Bridge expansion joints – performance and materials

1. 1 Introduction

Expansion joints are used in bridges to allow movements like expansion and contraction between the bridge deck spans and abutments. These movements are caused due to temperature, soil settlements, vehicle acceleration and other reasons (Klaiber, et al., 1987 and Dagher, et al., 1993 as cited in Thippeswamy, 2002). Expansion joints are subjected to severe loading due to the direct impact of the wheels. They are a very important component of a bridge structure and if carefully designed, properly installed and reasonably maintained will give a trouble free performance for many years. Though joints are made of various materials like rubber, silicone and polymer they deteriorate since they are constantly exposed to impact, vibration of traffic and natural elements like water, dust, ultra violet rays and ozone (Chang & Lee 2002). The durability of expansion joints is a major concern to bridge owners. The maintenance cost of joints is relatively high than the initial cost . This led to the design of jointless bridges. Jointless bridges do not develop stress due to corrosion of joints, accumulation of debris and differential elevation of joints (Thippeswamy, 2002). The behaviour of the jointless bridges not known and the designs being complicated are not implemented in spite of their advantages. This literature review deals with: characteristics of a good expansion joint that must be noted while design a joint, defects observed in expansion joints, survey studies conducted on existing joints to study their behaviour and some manufactures of bridge expansion joints in the industry. Studies on improving the performance of expansion joints is conducted, research on reducing the cost of maintenance of the joints should be conducted.

1. 2 Characteristics of a good expansion joint

A bridge expansion joint for proper functioning must have the ability to: accommodate movements in vertical and horizontal direction; withstand applied loads; resist skid and corrosion; operate silently with less maintenance (Lee, 1994). Price (1984) suggests that the performance of a joint is influenced by structural movements of the joint in horizontal and vertical direction, traffic loading, materials used, condition of the substrate, weather and temperature during joint installation, workmanship and performance of bearings.

1. 3 Commonly observed joint defects

Guzaltan (1993) as cited in (Chang & Lee 2002) studied some commonly observed defects in expansion joints. They include damaged seals, accumulation of debris in the joint components, rusting of metal plates and nuts, cracking of concrete, corrosion of steel reinforcement, water leakage, improper joint alignment and joint vibration during vehicle passage. Fincher (1983) as cited in (Chang & Lee 2002) presents the results of a survey conducted by Federal Highway Administration during a five year evaluation period which demonstrated that 60% of the expansion joints examined leaked. Additionally, Wallbank (1989) as cited in (Lee, 1994) explains that in a survey conducted on two hundred bridges by The London Department of Transport, the deterioration of the expansion joints was caused due to leaking and faulty drainage details. Chang and Lee (2002) conducted a study to observe the performance of joints in Indiana and found that some joints failed due to cracks in the seal and suggested testing it before installation. Fault tree modelling was used for qualitative explanation of bridge element interaction but could be used only for catastrophic failures (Attoh- Okine & Bowers 2006). These models are not applicable to bridges since they fail over an extended period of time. Fault tree models were also prepared by LeBeau and Wadia-Fascetti (2000) and Sianipar and Adams (1997) as cited in (Attoh- Okine & Bowers 2006). A new deterioration modelling based on belief networks that effectively capture and illustrate the hierarchical, interaction and uncertainty factors present in bridge deterioration was developed by Attoh- Okine and Bowers (2006). Belief networks are also called Bayesian belief networks and are based on Baye’s theory. The belief network approach is more appropriate than fault tree analysis since it can be used to investigate the components of a bridge including deck material, girders, bearings and abutments have a great influence on deterioration.

