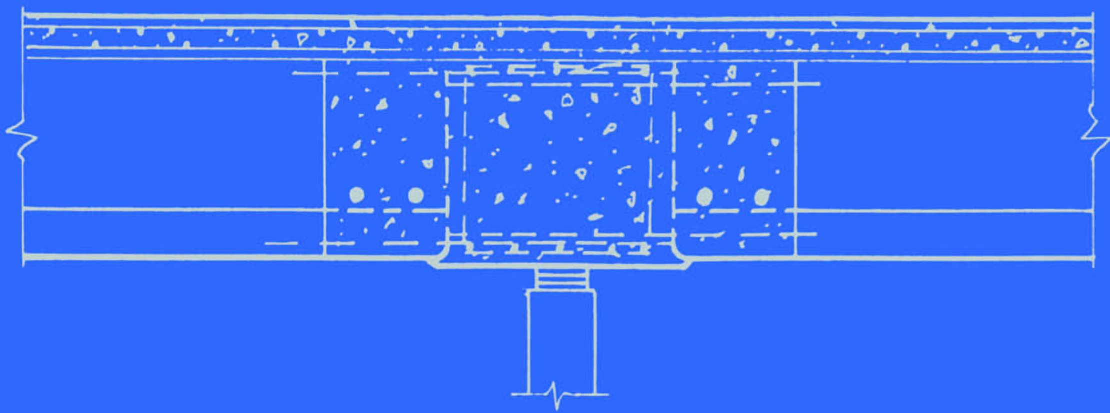

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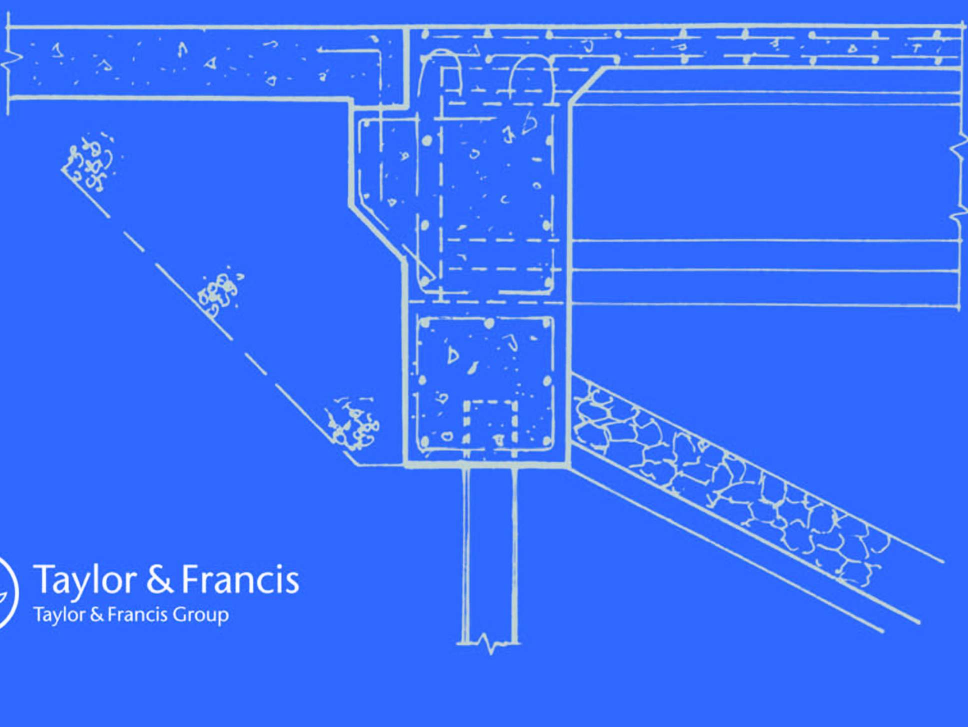

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Continuous and Integral Bridges

Proceedings of the Henderson Colloquium
'Towards Joint-Free Bridges'
organized by the British Group
of the International Association
for Bridge and Structural Engineering

Pembroke College, Cambridge, UK
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Preface

Welcome to the proceedings of the British Group of IABSE's annual colloquium which this year concerned joint-free bridges. The first of these colloquia was held in 1974 during the Chairmanship of Dr William Henderson from 1967 to 1979. In appreciation of his contribution the British National Group has named them 'Henderson Colloquia'.

