Replacement of Existing Mechanical Bearings with Elastomeric Bearings for Ahmad Shah Bridge, Temerloh, Malaysia

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Abstract:

The Ahmad Shah Bridge is a high level bridge with main spans of the bridge consisting of two continuous spans of steel twin-box girders approximately 150 m and 120 m in length. In June 1997 it was discovered that the existing mechanical roller bearings at the west abutment had damaged severely to the extent that the roller had been displaced. The existing bearings are of *HiLoad* type mechanical bearings. Despite that it is a common practice of Public Works Department Malaysia (PWD) to use mechanical bearings for spans exceeding 50 m, PWD has decided to use elastomeric bearings of natural rubber to replace all the four existing bearings at the abutment. This paper discusses the investigation carried out to determine the main causes of the problem; as well as the design, installation and monitoring of the new elastomeric bearings. Some cost comparisons are also made to highlight the amount of savings made by the Department's bold decision.

BACKGROUND

The Bridge

The Ahmad Shah Bridge is a high level bridge which crosses the Pahang River at Temerloh, Malaysia. The main spans of the bridge consist of two continuous spans of steel twin-box girders approximately 150 m and 120 m in length (Figure 1). The bridge is linked at either end by an approach viaduct of simple span prestressed concrete construction. The bridge was constructed in 1975 to replace the existing low level bridge damaged in the 1967 and 1971 floods.

Each box girder is supported on two rocker bearings at the east abutment and expanded over roller bearings at the west abutment. The main pier carries rocker bearings on the pier head and has been designed as a slender column to accommodate thermal movements. A comb-typed expansion joint is provided above the west abutment, which permits a maximum movement of 85 mm. A detailed description of the bridge is given by Lee and Wallace [1].