1. 4 Studies conducted on the performance of existing expansion joints

Chang and Lee (2002) conducted a study to observe the performance of the different joints used in the highway bridges in Indiana. Five popularly used joints were: compression seal (B. S), strip seal (S. S), integral abutment (I. A), poured silicone (X. J. S) and polymer modified asphalt (P. M. A). The data was obtained from questionnaire survey, analysis of Indiana Department of Transportation (INDOT) roadway management data and expert interviews. Questionnaire survey was conducted by giving questionnaires to the state bridge inspectors and engineers around Indiana. The problems with joints were encountered and possible improvements were suggested. The analysis of historical data using logistic regression approach found that S. S joint had the best performance. The expert interviews consider I. A joint to offer good results and suggest improvement of B. S and S. S joints. An inspection campaign was conducted on 150 expansion joints of 71 road bridges in Brisa, Portugal where the maintenance cost reached a peak of 25% (Lima & Brito 2009). The joints installed within the traffic lane of the bridge were considered. The expansion joints were characterised based on their type, and age of the bridge. It was recorded that the joints used more frequently included reinforced elastomeric cushion joints, elastomeric flexible strips, and asphaltic plug joints. The data obtained from the inspection campaign was statistically analysed. The results showed that joints that were replaced mostly frequently were elastomeric joints and that different joints have specific maintenance needs. The transition strip and the anchorage cavities of the expansion joint are the parts that require more maintenance. It was also observed that the errors during installation and lack of maintenance caused pathology of the joint. The results of campaign conducted show that there was a lot of improvement in the commercial expansion joints and suggests investigation on the new or improved systems and materials. It also suggested that simple systems with fewer components are more reliable and require less maintenance. Asphalt bridge expansion joints when used in cold countries cracked within the first two years. To improve the performance the commercial MEIJIA asphalt binder was modified with polymers: thermoplastic rubber and rubber (Yu, et al., 2009). The polymers were used in various combinations, and their performance at low temperatures is evaluated by conducting tests including: ductility, penetration, indirect tension and bending tests. The data from ductility and penetration tests performed on binders indicated that the strength and deformation capacity at low temperatures improved. Four expansion joints made with the modified asphalt mixtures were installed on two bridges in a cold region and found that the joints showed good performance.

1. 5 Assessment of expansion joint performance using monitored data

A study was conducted by to develop a procedure for verification of the design and evaluating the condition of expansion joint by monitoring joint displacement and bridge temperature on a long term (Ni, et al., 2002). This method was applied to Ting Kau, cable stayed bridge in Hong Kong. The service life and replacement of joint depends on the cumulative displacement. An accurate prediction of the cumulative displacement will provide the time interval for joint inspection or joint replacement. Monitoring the thermal movements at the expansion joints and comparing them with the design values provide verification on design. The whole system had more than 230 sensors like anemometers, accelerometers, displacements transducters to measure displacements located at the ends of the deck, temperature sensors, strain gauges, weight in motion sensors and global positioning system. A good correlation between the movement of the expansion joints and effective temperature was observed. The daily average cumulative displacements of the expansion joints in the bridge are much less than design values. Additionally monitoring systems had been implemented on many bridges in different countries by (Andersen & Pedersen 1994; Cheung et al. 1997; Barrish et al. 2000; Sumitro et al. 2001; Mufti 2002; Koh et al. 2003; Wong 2004) as cited in (Ni et al. 2002).

1. 6 Effect of SSI and ground motion spatial variation

Chouw and Hao (2008(a)) studied the effects of soil-structure interaction (SSI) and ground motion spatial variation effect on bridge pounding responses for bridges with a traditional expansion joint between adjacent girders. The study was conducted on two adjacent bridge frames. It was confirmed that structures that are built on stiff soils may experience larger pounding forces than those on soft soils. It was also examined that decrease of ground motion correlation caused larger pounding responses. Numerical simulation was conducted by nonlinear dynamic response analysis and investigated pounding mitigation and prevention of unseating in the highway bridges due to seismic forces (Raheem, 2009). It was observed that seismic pounding generates significantly higher magnitude and short duration acceleration pulses than typically assumed design magnitude. This results in severe impact forces that damage structural members like the deck or pier. Additionally the effects of SSI and bridge pounding response for bridges with modular expansion joint system (MEJS) were observed (Chouw & Hao 2008(b)). It was concluded that the girders with a large gap of a MEJS caused stronger impact forces. It was found that significance of nonuniform ground motions depends on the properties of the ground motions, subsoil and the structures.