The subject for a colloquium is selected as being of current concern and worthy of debate over 2½ days by some 30 contributors cloistered in Pembroke College, Cambridge. The contributors are invited on the basis of their experiences and the views they are likely to have, and come from several countries to maximize the benefits to be gained by all. The informal arrangements encourage discussion and debate and also provide introductions to new colleagues. The subjects in the past have dealt with design methods, materials, construction practices, professional liability and with types of structure, such as surface-stressed building structures in 1992. The proceedings are published to make the information and views expressed available to all interested people and are later discussed at a joint meeting organized by the British Group of IABSE and the Institution of Structural Engineers.

On behalf of the British Group of IABSE I thank all the participants for their contributions to the colloquium and the spirit of camaraderie which developed. We are all grateful for the preparation of the colloquium by Brian Pritchard and his organizing committee as well as Bob Milne who made it all happen.

D.W. Quinion
Chairman, British Group, IABSE

Introduction

The late Bernard Godfrey, fondly remembered as a very active member of the (then) British Constructional Steelwork Association, besides IABSE, visited America in 1989. He returned full of enthusiasm for the examples of the new joint-free type bridges he had come across, particularly some very long viaducts in Tennessee. At the next IABSE British Group meeting he proposed that the 1993 Henderson colloquium should be on the subject of joint-free bridges. Bernard's proposal was immediately accepted and he started to recruit his committee. Sadly, Bernard died several months later.

Responding to Bernard's enthusiasm, a programme entitled 'Towards joint-free bridges' was put together by an organizing committee consisting of:

B.P. Pritchard (Consultant, W.S. Atkins Consultants Ltd) Chairman
A.M. Low (Ove Arup & Partners)
G.A. Paterson (Department of Transport)
D.W. Quinion (Chairman, British Group, IABSE)
Dr G.P. Tilly (Gifford & Partners Ltd)
R.J.W. Milne (Institution of Structural Engineers) Secretary

The first five named individuals also acted as chairmen and reporters for various sessions. Mr S. Shanmugam (Department of Transport) also helped by reporting on two of the sessions.

The nature of the colloquium is unique, in that attendance is by invitation only, with each of the 30 delegates, including representatives from eight overseas countries, contributing a paper. Only short introductions are given by authors and the main purpose of the colloquium is hopefully fulfilled by the lengthy discussion periods allocated after each session.

Bernard Godfrey's enthusiasm reflected the growing world-wide interest in joint-free bridging. Joints are a continuing problem in existing bridging not just because of their own failures and maintenance problems, but because of the enormous amount of corrosion damage, measured in billions of pounds, which can be caused to the underlying substructures by leakage through the joints of deck run-off water containing corrosive de-icing salts. It is not, therefore, surprising that the UK Department of Transport are currently favouring multi-span bridge deck continuity and, indeed, joint-free integral bridges up to some 70 m long. It is also evident that longer and longer integral bridges are being constructed in Europe and America.

With these factors in mind, the organizing committee invited representatives from all sectors of the bridging industry and particularly from countries heavily involved in integral bridge construction. After much deliberation, it was decided to divide the two-day colloquium into eight sessions, having the following themes:

1 Problems of bridge articulation
2 Advantages of bridge continuity
3 Continuous bridges
4 Integral bridges
5 Long-length continuity
6 Retrofitting
7 Precast beam deck continuity
8 Soil–structure interaction

In the event, the colloquium attracted excellent papers in all sessions, with lively and informed discussion inevitably exceeding the time allotted.

It is hoped that this book conveys these qualities, which were very evident to those who attended the colloquium. It cannot convey, however, the spirit of the event – a heady mixture of international camaraderie and expert first-hand knowledge overlain with the nostalgia for student days which Cambridge generates.