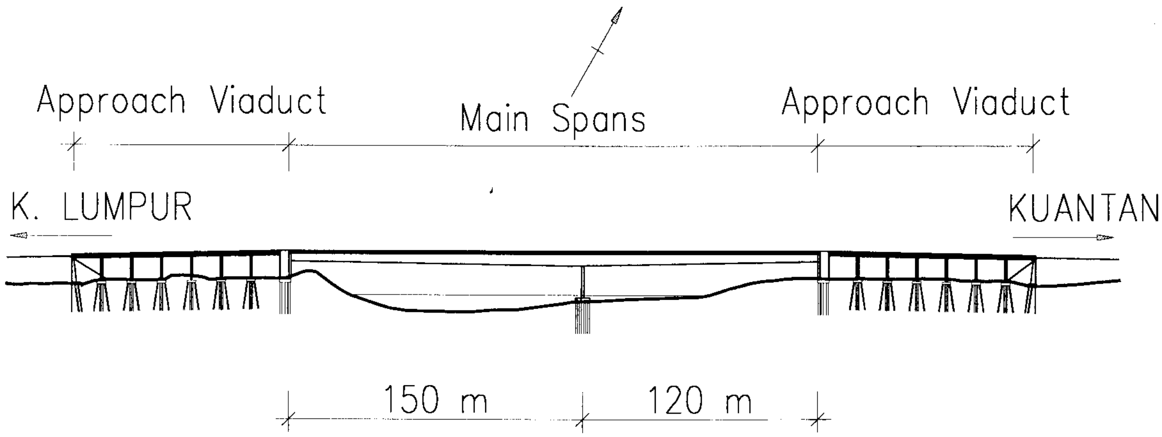


Figure 1 a. Ahmad Shah Bridge – Side elevation

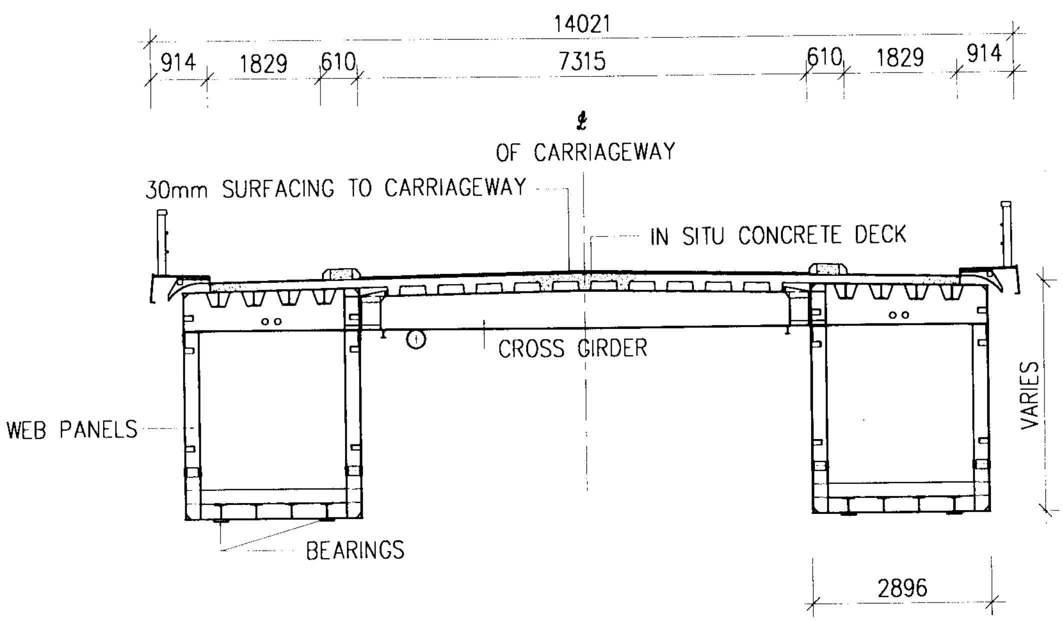


Figure 1 b. Ahmad Shah Bridge – Typical Cross-section

The Problem

In June 1997, it was reported that one of the four mechanical roller bearings (the interior bearing of the North Girder) had damaged severely to the extent that its roller had been displaced. A detailed inspection of the other interior bearing revealed that it had also experienced similar type of damage. The conditions of the two exterior bearings were not examined due to lack of access. It was however believed that they were still in function and were indeed carrying additional loads shed by the two failed bearings. Due to the failure, the deck level had dropped by 15 mm. In order to alleviate this problem, steel plates of 16 mm thick were placed on the deck to flush with the approaches. To prevent further settlement of the decking, a makeshift rocker bearing fabricated by the Public Works Department Malaysia (PWD) mechanical workshop were installed in place of each displaced bearing as a temporary substitute (Plate 1).

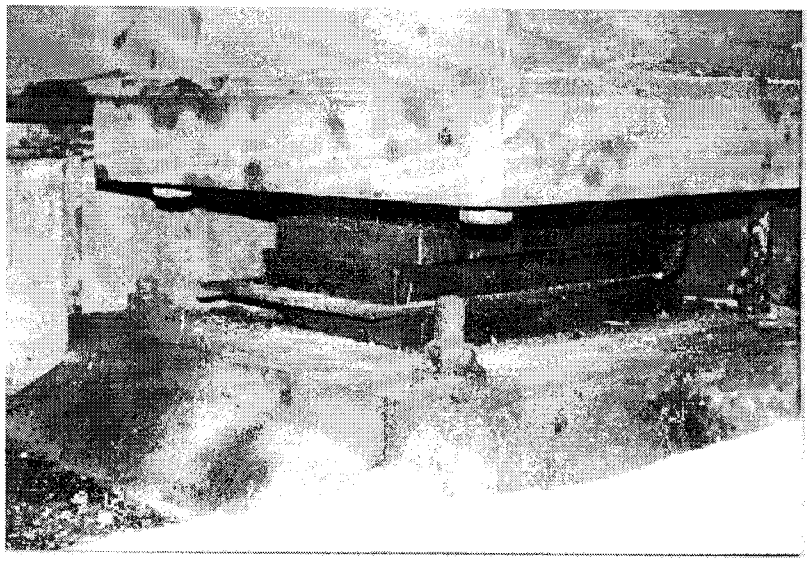


Plate 1. The PWD makeshift rocker bearing

The PWD had quickly decided that an immediate replacement of the damaged bearings was called for. In addition, it was important that the likely causes of the bearing failure be identified so that necessary precautions would be taken for the design and installation of the new bearings.

INSPECTION AND APPRAISAL OF THE PROBLEM

Observations

The existing bearings were of the *HiLoad* type as illustrated in Figure 2. According to the manufacturer's catalog, the roller is guided, by means of flanges, which engage on the sides of the contact plates, to prevent skewing and lateral movement, and also to resist lateral forces. In addition, to ensure that the roller does not slide, and to prevent it from being displaced by relative rotation between the two contact plates, pinions attached to the ends of the roller engage in racks alongside the plates.

