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PERFORMANCE OF DIAMOND SHAPE ELASTOMERIC BEARING PADS IN KUALA LIPIS BRIDGE

Elastomeric Bridge Bearings/Skewed Bridges/Bridge Rehabilitation

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1. BACKGROUND

1.1 The Bridge

The bridge over Lipis River was constructed in 1991 and opened to traffic in October 1992. It comprises nine simply supported spans of 31.24m prestressed concrete I-beams with a total length of 281.16m. Each span is free at one end and is restrained by dowel bars at the other. The bridge comprises two abutments and eight piers with six nos. of I-beams on each span supporting the deck slab with a carriageway width of 10.0m and skewed at 35^0. The piers and abutments were supported by 400mm diameter steel pipe piles of 9.5mm thick.

This bridge served as a vital link across Lipis River to Tanjung Lipis. For the road adjoining Tanjung Lipis to Kerambit at the Jerantut border, the construction of the new roadworks only commenced in early 1995 and was completed in December 1998. The bridge was traversed by heavy vehicular traffic in early 1995 with the mobilisation of heavy construction equipment and transportation of materials for the roadworks construction. Presently, the traffic volume is low eventhough the roadworks had been completed since 1998.

One unique feature of this bridge is the use of diamond shape elastomeric bearing pads apparently so chosen to tackle the skewing effect of the bridge deck (Figure 1). Bridge bearing pads of shape other than rectangular have never been used in Malaysia.

Figure 1 : Diamond Shape Elastomeric Bearing Pad (Plan View)

1.2 The Problem

In 1995, through the regular inspection exercise carried out by the district office of Public Works Department (PWD) Lipis, it was found that 8 out of 108 of the elastomeric bearing pads had walked from their original positions. The locations of the walked bearing pads are as illustrated in Figure 2. On close examination, it was observed that approximately 20% of the dislocated bearing pad was still in contact and seated on the epoxy mortar bedding (Figure 3). Tell-tale marks on the bearing pads and beam soffits suggested that the bearing pads had progressively rotated in a clockwise direction (Figure 4).