May I conclude this introduction by recording my heartfelt thanks to the participants and to the hard-working members of the organizing committee, who all contributed so much to this successful event. I must also thank Bernard, no doubt in a bridge-decorated afterlife, for pointing the way.

Brian Pritchard

PART ONE

PROBLEMS OF BRIDGE ARTICULATION

1 PERFORMANCE OF DECK EXPANSION JOINTS

I.D. JOHNSON
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Abstract
The infrastructure developments of the 1960's led to a considerable increase in the UK bridge stock. It is recognised that the maintenance of this stock now represents a major annual expenditure which has been increased by the combination of the use of rock salt for de-icing and the deficient performance of expansion joints.

Due to concern expressed by the Department of Transport regarding bridge deck expansion joints the Transport Research Laboratory appointed G. Maunsell & Partners to carry out a study of the condition and performance of 250 highway bridge deck joints in-service. The commission was awarded in February 1990 and completed in July 1992.

This paper is based on the findings of the study and discusses the selection, specification and detailing of joints and associated components.

Inspections of the joints indicated that a substantial proportion has some form of defect and that a significant proportion leak. Bearing shelves and sub-surface drainage systems were found to be poorly detailed or badly maintained in a large number of cases and this exacerbated the effects of the leakage of run-off water through expansion joints.
Keywords: Bridge, Expansion Joint, Performance, Selection, Specification, Detailing.

1 Background

Several studies have been conducted over the last decade into the durability of highway bridges, Booth et al (1987), Weisgerber et al (1987), PIARC (1987) and Wallbank (1989). All of these studies, regardless of the country involved, highlight expansion joints as being critical elements affecting the maintenance-free lives of structures and include recommendations that specific studies be conducted on the performance of joints in-service. The most recent national investigations of expansion joints in the UK prior to this study were conducted by Price (1984).

Until the mid 1970's the most common forms of expansion joint in use in the UK were the buried and nosing types, however, as a result of the failure of the surfacing over buried joints and the generally poor

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performance of nosing joints, the asphaltic plug joint (APJ) has now been widely adopted.

The original APJs, developed in Italy and the UK during the late 1970's, suffered from an unacceptable degree of tracking during periods of hot weather and, although there have been continuing modifications of the bitumen binders by the manufacturers, it is noticeable that the present day performance of APJs is not wholly satisfactory.

The work by Price included a limited survey of APJs. The significant annual expenditure now associated with the maintenance of the UK bridge stock, coupled with the increased use of APJs, and the identification of the performance of expansion joints as critically affecting the durability of highway bridges lead to the Transport Research Laboratory appointing G. Maunsell & Partners to conduct a study of the condition and performance of expansion joints in-service.

The study was intended to update the available knowledge concerning the performance of the more commonly used types of joint, namely APJs, reinforced elastomeric joints (REJs) and elastomeric in metal runner (EMR) joints and involved the inspection of 250 joints over a period of 18 months. Full details of the joint types studied, procedures used and the locations of the joints surveyed are included in the final report, Johnson and McAndrew (1993).

It was found that the majority of expansion joints have some form of defect and that the problems identified by previous workers still persist. This paper is based on the findings of the study and discusses the selection, specification and detailing of joints and their associated components.

2 Selection

2.1 Performance requirements

The purpose of expansion joints is to permit movement of the bridge deck whilst ensuring that the ride quality and watertightness of the joint are not unacceptably affected. Furthermore, it is important that the joint be able to accommodate freely the design movements expected of the structure, whether they be rotational, lateral or longitudinal, without either transferring potentially damaging forces into the structure or causing distress to the joint itself.

As well as these performance requirements, the process of selection of an appropriate joint should also take into account the characteristics of the site that is being considered. Although the Department of Transport (DoT) Departmental Standard and associated Advice Note provide some guidance on the selection of joints, DoT (1989a), DoT (1989b), it could be argued that the implementation of the current UK Specification for Highway Works, DoT (1992), limits the selection process and does not necessarily enable to engineer to specify the most durable or appropriate joint type for a given situation. DoT policy with respect to the assessment of durability is currently under review and it is understood that the concept of whole life costing is to be introduced, this point is discussed further on in this paper.