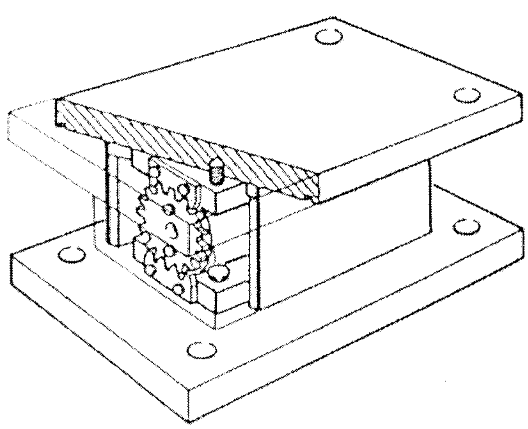


Figure 2. The *HiLoad* type mechanical bearing

On close examination of the failed bearings, it was found that the racks and pinions in one of the interior bearings had been detached from the assembly due to shearing off of the bolts. The flanges of the roller had also been broken off (Plate 2).

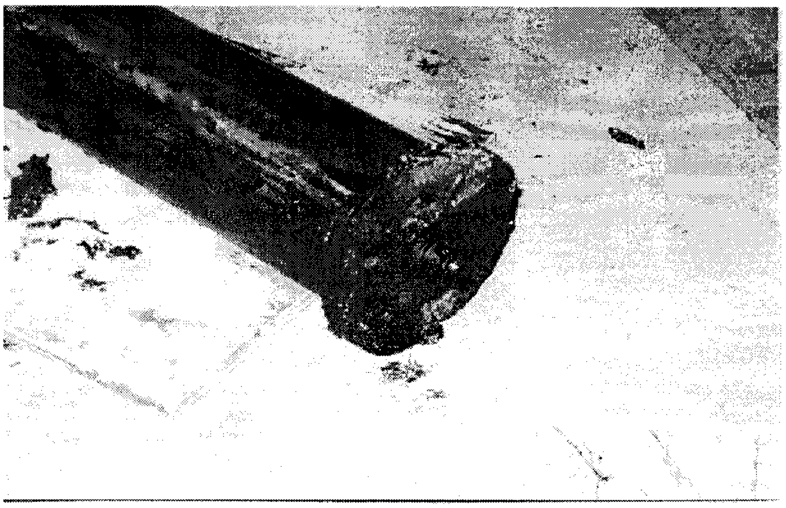


Plate 2. Breakage of roller flanges

Such failures could be due to one or combinations of the following reasons:

- misalignment of the bearings due to improper installation
- presence of lateral force from an external source
- the roller was frozen

It was very unlikely that there was a misalignment of the bearings due to improper installation and this was confirmed by field measurement. There was no sign of rusting in any of the bearing components for they were effectively protected in grease. From the telltale marks on the surface of the contact plates, it was clear that the superstructure had not been moving along its longitudinal axis but rather in a skewed direction. Also, there was sign that the roller was sliding in between the contact plates rather than rolling (Plate 3).

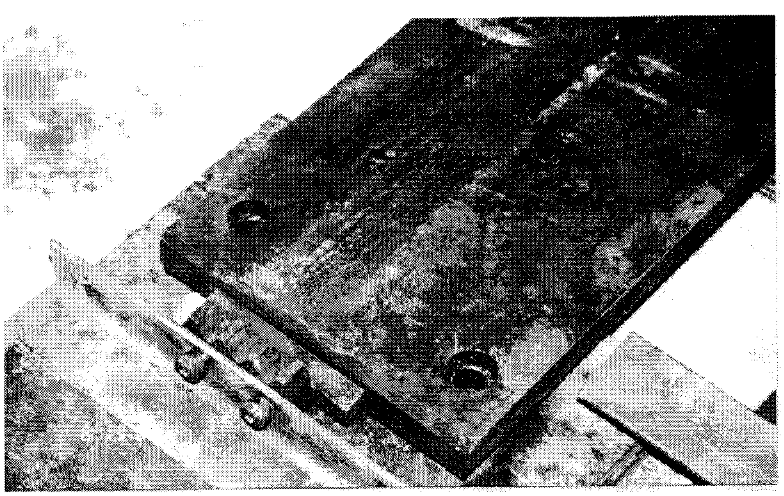


Plate 3 Telltale marks on the surface

It was reported in [1] that the temperature difference between the inside surface of the outer web plate and that of the inner web plate for one of the box girders was approximately 22°C. This temperature difference would yield a differential expansion of approximately 72 mm between the outer and inner webs of a box. On the other hand, field measurements of the girders by the contractor recorded a maximum expansion of 32 mm in the longitudinal direction and 1 mm in the transverse direction (Figures 3). Although the recorded transverse movement is small, the lateral forces due to the differential expansion of the box girder may have exceeded the strength of the roller flanges. Besides, the design of the *HiLoad* bearing has required such perfect fits in the assembly that any slight deviation might have damaged the flanges or pinions.