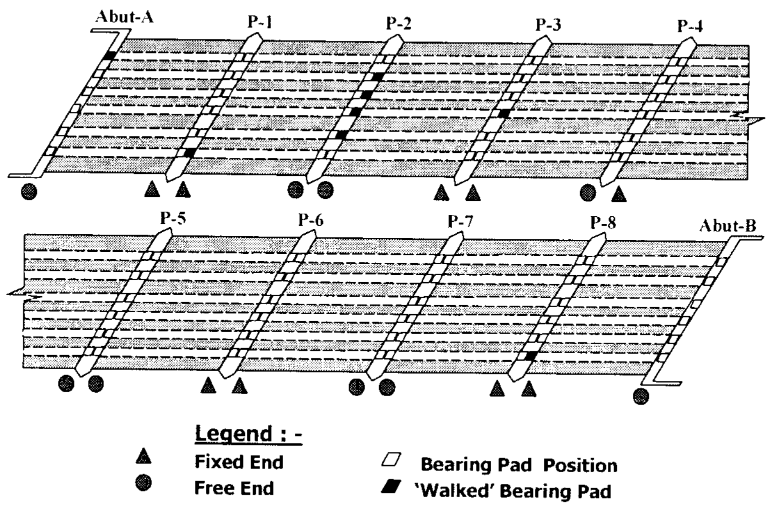

Figure 2 : Locations of Walked Bearing Pads

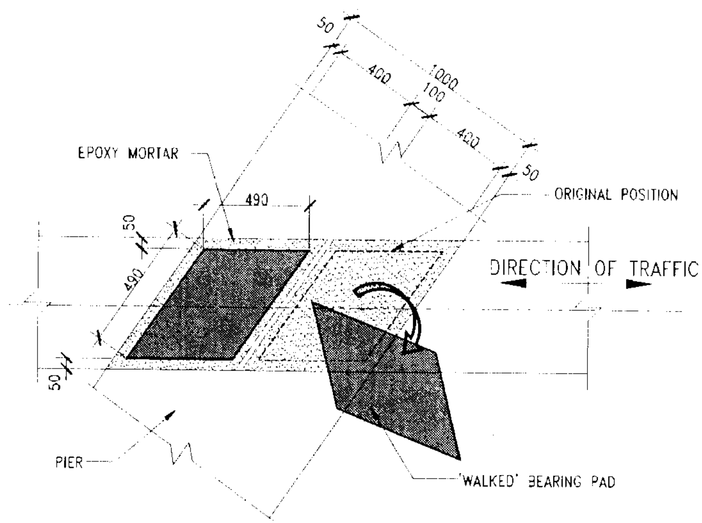

Figure 3 : Plan View of A Walked Bearing Pad

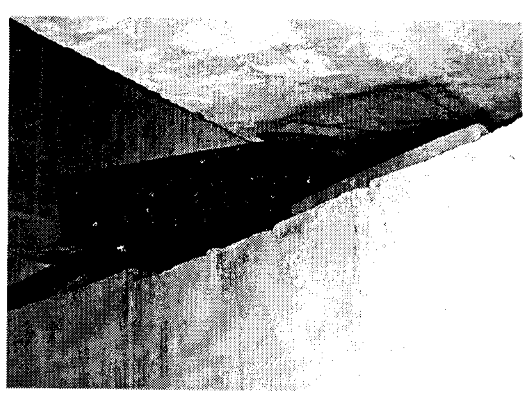

Figure 4 : A Typical Walked Bearing Pad

2. INSPECTION, TESTING AND APRAISAL OF THE PROBLEM

2.1 Observations

The bearing pads were manufactured locally by an international firm. Details of the bearings are as follows:-

Overall Dimensions	= 490 x 490 x 159mm
Inner Rubber Layers	= 2 x 48mm
Steel Plates	= 3 x 4.5mm
Rubber Top and Bottom Cover Thickness	= 24mm
Rubber Side Cover Thickness	= 10mm
Shear Modulus of Rubber	= 0.77N/mm^2

Besides the displacement of the bearing pads there was also concern about the quality of the material used in the manufacture of the bearings. This concern was based on the observation that there was a sticky and waxy substance found on the surfaces of the bearings. In addition, extensive permanent bulging was noticed in each lamination as the loads push the elastomer out. There were cases where cracks had occurred at these bulged faces (interface between the rubber and steel laminate). These cracks could possibly be due to the deterioration of poor quality elastomeric material which often develop along the point of greatest bulge. In order to ascertain the causes of the material deterioration two pieces of the walked bearings were sent to Rubber Research Institute Malaysia (RRIM) for material and stiffness tests.

2.2 Testing of Walked Diamond Shape Elastomeric Bearing Pads

The two samples of rubber bearings were tested at RRIM in accordance with BS5400:Part 9:Section 9.2:1983. Results of the material and performance tests are as shown in Table 1 and Table 2 respectively. The results for the material tests exhibited signs of non-conformance for the observed tensile strength of 11.5Mpa, elongation at break of 430%, low IRHD of 54 and accelerated ageing with change in tensile strength of –16% as shown in Table 1. Compressive stiffness test results of 76kN/mm and 60kN/mm for the two samples exceeded that of the actual requirement of 45.2±20% as shown in Table 2.

The test certificate results of the bearing pads performed at RRIM during construction stage in 1992 indicated conformance to requirement. However accelerated ageing with change in tensile strength of -33% was not within the requirement of ±15% max. Compressive stiffness test results of 60kN/mm and 63kN/mm also exceeded that of the performance test requirement of 45.2±20%.

By observing and comparing the results of the performance tests done during construction and recently, it is apparent that deterioration of the rubber had taken place. Indeed, test results on the accelerated ageing had indicated the inferior quality of the material in durability. The presence of sticky substance can perhaps be explained by the effects of material disintegration due to ageing.