2.2 Movement

Acceptable movement ranges for the various joint types in use on UK roads are given in the Departmental Standard, however, the relative proportions of static and dynamic components can significantly affect the performance of a joint. The acceptability limits provided for these components in relation to joint performance, particularly with respect to APJs, is less clear and is open to some conjecture.

The surveys conducted as part of the study identified that the performance of APJs was often incompatible with the relatively large magnitude of dynamic, or high frequency, displacements and rotations that can be experienced on steel composite decks when these structures are subjected to heavy traffic densities, particularly those incorporating a high proportion of heavy goods vehicles (HGVs). It was noted, however, that the cracking and leakage of APJs resulting from this incompatibility was usually confined to untrafficked areas, such as the hardshoulder or central reserve, and, to a lesser extent, to the outer lane of dual 3 lane carriageways. It is considered that this distribution of defects is due to the remoulding effect that trafficking, particularly by HGVs, can have on the binder matrix of APJs.

It was reported by maintenance engineers that cracking of APJs was often initiated after the occurrence of hard frosts. The onset of this cracking is considered to be the result of relatively sudden thermal movements associated with rapid temperature changes.

Cracking, due to either trafficking or frost, is believed to occur due to limitations in the elasto-plastic behaviour of the binder material. It is, however, considered that insufficient information is currently available to enable practical guidelines to be prepared which would then permit the design engineer to assess potential joint performance from the binder properties.

Concrete decks generally tend to be stiffer than their steel counterparts, the dynamic component of the total joint movement is, therefore, not as onerous. It is, however, essential that the static, or low frequency, movements arising from the creep and shrinkage of concrete decks are fully assessed; inadequate provision for these movements has been found to result in the dislocation of elastomeric inserts in EMR joints. Similar errors could also cause distress in REJs and may lead to splitting. Movements due to creep and shrinkage appear to be significant only on relatively long span, or multi-span continuous structures. No deleterious effects in APJs have been attributed to these movements.

2.3 Influence of site on joint type

The performance requirements of a joint are partially related to the characteristics of the site in which it is to be placed and the site should, therefore, influence the selection procedure. Moreover, the nature of the installation itself, whether new construction or replacement work, can place significant restrictions on the suitability of some joint types.

Heavy trafficking is a primary concern and can lead to tracking of APJs and an unacceptable ride quality. If tracking is allowed to develop unabated then increased impact loads can result in the deterioration of the adjacent surfacing and the eventual potholing of joints. Because of this, it is recognised by many maintenance authorities that regular resurfacing of the upper 40mm of APJs may be required on busy routes.

The behaviour of REJs and EMR joints can also be adversely affected by trafficking. The inspections carried out indicated that bolted connections, and particularly those anchored by the placement of a mortar bed under the complete joint, are inappropriate for routes with a high flow of HGVs. The vibrations caused by such vehicle flows have been found to result in the stripping of bolt threads and, in some cases, severe deterioration of the anchorage material. It should be noted that an anchorage bedding has been observed to reach the point of disintegration within a period of three months from the time initial signs of distress were noted; this highlights the need for the regular inspection of joints to assess their integrity.

In addition to vibration related damage, mechanical anchorages are also subjected to dynamic impact loads which have been shown to be up to 1.7 times the static wheel load, Koster (1986). These impact loads no doubt play a significant role in the deterioration of anchorage beddings as noted above. Such deterioration is not as frequent in the anchorages of EMR joints, the majority of which are cast-in and have a reinforcement cage integral with that of the deck.

Cast-in anchorage details are, however, usually wholly inappropriate for repair situations where a failed joint is to be replaced. In such instances surface mounted joints are finding much favour in the UK. These are bonded to the deck via resin nosings and although one manufacturer has gained a good track record, other systems, based on the same principle, have failed during service trials due to inadequate anchorage.

Deck joints which experience mechanical anchorage failure will usually require considerable remedial works to return the joint to a serviceable state. This is equally true of segmental bolted joints where damage to a single segment results in the need for the replacement of that component; the time taken for the repair of bolted joints can be significantly increased, and thus serviceability seriously impaired, due to the ingress of salt and grit.