STRUCTURAL ANALYSIS AND DESIGN OF NEW BEARINGS

Analysis

Simple analysis treating the structure as continuously expanding over a fixed support and two free supports shows that the reaction on each free-end bearing under dead load is about 3,000 kN. Assuming a dead load/live load ratio of 75:25, which is common for this type of bridge span, the total load on each bearing is estimated to be 4,000 kN.

A finite element (FE) analysis was done using a standard package LUSAS to study the stresses in the box girders caused by raising one box or two boxes simultaneously by 300 mm. The results indicated that either method would not cause any over stress in the girders [2]. However, in order not to introduce high stresses to the concrete deck it was decided that the two box girders be jacked simultaneously.

From calculations a total jacking force of 16,000 kN (4,000 kN x 4) was required to raise the free end of the deck. In order that the reaction force at each jacking point was not too high, it was decided that four jacks were used to raise the two boxes. Analysis of the end diaphragm indicated that the diaphragm needed some strengthening at the points of jacking. Two pieces of steel plates of grade 50B and of size 1200 x 200 x 25 mm were thus welded to the end diaphragm at each jacking point. These stiffeners were meant to remain after completion of the project, to allow for future jacking when the need arised.

Further structural analysis was carried out by the contractor using a 2-D Plane Frame Analysis. It indicated that by raising 50 mm at the free end would hardly raise the deck at the intermediate support. This result eliminated the concern that raising the free end would damage the rocker bearings over the pier head or otherwise displace the locating pins for the rocker bearings.

Mechanical Bearings Versus Elastomeric Bearings

It has been a common practice for PWD to use mechanical bearings for spans exceeding 50 m. For Ahmad Shah Bridge, it seemed that the most logical solution would be to use back similar type of mechanical bearings. However *HiLoad* bearings were not readily available in the market and must be custom made in the U.K. Use of this type of bearing would thus be costly and would necessitate some waiting time for the fabrication and delivery of the bearings from the U.K. A popular type of mechanical bearing known as the Pot bearing was also considered as an alternative.

The economic turmoil that hit the nation in 1997 had reaffirmed Malaysians on the need for an austerity drive; especially in buying imported goods. There was also some inquisition among some Malaysian researchers and engineers as to why elastomeric bearings could not be used for long span bridges.

J. E. Long [3] states that elastomeric bearings have a limit in vertical load capacity of 3,000 kN. This might have been the basis for not using elastomeric bearings in long span bridges. However, a study conducted by TRRL of the UK had shown that elastomeric bearings could withstand a load 200% of design value [4]. The TRRL study and a study at University of Colorado [5] had also shown that elastomeric bearings (of natural rubber or neoprene) exhibit satisfactory behavior under long term cyclic loading. Any remaining skepticism regarding the long term performance of rubber products should be cleared by the observation in Australia of a natural rubber pad which had suffered little oxidation after close to 100 years' service [6].

A rough calculation shows that PWD Malaysia has used elastomeric bearings on some 360 bridges since 1970. Only two bridges, Bridge FT007/018/10 in Alor Star and Dambai Bridge in Sabah were found to have failed [7]. Formation analysis carried out by the Chemical Inspection and Testing Institute of Japan on samples collected from the two bridges suggested that the bearings in Bridge FT007/018/10 were due to ozone attack aggravated by presence of water [8]. Dambai Bridge was, on the other hand, due to excessive concentrated load on the bridge bearings [8]. Failures of elastomeric bearings are considered rare. With the above observations and further consultation with Rubber Research Institute of Malaysia (RRIM), PWD decided to use laminated elastomeric bearings of natural rubber instead of the Pot bearings. Adding laminations was intended to increase the capacity of the bearing in horizontal movements. This was necessary in order to reduce the horizontal loads transferred from the superstructure to the substructure and the piles.