1. 7 Types of Expansion Joints

1. 7. 1 Selection of joint type

The type of joint is selected depending on the movement expected for serviceability limit state. More than one type of joint may be suitable for a particular range of movement. The movement range that should not be exceeded for each expansion joint is given in Table 1.

Table 1. Selection of joint type (Department of Transport, 1989)

Joint Type	Total acceptable longitudinal movement		Maximum acceptable vertical movement (mm)
	Maximum (mm)	Minimum(mm)	
Buried Joint under continuous surfacing	5	20	1. 3
Asphaltic plug joint	5	40	3
Nosing joint with poured sealant	5	12	3
Nosing with preforme	5	40	3

d compression seal			
Reinforced Elastomeric	5	*	3
Elastomeric in metal runners	5	*	3
Cantilever comb or tooth joint	25	*	3

* Maximum value varies according to manufacturer or joint type

1. 7. 2 Modular bridge expansion joint

Modular expansion joint is used when the joint movement exceeds 100mm. The modular expansion joint has many advantages including: water-tightness, corrosion protection, great potential as they increase the life of concrete and steel bridges (Crocetti & Edlund 2003), greater movements in translation and rotation. It can accommodate the three dimensional movements without generating additional stresses or strains in the load-bearing members or in adjacent bridge or abutment structures.

1. 7. 2. 1 Noise generation in a modular expansion joint

The traffic generates more noise on bridges than on roads, as sound is produced on the top and bottom of the deck. The noise generated from a modular expansion joint under vehicle passage is louder than those of ordinary expansion joints (Ravshanovich, et al., 2007). The mechanism of noise generation for a modular bridge expansion joint which causes noise pollution was studied by conducting tests on a full scale model of a joint. A series of car-running experiments were conducted on the joint and studied its noise and vibration characteristics. A modal analysis of the joint is performed using finite element modelling. It was observed that the frequency of the noise generated above the joint varies from 500 to 800Hz due to sudden change in air pressure within the gap formed by rubber sealing with the middle beams. The frequency is less than 200Hz below the joint caused by the sound radiation due to the bending vibration modes of the middle beams being excited by an impact force from the car wheels. Likewise a numerical investigation was conducted on a modular expansion joint of an expressway bridge to understand the generation and radiation mechanism (Ghimire, et al., 2009). The numerical analysis was conducted using finite element method.

1. 7. 2. 2 Performance of Modular expansion joint

Modular joints have the ability to cope with large thermal expansion and contraction of large bridges (Chouw & Hao 2008(b)). They are capable of preventing girder pounding during strong earthquakes. A complex joint was modelled to study the dynamic response of a modular bridge expansion joint (Crocetti and Edmund, 2003). The vertical loads perpendicular to the roadway plane were considered. Horizontal loads were eliminated since the excitation mechanism was sophisticated and the behaviour of the joint in the horizontal direction was stochastic in character. A single fatigue test was performed. Data from the field tests including measurement of wheel load distribution factors, horizontal and vertical wheel loads, determination of damping and natural frequencies were obtained from Lehigh University, Bethlehem, Pennsylvania. The result of the fatigue test conducted agreed with the S-N curve plotted for welded connection between the support bar and the centre beam suggested by Dexter, et al. (1997) cited in (Crocetti & Edmund 2003). Additionally an experimental investigation was performed to study the fatigue performance of a welded multiple support bar modular bridge expansion joint (Chaallal, 2006). The welded multiple support bar modular bridge expansion joint was used in the rehabilitation of Jacques Cartier Bridge in Montreal. The vertical and horizontal loads were considered unlike (Crocetti & Edmund 2003) which is more practical since the expansion joints are subjected to both vertical and horizontal loads. Experimental tests were conducted on three subassemblies of the modular joint for various loads and S-N curve was plotted.