Table 1: Material Test on Test Pieces Cut From Bearing

PROPERTY	OBSERVED	REQUIREMENT BS5400 (1983)
Tensile Strength, MPa	11.5	15.5 minimum
Elongation at Break, %	430	450 minimum
Hardness, IRHD	54	55
Compression Set, (22h/70^0 C), %	18	30 maximum
Bond Strength, N/mm	19.1R; 17.3R 20.6R; 19.8R	7 minimum
Ozone Resistance (25pphm/20%strain/96h/30^0 C)	No Cracks	No Cracks
Properties after accelerated ageing in air, 7 days at 70^0 C		
Change in Tensile Strength, %	-16	15 maximum
Change in Elongation at Break, %	-6	20 maximum
Change in Hardness, IRHD	4	10 maximum

Table 2 : Stiffness Tests on Whole Bearing

PROPERTY	OBSERVED Sample A	OBSERVED Sample B	REQUIREMENT AS PROVIDED IN DESIGN
Compression Stiffness, KN/mm (Design Load = 887KN)	76	60	45.2±20%
Shear Stiffness, KN/mm (Design horizontal movement = 15.1mm)	0.97		1.18±20%

2.3 Sources Contributing to Walking of Bearing Pads

A study by Bridge Unit suggested that the walking of the bearing pads was most probably due to one or combinations of the following factors :-

a) A diamond shape bearing pad has a longer perimeter and thus a smaller *shape factor* as compared to a rectangular bearing pad of the same plan area. *Shape factor* is defined as the ratio of the loaded area to the total force-free area (Gent and Lindley, 1959). For a rectangular bearing pad with length L, width B and thickness t, the shape factor is given by LB / [2t(L+B)]. In general, *shape factor* indicates the effectiveness of the size, thickness and shape of the bearing pad. Since rubber is, like water and incompressible, the shape factor dictates the amount of compression under vertical load. The smaller shape factor of a diamond shape bearing pad leads to a larger deformation than that of a rectangular one.

b) The thickness of the existing bearing pad (159mm) with only three layers of 4.5mm thick mild steel plates had resulted in a lower stiffness. The high flexibility of the bearing pad had allowed extensive bulging of the elastomer to occur. The design check for the existing elastomeric bearing pad based on BS5400:Part 9.1:1983 also revealed that the criteria based on maximum design strain and vertical deflection had not been satisfied.

c) Rubber bearing pad leads to a deformation perpendicular to the line of each bearing edges under the vertical loads. For rectangular bearing pad, the direction of this deformation is parallel to the direction of the horizontal movement of girder caused by temperature differences (Takagi, 1998). However, for diamond shape bearing pad, these directions are not parallel to each other and the difference in the directions produces distortion of bearing pad and finally resulted in the rotating force on the bearing pad (Figure 5).

d) The loading condition and dynamic behaviour due to vibration of the bridge are also influential as these affect the behaviour of the bearing pads at different supports (Basir, 1998).

e) The severely skewed bridge could cause transverse movement of the bearings due to the geometry and deck concrete creep that arise (Park, 1984). Moreover, keeper plates and shear key were not provided in the Kuala Lipis bridge superstructure.