Design of Rubber Bearings

Most designers in Malaysia assume and use a temperature range of between 11°C and 21°C in the calculation of thermal expansion. During detailed bridge inspection by PWD engineers, the temperature range at the west abutment of Ahmad Shah Bridge was measured to be 4 °C for a period of 24 hours. This would correspond to a longitudinal movement of the girders of 19.5 mm measured at the site. To increase the factor of safety a temperature range of 10 °C was used instead to calculate the thermal movement. This worked out to be about 32.6 mm.

The elastomeric bearing was thus designed for a horizontal movement of ± 20 mm, a rotational movement of 1.33 x 10^{-3} rad. and a vertical load of 4,000 kN in accordance to BS5400 Part 9 [9]. The details of the proposed bearings are as shown below:

Overall Dimensions	= 650 x 350 x 57.5 mm
Inner Rubber Layers	= 2 x 12 mm
Steel Plates	= 3 x 4.5 mm
Rubber Top and Bottom Cover Thickness	= 10 mm
Rubber Side Cover Thickness	= 10 mm
Shear Modulus of Rubber	= 0.9 N/mm^2

The bearings were manufactured locally by Min Industries Sdn. Bhd., Kuala Lumpur. Performance tests on two sample bearings carried out in RRIM indicated that the mean compression stiffness was 1,931.5 kN/m and the mean shear stiffness was 3.89 kN/m.

INSTALLATION OF NEW BEARINGS

Jacking System and Safety Consideration

To avoid any possible leakage of hydraulic pressure under maintained load, hydraulic jacks equipped with a built-in safety locking nut system were used (Plate 4). 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. Since this was a long span bridge, this feature was essential.

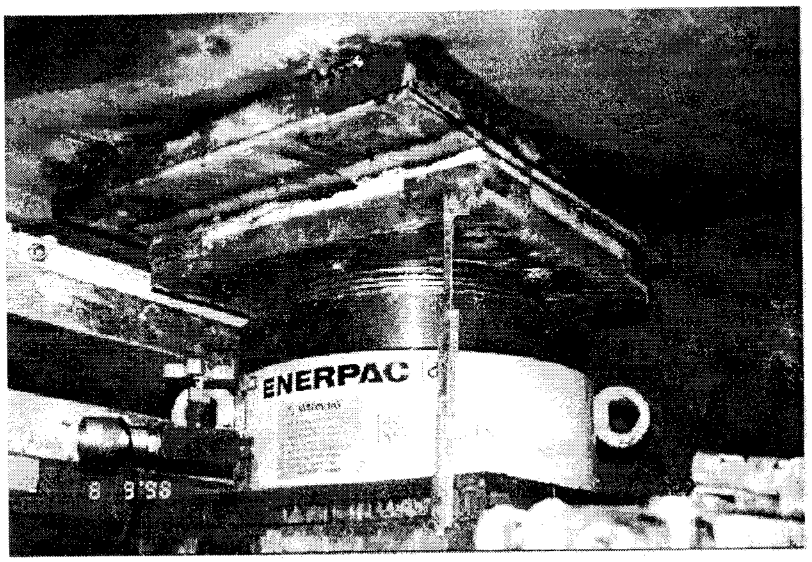


Plate 4. Jacking system

In order to minimise any torsion caused to the deck, the four jacks were coupled in a manifold 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 the box girders that might have tilted. Further, a sliding system with two pieces of 15 mm thick PTFE sheets was provided at the top of the jack saddle to cater for any horizontal movement. Lest the superstructue would move side way while being raised, side restraints were also provided at the outer webs of each box girder.

Replacement of Bearings

The replacement works began with jacking and lifting the free end of the superstructure to relieve the existing bearings from the loads. The work sequence that followed consisted of

- Removal of existing bearings
- Surface preparation of the masonry plates and sole plates of existing plates
- Placement of special masonry plates for new bearings (see Plate 5)
- Placement of new bearings
- Placement of special sole plates over the new bearings
- Filling of gap between the existing sole plates and new special sole plates
- Release of jacks to shed the load on the new bearings

The replacement works were very much simplified by the decision not to remove the old bearings completely. The old masonry plates and sole plates remained to form parts of the new bearing assembly (Figure 3). Additional special masonry and sole plates were fabricated of mild steel and galvanised. There were 'keeper plates' to hold the masonry and sole plates in position. In fact, such restraints were not necessary because the dead load alone was sufficient to provide the friction to keep the existing and new steel plates from sliding. Shedding the load onto the new bearings was done by releasing the jack at such time when the superstructure was midway between the expanded and contracted length. This way, the elastomeric bearings would have sufficient horizontal movement capacity to move in either direction. A 12.5 mm gap was provided between the old sole plates and the new ones to facilitate the placement and positioning of the elastomeric bearings. This gap was finally filled up by a flowable epoxy mortar before releasing the bridge superstructure on to the new bearings.