The acceptability of maintenance operations, whether they be regular minor works to APJs or infrequent major repairs to failed mechanical joints, must be considered with respect to the disruption that would be caused to road users, particularly on major arterial routes such as the M25. Such considerations may demand the selection of a more reliable form of joint even if this incurs an increase in the initial capital cost.

An over-riding factor in the selection of the form of joint may be the resurfacing requirements for the main carriageway. This is particularly applicable to multi-span simply supported structures such as the elevated sections of the M5 and M6 through Birmingham. There may be a case for re-articulation of the deck and the introduction of continuity when major maintenance of such structures is carried out. G. Maunsell & Partners adopted this approach for the refurbishment of the A19 Tees Viaduct and the subject is to be covered in greater detail by another author. Such refurbishment exercises can modify the performance requirements for expansion joints, eg. the transfer of braking loads between spans. These must be taken into account during the selection and specification procedure.

The study has shown that up to 70% of the APJs and approximately 65% of the REJs inspected were leaking. In contrast, leakage through EMR joints occurred in only 40% of cases and the majority of these were related to the use of preformed sheet waterproofing systems; the use of a liquid membrane system would probably alleviate many of these cases. The expenditure on the repair and rehabilitation of the DoT stock of concrete bridges has been reported by Wallbank to be in the order of £60 million per annum, a significant proportion of which has been necessitated by the effects of chloride laden run-off water leaking through expansion joints. In cases where concrete sub-structures cannot be provided with protection, e.g. waterproofing the bearing shelf area and deck ends, then a heavy onus should be placed upon the performance of the selected joint with respect to watertightness.

3 Detailing and specifications

The selection of an appropriate joint must be supported by the conscientious detailing of the joint, drainage systems and the underlying substructure in order to ensure that a durable design is achieved.

An Advice Note on Design for Durability, currently being prepared by the DoT, Holland (1993), contains guidance on the provision of abutment galleries where conventional abutments are to be used as well as other design aspects pertinent to expansion joints.

The current UK DoT Specification for Highway Works restricts the level of detail that can be incorporated in specifications for expansion joints. Provision is made for the specification of sub-surface drainage and it is strongly recommended that such drainage be provided where water is likely to pond on the bridge deck adjacent to the joint.

A large majority of the problems observed with expansion joints can be attributed to the inefficient drainage of sub-surface water. Unfortunately the drainage systems currently used either have insufficient capacity or appear to be unmaintainable and become blocked over an unacceptably short time scale. Transverse drainage systems can be detailed such that they can be rodded or jetted and such detailing should be encouraged wherever possible.

If feasible the inclusion of dual drainage systems should be considered; transverse drainage can be placed immediately adjacent to the joint and combined with through-deck drainage some distance away from the joint. Consideration must, however, be given to the discharge from such drainage to ensure that other areas of the structure, e.g the internal surfaces of box decks, are not inadvertently affected by run-off water or put at potential risk.

There is a real need for further developments in the design of sub-surface drainage systems and this will become increasingly necessary with the introduction of porus asphalt surfacing. The need for such drainage can however be alleviated by the use of buried joints if articulation can be arranged such that the lowest end of the deck also acts as the point of fixity and that dynamic rotational movements are limited.

Despite the restrictions on the engineer's freedom to specify joint details, it is strongly recommended that the requirements of the Departmental Standard and Specification are clearly shown on tender and contract drawings. The adoption of such practices partially resolves the problem of expansion joints being regarded as secondary components in bridge design and should prompt both the design engineer and contractor to consider the detailing and installation of joints more fully.

The previous discussion of the parameters that should be taken into account when selecting an appropriate form of joint highlight some of the deficiencies in the existing specifications. It has been stated earlier that the engineer is currently unable to apply the full selection process when either specifying the form of joint to be used or when considering the contractor's selection of a joint. This state of affairs may be partially redressed by the introduction of whole life costing by the Design for Durability Advice Note. It has, however, been suggested that there may be insufficient cost data available to apply the method as comprehensively as may be desired, Leeming (1993). The current study has certainly shown this scarcity of data to be true of maintenance costs and of estimates of maintenace-free lives for expansion joints.

