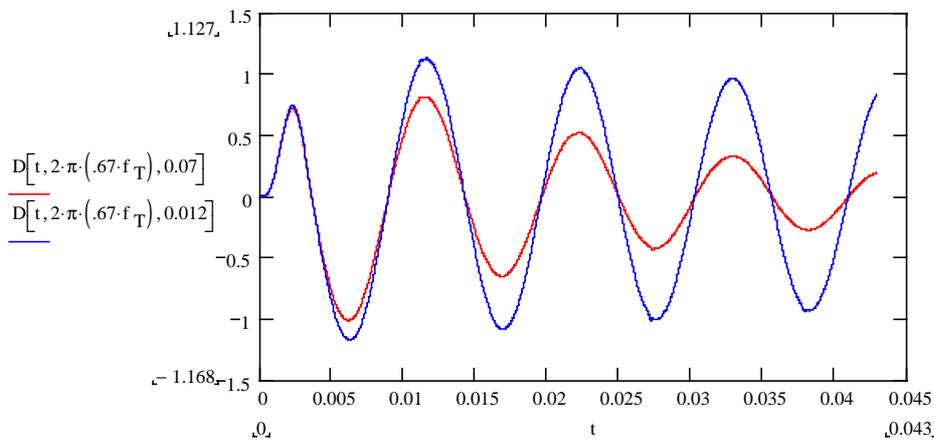


Figure 16: Damping effect –showing difference between 1.2% and 7% damping

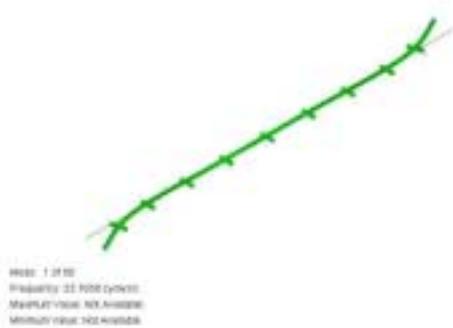


Figure 17: Transverse “wagging”



Figure 18: Vertical “wagging” mode

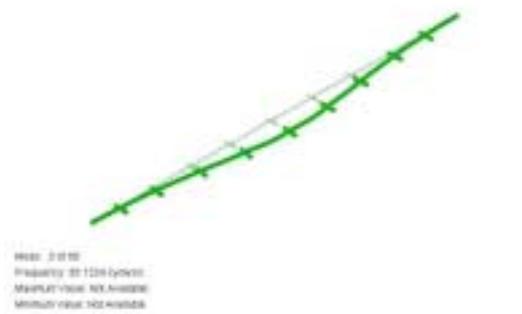


Figure 19: Transverse Uniform mode

Figure 20: Vertical Uniform mode

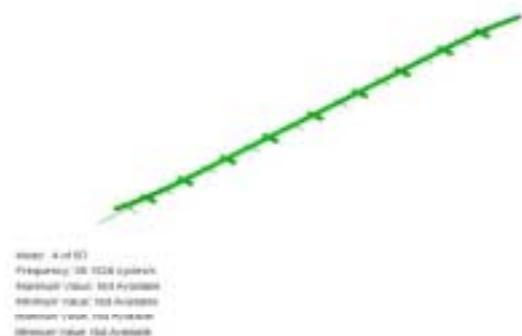


Figure 21: Axial Uniform mode

Figure 22: Transverse 2nd mode

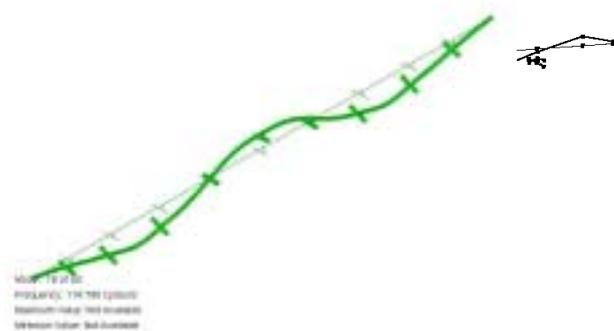


Figure 23: Vertical 3rd mode

Figure 24: EMA mode shapes from RTA Taree showing similar modal shapes.

Single Support Bar (SSB) Modular joints require careful attention to the selection of appropriate compressive stiffness and pre-compression of the bearings used in the yoke connection of the beams to the support bars. Particular attention is given to the Yokes at the centre of the support bar, with the higher the number of seal elements, the more pronounced the deflections and strains are. - Refer to Figures 25 to 27 below.

Yokes- Upper and Lower Impact Absorption with increased precompression

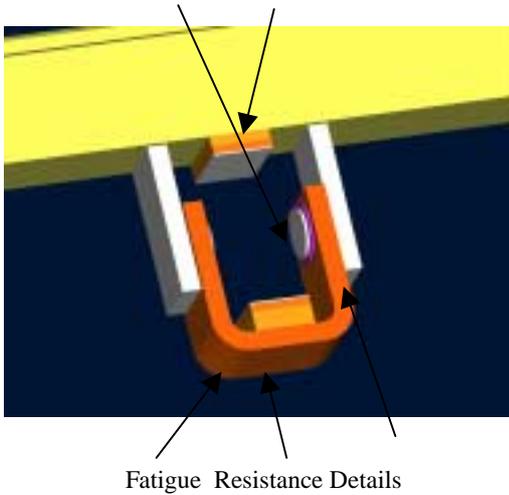


Figure 25: Schematic of Yoke for Single Bar Modular joints

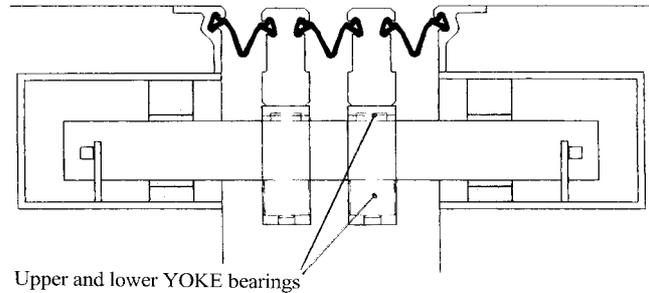


Figure 26: Section of Single Support Bar Modular showing location of YOKE bearings.