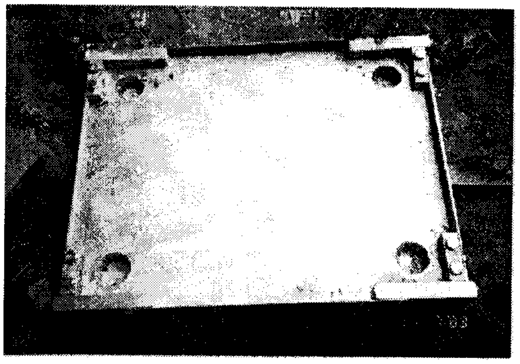


Plate 5. Special masonry plate for new bearing

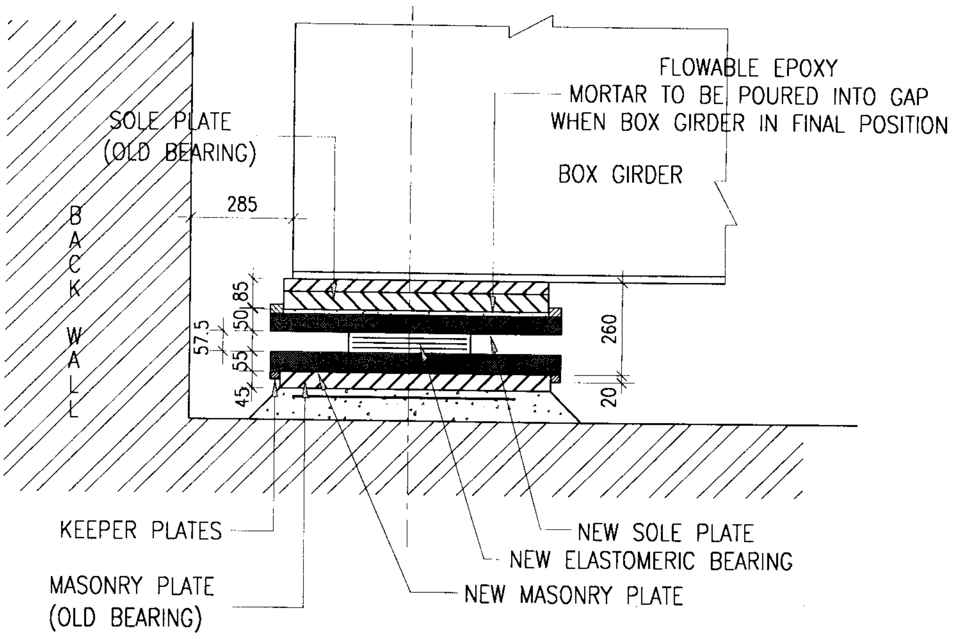


Figure 3. New bearing assembly

Monitoring during Installation
Instrumentation was set up to monitor the displacements of the girders during jacking. Site measurement prior to jacking showed that the twin box girders had tilted transversely toward the centre of the deck. The interior bearings at the South Girder and North Girder had dropped by 23 mm and 21 mm respectively because of this tilting. The original idea had been to operate the two inner jacks only with the intention of leveling the box girders first before further lifting by all four jacks. The attempt was however not successful. Each girder was lifted by 4 mm with the jacking force recorded at 2,700 kN. Increasing the jacking force did little to lift the box girders any further.

The second attempt of lifting was carried out by jacking four jacks simultaneously. It was observed that the inner sides of each steel girder began to move upward while the two outer sides remained stationary up to a jacking force of 1,930 kN. It was also observed that there was an inward movement of the box girders measured at 12 mm and 10 mm for the South and North Girders respectively. This might indicate that the bridge was 'fiinding its own level' by distribution of loads among the four jacks.

At a jacking force of 2,240 kN for each jack, the superstructure was successfully lifted up. No further increase of jacking force was recorded while the girders continued to rise. The jacking operation was terminated when the jacks had reached their maximum stroke, i.e.; 45 mm.