4 Concluding remarks

It has been found that the majority of expansion joints have some form of defect and that the problems identified by previous workers still persist.

A significant proportion of expansion joints leak and thus represent a major cause of deterioration of highway bridges.

There has been a notable increase in the use of asphaltic plug joints throughout the road network in the UK. However, the response of binders to dynamic and sudden thermal movements remains questionable and research to define both the required properties and to provide further guidance to engineers is required.

The current UK DoT Specification does not allow the full selection process for joints to be implemented by the specifying engineer and thus, at present, may lead to the installation of expansion joints which do not provide the best solution for the specific site being considered. There is, therefore, the need for a revision to the specification either to enable the engineer to select appropriate joint types or to comprehensively incorporate the selection procedure in a form of performance specification. If the latter course is to be taken, definitions of exactly what constitutes a failed joint will have to be prepared; these do not exist at present.

There is an increasing amount of interest in the adoption of integral bridges as a common design concept. There is, however, debate as to whether deterioration occurs in the surfacing at the interface between the road pavement and the bridge structure and whether an expansion joint should be provided at this location. This deterioration will probably be exacerbated by the introduction of porous asphalt on to the UK road network. The requirements for such a joint will be similar to those applicable to a conventional abutment and the inadequate selection, detailing and specification of such joints will result in expenditure on remedial works over an unacceptably short maintenance cycle.

Examples of expansion joints which exhibit satisfactory in-service performance have been observed during this study and prove that close attention to detail at the design and installation stages can avoid the defects which are commonly associated with deck joints.

5 Acknowledgement

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The views expressed in this paper are not necessarily either those of the Transport Research Laboratory nor those of the Department of Transport.

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2 RESEARCH REQUIREMENTS FOR BRIDGE DECK EXPANSION JOINTS

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Abstract
Any type of joint is a potential source of weakness. Modern concrete and steel bridges have joints to accommodate the movements of the bridge deck relative to the adjacent pavement. Many of these joints leak, allowing water and chlorides to penetrate deck ends, abutments, piers and crossheads and cause corrosion of the reinforcing steel. The performance of current joints is very variable. Some are satisfactory, but many have service lives of only a few years and are expensive to maintain.

Joint performance is determined by a complex combination of factors. Some of the main factors are; the movements at the joint resulting from thermal variations and wheel loading, the properties of the materials used, and the installation conditions and standard of workmanship.

This paper gives an overview of research to develop a performance based specification based on approval testing. Laboratory tests are needed to simulate movements and wheel loading on new joints, and material tests need to be developed for use in quality control.
<u>Keywords:</u> Bridge, Expansion joints, Surveys, Fatigue testing.

1 Introduction

Bridge substructures move very slowly, but the deck is subject to short duration traffic induced movements, as well as those due to changes in the environment such as temperature. The amount of movement depends on the span, traffic loading and form of construction. Any type of joint in a structure is a potential source of weakness and expansion joints are no exception.

Designing out some or all of the expansion joints may be appropriate for new bridges and some existing multi-span structures, but for the great majority of existing highway bridges expansion joints will have to be maintained, and replaced several times during the life of the structure. Irrespective of the type of joint used, the requirements are simply stated.

- To provide a seal between two parts of the structure which are moving relative to one another.
- To provide a smooth, quiet, durable running surface for traffic.

2 Joint types

Several types of expansion joint are used in the UK to cater for different movement ranges; buried (20mm max movement), asphaltic plug (40mm), nosing (40mm), elastomeric, in metal runners and cantilever comb or tooth (mechanical joints). The maximum capacity of the latter three types varies according to manufacturer and type. Requirements for expansion joints on highway bridges are given in Departmental standard BD 33/88 (Department of Transport, 1989a), with additional advice in a companion Advice Note, BA 26/88 (Department of Transport, 1989b).