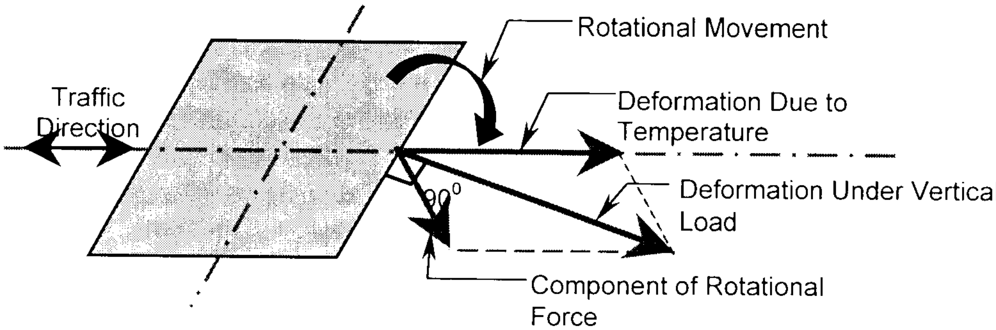

Figure 5 : Schematic Diagram of Deformation Causing Rotational Movement

2.4 Selection of Replacement Bearings

It might be socially unacceptable for the replacement bearings to fail. An extra effort must thus be made to replace the existing bearings with new ones that would promise a better performance. The causes of the failure need to be identified. In view of the likely causes of the problem as given in 2.3, a solution to the problem was adopted after having considered various feasible alternatives. The solution involved a new bearing design with the features:- 1) rectangular in shape; 2) thinner and 3) physical restraint.

The elastomeric bearing was thus designed for a horizontal movement of 15.1mm due to temperature, shrinkage and creep, a longitudinal rotation of 2.814×10^{-3} radian, a transverse rotation of 2.494×10^{-3} radian and a vertical load of 980KN in accordance with BS5400:Part 9:1983. The details of the new bearings are as follows:-

Overall Dimensions	= 400 x 250 x 56mm
Inner Rubber Layers	= 3 x 12.0mm
Steel Plates	= 4 x 3.0mm
Rubber Top and Bottom Cover Thickness	= 4mm
Rubber Side Cover Thickness	= 6mm
Shear Modulus of Rubber	= $0.9 N/mm^2$

To provide physical restraint the new elastomeric bearing pad was bonded to a 50mm thick mild steel plate by vulcanization during the manufacturing process in the factory. The unit was welded to another piece of steel plate that was secured to the pier by four bolts (Figure 6). The 50mm thick plate while serving to restrain the bearing from any slippage, also makes up for the loss in bearing level due to use of thinner bearing pads. In total, all 108 numbers of bearing pads were replaced.

Two pieces of the elastomeric bearing pads manufactured to the new design were sampled and tested in accordance with BS5400: Section 9.2:1983 at the RRIM. Results for the material and performance tests are as shown in Table 3 and Table 4 respectively. The results conformed to all the requirements.

Table 3: Material Test on Test Pieces Cut From Bearing

PROPERTY	OBSERVED	REQUIREMENT BS5400 (1983)
Tensile Strength, MPa	22.9	15.5 minimum
Elongation at Break, %	450	400 minimum
Hardness, IRHD	65	60-65
Compression Set, (22h/70^0 C), %	11	30 maximum
Bond Strength, N/mm	15.1R; 28.3R 18.8R; 13.4R	7 minimum
Ozone Resistance (25pphm/20%strain/96h/30^0 C)	No Cracks	No Cracks
Properties after accelerated ageing in air, 7 days at 70^0 C		
Change in Tensile Strength, %	-6	15 maximum
Change in Elongation at Break, %	-1	20 maximum
Change in Hardness, IRHD	2	10 maximum

Table 4 : Stiffness Tests on Whole Bearing

PROPERTY	OBSERVED Sample A	OBSERVED Sample B	REQUIREMENT AS PROVIDED IN DESIGN
Compression Stiffness, KN/mm (Design Load = 887KN)	511	455	431.8±20%
Shear Stiffness, KN/mm (Design horizontal movement = 15.1mm)	2.12		1.89±20%

It is interesting to ask why mechanical bearings, for example, pot bearings were not considered as a solution to the present problem. An argument advocating elastomeric bearings over pot bearings had been presented in a recent seminar in Singapore (Lee et al., 1999). It was highlighted that only the elastomeric bearing pads used for two bridges out of some 360 bridges constructed since 1970 were reported to have failed due to ozone attack aggravated by presence of water and excessive concentrated load concentration. The long term performance of natural rubber pads had been proven as those installed in Australia since 1889 indeed suffered little oxidation and were still functioning (Rubber bridge pads from Victorian age, 1985). In addition 9000 natural rubber bearings are in service in Penang Bridge (Chin, 1986) and these are expected to perform well.