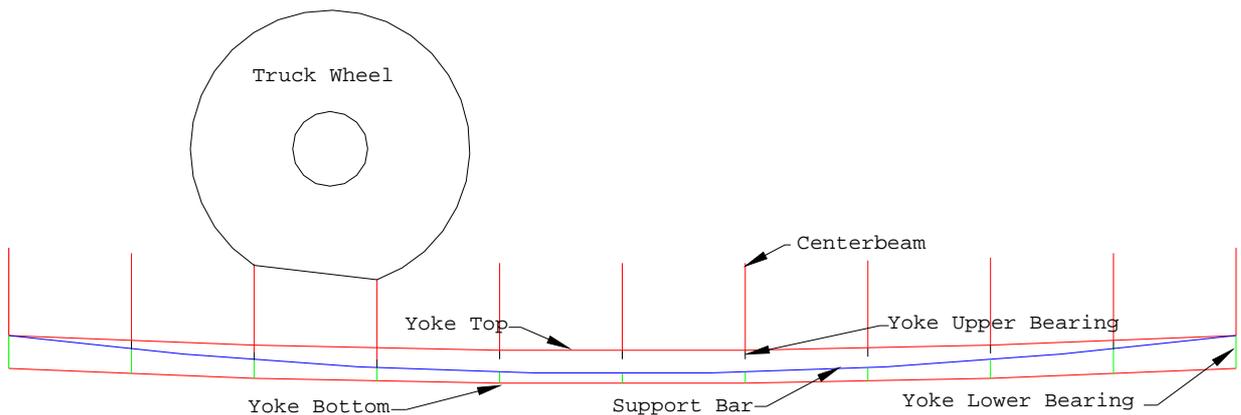


Figure 27: side view schematic of support bar showing progressively larger deflections of bearings towards central centre beams.

2.3 Outcomes for Modular Joints arising from above design approach

The above selective issues of design approach are not all encompassing in the overall design assessment of larger Modular joints. Some of the other issues not referred to above and covered in the design considerations include but are not limited to:-

- Support integrity under control boxes
- Design variations of the lower and upper support bearings
- Static analysis check
- Weld design of all connections

- FEA modelling of load synchronisation of wheel loads on the centre beams
- Structural strength of control box base support plates

The RTA of NSW draft specification requirements result in the following desirable outcomes for future Modular joint supply.

- “Prime Cost” or “Provisional Sum” product
- Encourages manufacturers to carry out field EMA’s on their as installed modular joints.
- Use of EMA to calibrate FE and design outcomes
- Larger section size centre beam and support bar components
- Closer spacings for control box supports
- Greater analytical approach to the design of support bearings instead of using predetermined commonly used bearings and then designing around this particular component.
- Requirements for easy access for ‘replacement’ components such as upper and lower bearings, yokes and seal spacing control buffers.
- Requirement for attendance of manufacturers representative during installation
- Single Support Bar modular joints become the logical avenue to achieve compliance.
- Requirements for documented weld procedures, Non Destructive Testing (NDT) of all centre beam to support bar full penetration weld connections.

2.4 Conclusion

The need to replace a Modular Joint system due to failure of major structural components is cause for extremely high costs relative to the initial cost of the product at time of the bridge construction.

There is obvious logic in requiring the Modular Expansion joint product to be a ‘prime cost’ item and that the joint system is designed dynamically, as achieved by specifications such as the current draft B316 RTA of NSW specification.

The nominal 20 to 40% cost increase impost to achieve an infinite cycle to failure Modular Expansion Joint (a joint that will last the life of the structure) is ‘peanuts’ compared to replacement costs which need to cover not only the prime costs of the replacement joint, but also the consequential costs of traffic control, plant and equipment, labour etc for re-installation and the community costs associated with disruptions to normal traffic access to the bridge structure.

Not covered in this paper, but time permitting will be some slides of one such Modular Joint replacement event on the Mooney Mooney Bridge on the F3 Freeway, Gosford, NSW for the RTA of NSW.

3 REFERENCES

- 1 Austroads Bridge Design Code 1996
- 2 Final draft of Australian Standard AS-5100
- 3 FASTENER HANDBOOK – issue 99 – *Tables 29 and 31* – Published by Ajax Fasteners
- 4 MARTIN P BURKE “Flawed Assumptions and the failure of Bridge Deck Joints and Bearings” *Paper at Third World Congress on Joint sealing and Bearing Systems for Concrete Structures – October 1991, Toronto Canada. Pp35-52. Published by the American Concrete Institute*

- 5 MOUSSA ISSA, BRENDA ROBINSON, and MOHSEN SHAHAWY “On Site Evaluation of Bridge deck Expansion Joints” *paper at the Forth World Congress on Joint Sealing and Bearing Systems for Concrete Structures – 1996, Sacramento USA. pp561-584. Published by the American Concrete Institute*
- 6 F. TSCHEMMERNEGG “The Design of Modular Expansion Joints” *Paper at Third World Congress on Joint Sealing and Bearing Systems for Concrete Structures – October 1991, Toronto Canada. pp67-86. Published by the American Concrete Institute*
- 7 Roads & Traffic Authority of NSW specification B316 – *Version for Tender on supply of replacement Modular Expansion Joint for Mooney Mooney Creek Bridge Structure.*