1. 8 Manufacturers of Expansion joints

1. 8. 1 The Bridge Joint Association

Bridge Joint Association (BJA) prepares standards and current practice sheets. It comprises of manufacturers and installers of bridge expansion joints which include: ASL CONTRACTS LTD, FREYSSINET LTD, GRACE

CONSTRUCTION PRODUCTS LTD, Highways Maintenance Specialists LTD and MAURER LTD (Bridge Joint Association, 2009).

1. 8. 2 Watson Bowman Acme Corporation

Watson Bowman Acme Corporation (WBA) found in 1950 isa recognized innovator in the development and manufacture of expansion joint controlsystems. Some of the joints manufactured by WBA include:

Wabo®Crete SiliconeSeal – This is a high performance expansion joint system that utilizes a two-part sealant between elastomeric concrete headers made of Wabo®Crete II capable of absorbing impact loads. The headers are coupled with Wabo®SiliconeSeal make it an ideal expansion joint system that is adopted in the industry for new construction or repair of existing joints. Wabo®Crete II elastomeric concrete is widely used in header applications for bridges and parking structures. Polyurethane is used in the header material to minimize edge spalling associated with high impact loads while achieving superior bonding capabilities. The Wabo®SiliconeSeal is a cold applied self levelling sealant requires no priming which simplifies & accelerates the installation process. Wabo®Crete SiliconeSeal system is licensed under US Patent No 5. 190. 395. This joint is adopted for applications with a maximum movement range of +100% / -50% of the joint gap (Watson Bowman Acme, 2007).

Wabo®Crete FlexFoam – This is an armorless expansion joint system that is designed with closed-cell foam joint seal installed with epoxy adhesive between an impact absorbing elastomeric concrete header. The high impact absorbing, ambient cured and self-levelling properties of the Wabo®Crete II joint header allows for the joint system to monolithically bond to the deck creating a watertight system. Using an elastomeric concrete joint header achieving superior bonding capabilities and minimizing edge spalling (Watson Bowman Acme, 2007).

Wabo®Expandex – This is a flexible asphaltic plug joint system designed to accommodate minimum structure movement while providing a smooth transition between the approach pavement and the bridge deck. Wabo®Expandex is used typically at abutments or asphalt overlays due to its unique asphalt compatibility. The system combines the use of a traffic bearing plate with special aggregate reinforced modified elastomeric material (Watson Bowman Acme, 2007).

Jeene® – This joint system comprises of a neoprene profile, which is air-pressurized and bonded in place with a specially formulated epoxy adhesive. With properly installation, the Jeene® joint system will not tear away, protrude out of, or slip from its original position on exposure to repeated mechanical or thermal movements. Complete adhesion of the epoxy to the profile and joint wall is achieved due to the air inflation during installation. Jeene® is the most durable, versatile, cost-effective and watertight expansion joint (Watson Bowman Acme, 2007).

Wabo®HSeal – This is a pre-compressed elastomeric coated expansion joint system designed to provide a permanent weather tight seal. The system is sealed in place with an epoxy, which allows it to accommodate horizontal, vertical, and skew expansion joint movements. Wabo®HSeal consists of a micro-cell, stable to UV, polyurethane foam impregnated with a hydrophobic polymer and topped with a traffic grade elastomeric coating. The impregnated foam provides a valuable secondary water tight seal in case the primary elastomeric coating is damaged. This system is supplied in pre-compressed sticks for easy installation (Watson Bowman Acme, 2007).

Wabo®Flex – This is a molded rubber cushion expansion joint which is designed to accommodate structure movements from 2 inches up to 13 inches. In Wabo®Flex system the molded rubber cushions are steel reinforced and imbedded with corrosion-resistant aluminium wear plates. Tongue and grooves at the end of each rubber cushion ensure a watertight connection and prevent uplift or separation (Watson Bowman Acme, 2007).

Wabo®TransFlex – This is an original reinforced elastomeric molded rubber expansion joint system. All sections feature tongue and groove fittings for tight end-to-end mating across decks and at curbs and are steel reinforced. It can be installed in new decks, or in older structures on rehabilitation projects. These joint systems readily adapt to skew angles. Wabo®TransFlex system will accommodate anticipated thermal movements reject debris and create a level, smooth-riding, wear-resistant surface if properly installed (Watson Bowman Acme, 2007).

Wabo®Seismic WeatherSeal – This is a pre-compressed elastomeric coated expansion joint system that works under its own constant internal pressure to provide a weather resistant seal. The system contains an open-cell foam seal impregnated with a hydrophobic polymer sealing compound. Wabo®Seismic WeatherSeal can be used on applications which cause simple thermal movements or on applications where seismic movement is anticipated. The Wabo®Seismic WeatherSeal system is recommended for use on all interior and exterior wall, ceiling and soffit expansion joint applications (Watson Bowman Acme, 2007).

The joint systems manufactured by Watson Bowman Acme Corporation are compared as shown in Table 2, with respect to their features and their recommended area of implementation.

Table 2: Comparison between the various joints manufactured by WBA.

Joint	Features	Recommended for
Wabo®Crete SiliconeSeal	Watertight system, rapid installation, Cold applied, Expansion joint applications with a maximum movement range of +100% / -50% of the	Horizontal expansion joint applications on bridges and highways.

	joint gap	
Wabo®Crete FlexFoam	Accommodates movement cycle through compression and tension, Minimizes dirt or debris accumulation	Horizontal expansion joint applications on bridges and interstate highways.
Wabo®Expandex.	Provides smooth riding surface, can be milled or planed during resurfacing operations, joint openings with movements	Sealing joints on secondary highway bridge structures.

	up to +/- 0. 75″ at time of installation	

Joint	Features	Recommended for
Jeene® .	Accommodates forces associated with multi-directional movements, resists hydrostatic pressure, Accommodates thermal movement	Sealing joints on bridges roadways and tunnels.
Wabo®H Seal	Can accommodate horizontal, vertical and skew expansion	Sealing joints on bridges, sound wall & barriers

	joint movements, easy installation	
Wabo®Flex	maximum friction, prevents debris accumulation, reduces deflection under traffic loading, maximum movement of 13 inches	Bridge decks and ramps, Low height joint sealing restrictions
Wabo®TransFlex	Watertight connection, prevent uplift or separation maximum movement of 13 inches	Low height joint sealing restrictions bridges, decks and ramps

Wabo®Seismic WeatherSeal	seismic movement capability, weather resistant, self-expanding non-laminated construction, accommodates movement up to +/-50%	Stadiums, parking garages, Replacing failed joints

1. 8. 3 Universal Sealants Limited

Universal Sealants limited (USL) focuses on construction of bridges, tunnels, rail and other major structures. It manufactures supplies and installs specialist construction products including: bridge expansion joints; membranes for bridge deck waterproofing; protective coatings; concrete repair and car park refurbishment work. Some expansion joints offered by USL include:

Uniflex expansion joints – This system uses a butyl rubber membrane, bonded to the concrete and asphalt surfaces with Uniflex epoxy adhesive to provide an efficient and permanent joint that is easily installed. The system accommodates a variety of conditions from those experienced on an asphalt-covered traffic-free roof, to bridge decks with sheet membrane, spray on coating or asphalt waterproofing, also it can be used with two layer mastic asphalt or brick paving systems. The Uniflex system is chemically inert and completely impervious to water and water vapour. In buried joints the membrane is completely protected by the wearing surface. Uniflex membrane will not deteriorate during its service and the combination of a simple design and proven components makes the system naturally long-lasting and well up to the requirements of modern building and civil engineering practice (Universal Sealants UK Ltd, 2009).

Febajoint – This joint is fully registered with the Highways Agency, Scottish Executive and Welsh Assembley (BD 33/94: Joint Type 2) suitable for all class roads and motorways. The joint is nominally 500mm wide and not less than 100mm deep which will provide optimum movement capacity of +/- 20mm. The materials are applied hot and in a fluid condition, with temperatures up to 180°C. Careful considerations should be made by the engineer before using this joint. Binder compounds use thermoplastic materials which contain polymer modified bitumen, mineral fillers and chemical additives (Universal Sealants UK Ltd, 2009).