3. INSTALLATION OF NEW BEARINGS

A contract comprises remedial works to remove all existing bearing pads and the installation of new elastomeric bearing pads with the incorporation of a physical restraint casing system was awarded to a contractor by opening bidding. The isometric view of the complete component of elastomeric bearing pad are as shown in Figure 6. The site possession was handed over to the contractor on the 10 August 1999.

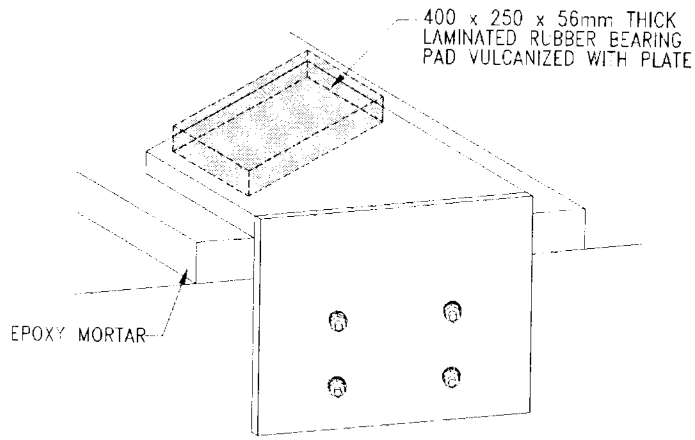

Figure 6 : Isometric View of Complete Component of Elastomeric Bearing Pad

3.1 Jacking System

In general, the jacking method would vary depending on the structural member involved in jacking, maintenance of traffic flow, availability of equipment and stiffening of structural members to accommodate jacking forces.

The jacking procedure adopted relies on the shearing resistance at the interface between the pre-cast beam and cast in-situ diaphragm beam, together with the reinforced deck slab section. This was necessary, as the four numbers of high yield steel reinforcement 32mm in diameter were not properly anchored at both edges. In addition, it was also difficult to judge whether full grouting of the circumference of the reinforcement and the whole length in the holes provided were well executed. As the jacking force is applied at the soffit of the end-diaphragm beams, the existing support reaction at the bearing is transferred to the jack via the shear resistance of the concrete section of diaphragm beam and deck slab. The end of each span will be lifted when jacking force exceeds the dead load, provided the shear resistance is greater than the dead load. A detailed analysis of stresses that would occur during jacking operation was also performed to ensure the structural integrity of the members.

The jacking operation was carried out at one end of each span at a time. The span end was lifted using low-height hydraulic cylinder jacks. To avoid any possible leakage of hydraulic pressure under maintained load, hydraulic jacks equipped with a built-in safety locking nut system were used. The selected jacks were also equipped with swivel-top feature that had an integral tilting saddles which could accommodate a rotation of up to 4 degrees.

As the precast beams for each span are connected by diaphragm beams, these 65 tons hydraulic capacity jacks shall be placed directly underneath the end diaphragm beam at close proximity to the precast beams. In total, 12 numbers of 65 tons capacity hydraulic jacks were used. The lifting operation was conducted by simultaneous jacking of 12 cylinders with 6 pumps to synchronize the jacking operation. Each jack was attached with an individual control valve and pressure gauge. With this arrangement, adjustment to individual jacks was possible. This was important because localized adjustment would be necessary to level up the precast beams that might have tilted. The possible occurrence of overstress in the bridge during the jacking operation would be negligible.