Site measurements by the contractor showed that the maximum expansion and contraction occurred at 4:00-6:00 p.m. and 6:00-8:00 a.m. respectively (Figure 4). The records also showed that the girders would be at their central positions around 1:00 p.m. and 11:00 p.m. It was thus decided that the bridge loads be transferred to the new bearings at around 1:00 p.m.

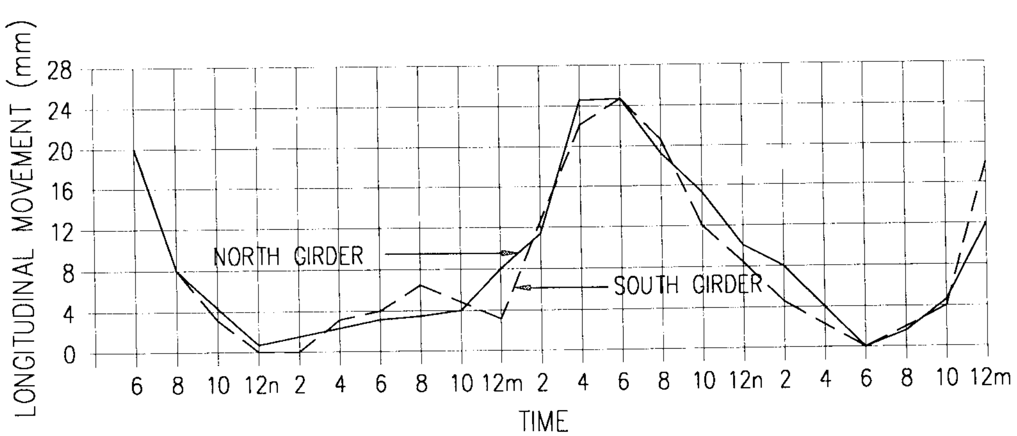


Figure 4. Longitudinal movements of box girders

Performance of New Bearings
When the load was totally shed onto the elastomeric bearings extensive slipping of the rubber encasement occurred for the two interior bearings (Plate 6 and Plate 7). Other than that, the two bearings exhibited the healthy bulging shapes of the internal rubber layers indicating that the bonding between the elastomer and steel plates were intact. Obviously the two interior bearings were carrying much higher load as compared to the exterior bearings.

There was concern about the long term performance of the bearings in this condition. Subsequent testing on additional bearings at the laboratory of RRIM was carried out. The bearings demonstrated similar type of behaviour under a load of 4,000 kN (Plate 8). When the load was removed, the bearings returned to their original shape without any permanent deformation.

Dr. Kamarul of RRIM was of the opinion that the encasement of 10 mm might be excessive [10]. The current Malaysian Standard Specification for Bridge Bearing [11] under revision now has specified a minimum thickness of encasement of 3 mm. It appears that a limit to the maximum thickness should also be specified.

Regardless, the performance of the new bearings at Ahmad Shah Bridge was being monitored by RRIM since they were placed under operation. The creep effect of the bearings will be studied and the results to be published in the near future.

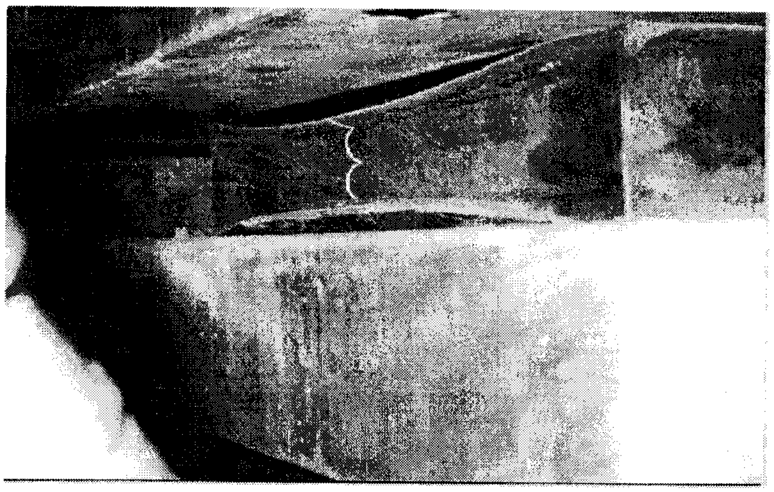


Plate 6. Elastomeric bearing under load (transverse direction)