In general there are few problems with elastomeric joints. The elastomeric seal may be damaged by sharp debris, but it can be replaced. However, the majority of the UK bridge stock consists of short span bridges, asphaltic joints are more common than the larger capacity types. Buried and nosing joints were widely used in the 1970's, but asphaltic plug joints are currently the most popular type. Current research at the Transport Research Laboratory (TRL) is therefore concentrated on asphaltic plug joints (but large mechanical joints may become more widely used in future to provide a single joint in an otherwise continuous structure.

3 Review of Department of Transport (DOT) research

Trials and surveys of several joint types were carried out in the early eighties. These included buried joints (Price, 1982), open gap (nosing) type joints (Price, 1983) and a seven year study covering all the main types then in service (Price, 1984). Since then, buried joints and open gap (nosing) joints have largely been superseded by asphaltic plug joints and these have been further developed with the introduction of new materials. Nevertheless, many of the conclusions of that study are still valid. They can be summarised as follows.

- Joint performance is determined by a complex combination of factors which vary with and within joint types.

- A principal factor affecting joint performance is the nature and magnitude of the structural movements at the joint resulting from thermal variations and traffic loading.
- Installation conditions can severely limit the life of a joint; poor workmanship was responsible for many premature failures.
- The choice of materials can significantly affect long term performance.
- Structures with relatively flexible decks can present severe conditions for certain types of joint. Joints are also affected by bearing performance.
- Weaknesses in joint design were responsible for premature failure, mainly in the wheel tracks.
- Leakage at joints often caused damage to substructures and bearings.

The emphasis was then switched to laboratory testing.

Nottingham University were commissioned to develop a laboratory test facility for movement testing of buried joints. Joint specimens were made up in a tray, 0.5m wide by 1.0m long. The tray is in two halves, connected only by the joint material. Horizontal and vertical movements can be applied separately or in combination and rotational movement can be applied in place of the vertical movement if required. Both rapid movements due to traffic and slow changes simulating thermal variations can be applied. The specimen is housed in a temperature controlled chamber.

Tests were carried out on buried joints (Brown et al, 1991) to investigate thermal movement, traffic induced horizontal, vertical and rotational movement, and the effects of test temperature and stress condition of the joint at the start of the test. It was found that typical service failures could be reproduced in the laboratory and the performance of the test specimens was comparable with observations of service performance by Price (1982). This facility has now been installed at TRL, updated and developed to test asphaltic plug joints, see Figure 1.

At the same time, Reading University were asked to assess the feasibility of a laboratory test facility capable of applying service wheel loads in the laboratory. Many possible methods of applying wheel loading were considered. Similar equipment is used in pavement test facilities, but none of the existing designs was suitable. Rotary machines of manageable size would apply significant scrubbing forces, linear designs apply the load forwards and backwards which may well affect expansion joint performance, and most have too slow a cycling rate. The final design was a rotary machine with straight sections over three test areas.For reasons of cost a third scale machine was envisaged. However, a parametric study by Aberdeen University showed that a scale model could not provide the basis of an approval test. The visco-elastic properties of asphaltic joints would make it impossible to scale the effects of speed, temperature and material properties (eg aggregate size), and hence to relate the test results to behaviour at full scale. Also, it would be uneconomic to manufacture scale models of mechanical joints, and to be sure that the model would behave in the same way as a full size joint. The solution to this problem is outlined in section 6 below.

4 Research objectives

The current DOT approval system for expansion joints for highway bridges requires a one year trial installation period on a highway bridge, ie approval testing in the field.

Trials cannot provide reliable information on the performance of a new joint quickly enough to be useful. There are two problems. Conditions vary so widely that performance on one bridge cannot be regarded as representative, and secondly it is often impossible to identify the cause of any deterioration in service. The result is that the Engineer does not know which applications the joint may be suitable for, and the joint manufacturer has little guidance as to how to modify the joint to improve performance. There is also a natural reluctance to install untried joint types on heavily trafficked structures because of the possible traffic disruption. About 10 years of experience, and repeated condition surveys would be required to determine the performance of a joint in the full range of conditions, by which time it may be obsolete.