3.2 Precautionary Measures

During the jacking and lifting process the following precautions were exercised:-

a) Ensure that all the jacking surfaces are even, otherwise cushioned plywood or rubber sheet was added.
b) The lifting operation was stopped if crack lines were detected at diaphragm or precast beams during jacking. The causes of crack would be investigated and remedial measure taken.
c) Ensure all service conduit, cabling, water main pipe, sealant which were to span across the joints at the point of jacking would be able to permit the uplift of about 25mm.
d) At fixed end of each span, the dowel bars were checked to ensure that rubber dowel cap had been installed by the contractor during construction stage. This would facilitate uniform lifting once the jacking force exceeds the dead load.
e) Traffic speed was limited to 20kph and directed along the centre line of the carriageway for the span where lifting operation was in progress.

3.3 Replacement of Bearings

The replacement works began with jacking and lifting up the end of each span of the bridge deck superstructure to relieve the existing bearings from the dead and live loads action. The work sequence that followed consisted of :

a) Removal of existing elastomeric bearing pads (Figure 7).
b) Existing epoxy mortar bedding were removed and new bedding casted to a thickness of 90mm. This was required so as to maintain the finished level due the difference in thickness between existing and new bearings.
c) Fabrication and installation of complete unit of elastomeric bearing on top of existing epoxy mortar bedding. The elastomeric bearing pad vulcanized with an externally mild steel plates (trapezoidal in shape) as shown in Figure 8 is welded to a vertical plate component. This is then bolted to the pier wall through the vertical plate (Figure 9).

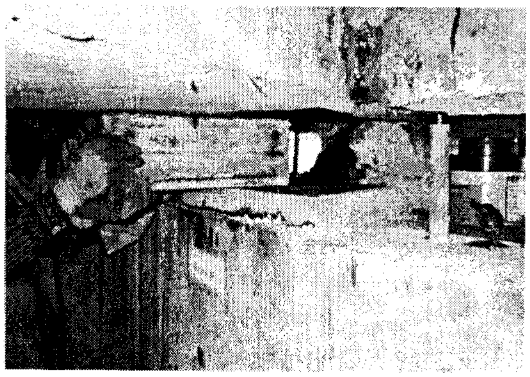

Figure 7 : Removal of Existing Bearing Pad

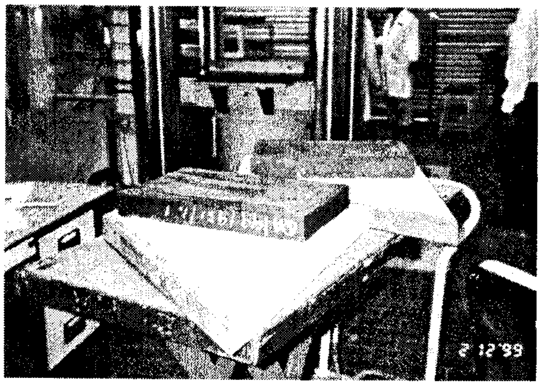

Figure 8: Elastomeric Bearing Pad Vulcanized With Trapezoidal Plate

Figure 9 : Complete Installation and Fabrication of New Elastomeric Bearing Pad

4.0 CONCLUSIONS

The main issue in this paper is the walking of bridge bearing pads. Though not conclusive, it is contended that the main culprit of the rotational movement of the bearing pads is their diamond shape. It appeared that flat objects of diamond shape would rotate under cyclical disturbance.

This phenomenon is also observed in another skewed bridge over Jegor River in the state of Kelantan (Sani, 1998). The bridge, skewed at 40^0, was found to have rotated and displaced. On the other hand, existing literature (Park, 1984; TRB, 1977) reports that elastomeric bearing pads tend to move for extremely skewed bridge decks. According to these reports, it is the geometry of the bridge deck rather than the shape of the bearing pad that has caused the bearings to move. From PWD experience, out of 22 bridges with skews of over 40^0 and installed with rectangular elastomeric bearings, none of them has any problem of walked bearings. This shows that in the Kuala Lipis Bridge, the diamond shape of the bearings has actually caused the dislocation of the bearing pads. Based on this observation, the Malaysian Standard Committee on Elastomeric Bearing had thus expressly confined the draft new standard to rectangular bearings.

5.0 ACKNOWLEDGEMENTS

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