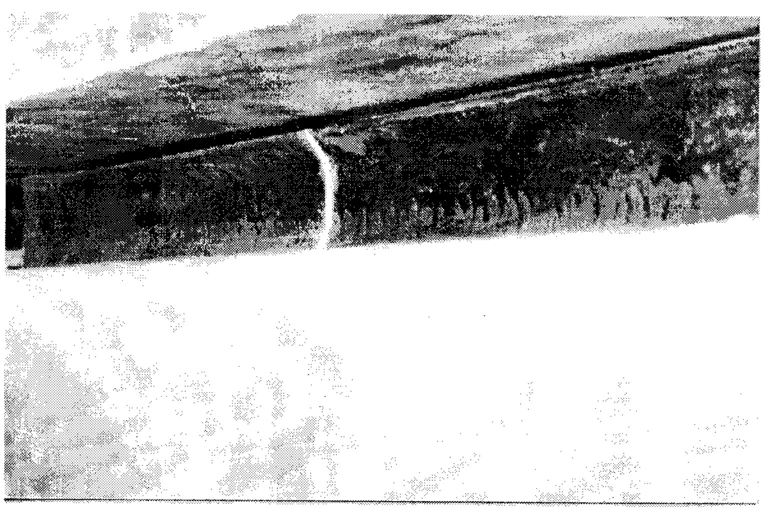
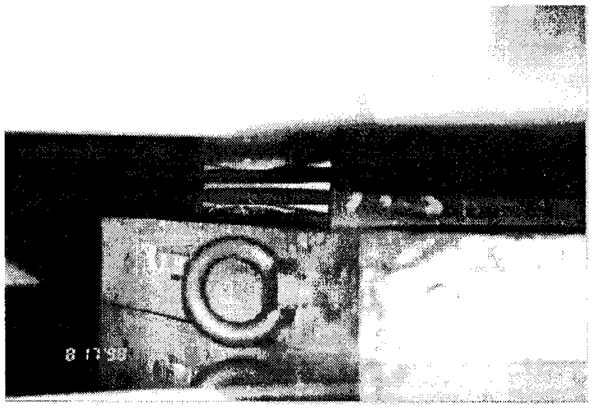
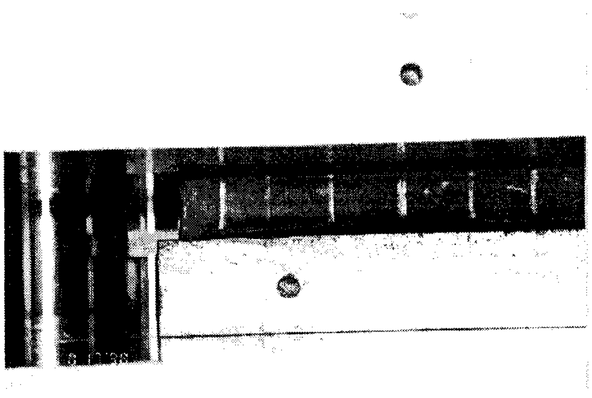


Plate 7. Elastomeric bearing under load (longitudinal direction)



Sample A



Sample B

Plate 8. Load test in RRIM laboratory

CONCLUSIONS

During project evaluation, cost analysis indicated that a mechanical roller bearing would cost about RM 70,000.00 as compared to only RM 800.00 for an elastomeric bearing. This huge saving in material alone was attractive enough to favour use of elastomeric bearings. Further, use of mechanical bearing would necessitate the superstructure to be raised up much higher (300 mm as compared to 50 mm for elastomeric bearing) in order to provide the room needed for the replacement works. Installation of a temporary bridging system, for example, the Bailey bridge; and traffic control became necessary. The additional costs could make the choice of mechanical bearings even more formidable.

Although the use of elastomeric bearing had been motivated by cost, it appeared through hindsight that rubber bearings were indeed the most appropriate choice after all. For a mechanical bearing, the assembly must be precisely installed. Thus, a substantial time and efforts are required for its installation. In the case of elatomeric bearing, the whole assembly was so simple. Lifting the bridge up higher might also require more accurate analysis of the bridge superstructure behaviour and in all likelihood some parts of the bridge might need to be strengthened before jacking. Use of elastomeric bearings had eliminated all these troubles. Indeed, the bearings were replaced without any disruption to the traffic at all.

ACKNOWLEDGEMENTS

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