FEBA HM expansion joints – The system is fully registered with the UK Highways Agency for type 2 application. It is a high modulus flexible, waterproof asphaltic plug joint. The main feature of this system includes a resistance to ‘ wheel tracking’. This joint is suitable for a maximum horizontal design movement of ±20mm. The ‘ FEBA HM’ system should be considered in places of high traffic volumes, constant standing traffic or heavy loading. The materials are applied hot and in fluid condition, with temperatures up to 180°C. Binder compounds are classified as thermoplastic materials and contain polymer modified bitumen, mineral fillers and chemical additives (Universal Sealants UK Ltd, 2009).

Nosing Joint (NJ) system – This joint system is an ideal for maintenance situations and has been developed to provide a whole life economic solution for applications where asphalt plug joints are unsuitable and is registered with the UK Highways Agency, The Scottish Executive and Welsh Assembly. A surface mounted nosing joint with an elastomeric insert bonded to the rapid curing elastomeric compound known as Britflex® Resin Mortar (Universal Sealants UK Ltd, 2009).

The Transflex, Waboflex and Euroflex – These joints are registered with the UK Highways Agency, the Scottish Executive and the Welsh Assembly for use on highway bridge decks (BD 33/94: Joint Type 5). These joints are reinforced elastomeric comprising of steel angles and a steel bridging plate system encased in a flexible elastomer. The movements that can be accommodated vary from 38mm to 330mm in structures including: All types of highway structures, car park decks, footbridges and podium decks (Universal Sealants UK Ltd, 2009).

The Britflex® BEJ Expansion Joint – These joints are registered with the UK Highways Agency, Scottish Executive and Welsh Assembley for use on bridge decks on all classes of roads and motorways. (Department of Transport BD33/94: Joint Type 6). This system is ideal for maintenance projects where there is a need to replace failed systems. The major benefit of this system is its speed of assembly on-site (Universal Sealants UK Ltd, 2009).

Londitudinal Joint (LJ) system – This system has been developed to provide an effective method of sealing longitudinal expansion gaps and soffits. This joint accommodates both longitudinal and vertical movement and also provides a substantially watertight seal. The LJ joint system can be used as a waterproof cover joint or as a drainage channel under joint with the facility to install drainage outlets into the system (Universal Sealants UK Ltd, 2009).

Table 3: Comparison between the various joints manufactured by USL.

Joint	Type	Features
Uniflex Expansion Joints	Type 1- Buried joint under continuous surfacing	Impervious to water and water vapour, long-lasting, simple design

Joint	Type	Features
Febajoints	Type 2- Asphaltic Plug joint	Provides optimum movement

		capacity of +/- 20mm, joint for use on highway bridges
FEBA HM Expansion Joints	Type 2- High Modulus Asphaltic Plug joint	Can accommodate impact loads, maximum horizontal design movement of ±20mm
Nosing Joint system	Type 4- Nosing with preformed compression seal	Rapid Installation, No drilling of deck, can only be used in the situation where the gap at carriageway level does not

		exceed 65mm.
Transflex, Waboflex and Euroflex Expansion Joints	Type 5-Reinforced Elastomeric	Accommodating movement from 38mm to 330mm. used for car park decks, footbridges, podium deck.
Britflex® BEJ Expansion Joints	Type 6-Elastomeric in metal runners	Rapid on site assembly, less future maintenance costs, easy to install
Longitudinal Joints	Longitudinal Joint System	can accommodate both longitudinal and vertical movement, rapid installation,

low

maintenance,

cost

effective ,

watertight

seal

1. 8. 4 Stirling Lloyd

Stirling Lloyd specialise in the development, manufacture and application of high-performance waterproofing and structural protection membranes and systems. They deal with road and rail bridge decks and tunnels, to commercial building developments, car parks and highway maintenance solutions. Some of the joints manufactured by Stirling Lloyd include:

Sentinel® B – This joint consists of a PVC flashing strip designed for various movement ranges. The flashing is bonded across the expansion gap and incorporated into the Eliminator® water proofing system to form a continous waterproofing detail below