A laboratory based approval system has several advantages. The severity of the applied movement and loading can be varied to assess a joint for use in a variety of conditions allowing the Engineer to select an appropriate joint for each application. Joint manufacturers will have a consistent, testable requirement to design to and could modify and retest new joints quickly in the event of early failure. Also the research necessary to define a set of approval tests will lead to a better understanding of joint behaviour and the conditions which joints have to withstand in service. The disadvantage is of course that the environment (weather etc) cannot be reproduced at justifiable cost in the laboratory.

There are two basic requirements which a laboratory system will have to meet. The test must reproduce the types of joint deterioration which occur in service, and it must produce results quickly to assess new products.

The aim of current and future research is to reduce expenditure on maintenance and replacement of expansion joints, and to prevent damage to bridge substructures due to faulty joints. Specifically, the objectives are as follows.

- To determine the performance of joints currently in service.
- To develop suitable tests for type approval of joints, and for routine quality assurance testing of installed joints.
- To devise a performance based specification for bridge expansion joints.
- To develop improved design guidance and promote higher standards of installation.
- To establish agreed failure criteria and provide guidance for maintenance authorities.

5 Asphaltic plug joints (APJ)

As noted previously asphaltic plug joints have seen greatly increased usage over recent years and are now the most common type. They are relatively cheap and quick to install, reducing traffic management costs. However, durability is a problem, with some joints failing in a matter of months. The most urgent need is therefore to understand and improve the performance of this type of joint. A typical APJ is shown in Figure 2.

Many bridges are resurfaced after about seven years and it is convenient to replace the expansion joints at the same time. It is calculated that APJ's are economic if they have a service life of at least 5 years. This gives a target life of 5-7 years.

The performance of an APJ depends on:

- The material properties of the plug.
- The installation (procedure and standard of workmanship).
- The design of the joint, eg joint geometry.
- The movements occurring in service (thermal and traffic induced.
- The wheel loading imposed by heavy goods vehicles (HGVs).

All of these may vary widely. Experience suggests that the most important factors are the actual material properties of the installed joint (as opposed to the design values) and the standard of installation and to a lesser extent the movements and wheel loads.

Failure of bridge bearings can also affect the expansion joints. Seized bearings will alter the position of the centre of rotation of the deck under a vehicle road and cause 'arching' of the deck instead of linear thermal movement. A partially seized bearing will tend to move in a 'stick-slip' manner, and the resulting rapid movements will be more damaging to the expansion joint.

5.1 Definition of failure

The main faults which occur in APJs are leakage, tracking, cracking and debonding. The details of the faults found by survey and their causes are discussed by Johnson and McAndrew (1993). However, there is no agreed definition of joint failure and maintenance practices vary. One of the problems for durability testing is that failures may be progressive and interactive.

There are two views about whether leakage constitutes failure of the joint. One is that most joints leak so the designer should make provision for water to be drained away harmlessly. The other view is, that it is the function of the expansion joint to prevent water getting to the structure below the roadway, therefore a leaking joint has failed. As usual there is no simple answer. For new designs it is good practice to provide drainage and provision for cleaning the drainage channels, but for some existing bridges this is not possible. The definition of joint failure should include an assessment of the consequences of the fault. Where a leaking joint would allow water to reach parts of the structure susceptible to chloride damage, then a leaking joint should be deemed to have failed.

A certain amount of tracking can occur without affecting the performance of the joint. However, serious tracking can lead to impact loads which in turn cause deterioration in ride quality and damage to the joint and adjacent surfacing. A limit on the acceptable surface profile across the joint, eg depth of tracking, would seem to be required. It may be possible to base this limit on the standards applied to road pavements.

Cracking of the joint material and de-bonding from the adjacent surfacing are progressive failures which are likely to lead to leakage and potholing. Surface cracks may be detected by visual examination and should be repaired to prevent further deterioration. However, a joint which appears perfectly sound on the surface may leak due to subsurface faults. Water may collect in the adjacent surfacing, and traffic loading can generate sufficient hydraulic pressure to force the water past any weak point.

5.2 Installation

Several factors acting separately or in combination can have a very large effect on the service performance of the joint. Some of the main ones are: