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High Load Multirotational Disk Bearings for Civil Engineering Structures

R.J. Watson[1]

ABSTRACT

High load bearings have long posed a specific problem for structural engineers in that finding a device that can accommodate all of the loads, movements and rotations is difficult. Conventional rocker/roller bearings are unidirectional and are often inadequate for today's complex structures. Elastomeric bearings have done an excellent job on short and simple spans, however they can become troublesome and costly as the loads and movements increase.

With these problems in mind high load multirotational disk bearings (HLMDB) were developed back in the early 1970's as a low cost, simple and maintenance free design for all types of civil engineering structures. The key component of HLMDB is the polyurethane load and rotational element. Polyurethanes have outstanding weathering properties and tremendous compressive strength. They also have a material stability range of -70º-+120ºC., so for normal atmospheric conditions the material remains flexible and stable. HLMDB have an outstanding field performance history on structures all over the world for over 35 years.

This presentation will cover the development of HLMDB and examine so some of the research that has been conducted to verify the efficacy of these devices. In addition several case histories will be explored that will demonstrate the versatility of HLMDB on a variety of structures. Projects such as the Pasco Kennewick Bridge, the Hoover Dam Bypass and the New I-35W Bridge in Minneapolis will be examined in detail.

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Introduction

Bearings are a vitally important part of a bridge structure, however they rarely get the attention necessary to ensure proper performance. Most of the bearings utilized on bridges today are conventional elastomeric bearings [1]. These bearings are typically comprised of neoprene or natural rubber and reinforced with steel plates. For the most part elastomeric bearings have performed well since the 1950's when the first installations occurred. The problems elastomeric bearings experience tend to occur as the loads and displacements increase resulting in larger and thicker pads.

Elastomeric bearings are manufactured under heat and pressure designed to cure the raw polymer in a thermoset reactive process. The problem with bearings that have a large mass of rubber is that it is difficult to get a uniform cure throughout the cross section of the elastomer. If the vulcanization process is too long the outer edges of the pad become brittle due to overcuring. Conversely if the curing process is cut short the center of the pad remains uncured resulting in excessive deflection under sustained load Fig. 1.

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Figure 1. Elastomeric bearing pad exhibiting excessive deflection.

The other problem with elastomeric bearings is that as the loads and displacements increase, the pads become excessively large in plan area and height due to the pressure limitations.

One of the ways to reduce the plan area of an elastomeric bearing is to increase the allowable pressure on the elastomer. However in doing that the elastomeric material becomes unstable unless confined in some manner. This idea led to the development of the confined elastomer or pot bearing back in the 1960’s. As reported at the 6th International Conference on Short and Medium Span Bridges in 2002 pot bearings have experienced many problems in the field [2]. Most prevalent has been sealing ring failure which has reached epidemic proportions in North America Fig. 2.

Figure 2. Pot bearing with sealing ring failure.

HLMDB Concept

With these problems in mind high load multirotational Disk Bearings (HLMDB) were developed in the early 1970's as a cost effective superior performance alternative to pot, spherical or elastomeric bearings Fig. 3.

Figure 3. Unidirectional HLMDB.

The key to the functionality of the HLMDB is the use of a polyether urethane load and rotational element. Polyether urethanes have tremendous compressive strength and have outstanding weathering properties. In addition they have a material stability range of -70° to +120°C [3]. The outstanding physical properties of polyurethanes result in their having many consumer uses such as garden hoses, bowling balls and in-line skates. In addition many paints and protective coatings contain urethane which give them good flexibility, durability and toughness.

Under the design load the polyurethane pad will deflect in the range of 10-15%. This differential deflection gives the bearing the ability to distribute rotations regardless of the orientation of direction. The maximum allowable pressure in the rotational element is set by AASHTO at 35 MPa. However the ultimate load the polyurethane is capable of is on the order of 20 times that load. Therefore the vertical load safety factor is very high. That is important because during the superstructure installation process bridge bearings are frequently overloaded. The rotation of these bearings transmits very little moment into the substructure, therefore they allow for an efficient foundation design where the superstructure loads are primarily vertical loads on the columns. On many projects where there is a very little room for large foundations, the HLMDB are frequently the designer's preferred bearing choice.

In order to accommodate translation a PTFE disk is bonded on top of the upper bearing plate. As a means of preventing the PTFE from migrating over time it is also recessed into the upper bearing plate which mechanically locks it into place. Bearing on top of the PTFE disk is an upper slide plate which is faced with a highly polished mirror finish stainless steel sheet. Sliding friction testing at design pressures of 24 Mpa typically yield coefficient of friction values of 2% or less.

Pasco Kennewick Bridge

One of the first major structures to utilize HLMDB was the Pasco Kennewick Intercity Bridge over the Columbia River in the state of Washington Fig. 4. The Pasco Kennewick Bridge was the first cable stay bridge built in the 48 contiguous states. It is 782 m long with a 296 m main span. The HLMDB on this bridge range from 2670 kN to 12400 kN in vertical capacity. Since the deck was designed to be continuous all of the movement of the structure was designed to be taken at one joint at the expansion abutment. A large modular expansion joint system was utilized designed for 660 mm of movement. Likewise the HLMDB at the expansion joint also had to accommodate this magnitude of displacement. This was simply done by designing the upper slide plate long enough to provide this amount of movement. From the PTFE down the HLMDB design would be the same regardless of the movement.

Over 35 years later the HLMDB on the Pasco Kennewick Bridge are performing well and are in excellent condition Fig. 5.

Figure 4. Pasco kennewick bridge.

Figure 5. Thirty-five year old HLMDB on the pasco kennewick bridge.

I-35W Bridge

August 1, 2007 is a day that most engineers will not forget for a long time to come. The collapse of the I-35W steel truss bridge sent shock waves through the engineering community Fig. 6. Remarkably just 3 days after the collapse the Minnesota Department of Transportation issued a request for qualifications from design/build teams interested in constructing a replacement bridge. Four days after this a short list of teams was issued. By October 8, 2007 the team of Flatiron Constructors, Manson Construction and Figg Bridge Engineers had received their notice to proceed with the replacement structure [4].

Figure 6. Collapse of the I-35W bridge in minneapolis.

The new bridge, constructed in 11 months (3 months ahead of an already aggressive schedule) is 377 m long with a 154 m long main span Fig. 7. In addition to the contract price of $234 million the team earned an additional incentive of $27 million for completing the structure by mid September. The bridge being out of service was costing the State of Minnesota in excess of $400,000 per day and early completion was rewarded with an incentive of $200,000 per day.

Figure 7. The completed st. anthony falls bridge (photo courtesy of figg bridge).

The bridge which is designed for a 100 year life has four 21 m tall piers supported on drilled shafts into bedrock. The bridge is comprised of twin structures with a combined width of 55 m which allow for 10 lanes of traffic and future potential for bus or light rail transit.

The main span is constructed of precast concrete segments while the approach spans of 97 m, 76 m and 45 m are cast-in-place concrete constructed on falsework. Each of the precast concrete segments are 13 m wide, 4.0 or 4.9 m long and up to 7.6 m deep. There are 120 segments which weigh from 1330 kN to 1780 kN each [5].

Supporting these segments and transmitting the load down to the substructure is the task of the little discussed but vitally important bridge bearings. In addition to accommodating the vertical loads these bearings must also transmit live load rotations and displacements due to thermal changes and creep shrink.

I-35W HLMDB Design

The fabrication and erection of the HLMDB for the I-35 W Bridge was a task in itself due to the staggering size and capacity of the bearings that were chosen for this project.

HLMDB bearings were chosen because of their excellent history of low maintenance, easy inspection, and simple design, in addition to the fact that supplier was able to meet the expedited schedule. The fabricator's engineering staff were in almost constant contact with the design-build team to design, manufacture, test, and ship the bearings to the site in order to meet the proposed schedule.

At the south abutment there are four guided and four non-guided expansion HLMDB which are designed for vertical service loads of 9780 kN with a horizontal strength load capacity of 3640 kN a maximum longitudinal displacement of 508 mm and a maximum rotation of ±0.02 radians.

At piers two and three, the 24 fixed HLMDB are designed for vertical service loads of 25,780 kN and a maximum rotation of ±0.02 radians Fig. 8. Another design feature for the bridge is at span three of pier four, which required eight guided expansion HLMDB to accommodate 890kN of uplift capacity in addition to 6220 kN of vertical load Fig. 9. The reason for uplift restraint at this span is related to a particular strength load-case, in which live load is positioned on one side of the box girder in combination with a wind load. Conventional HLMDB can be easily modified to resist uplift forces. First the shear resisting mechanism (SRM) at the center of the bearings is reconfigured so that it acts much like a trailer hitch on an automobile. By connecting the upper and lower bearing plates with this modified SRM the bearing then has the ability to resist uplift forces. If displacement capacity is also required of the uplift bearing the upper slide plate is then outfitted with guide bars that tuck underneath the upper bearing plate. Due to this innovative design, these bearings are capable of accommodating uplift, displacement and rotation simultaneously. The bearings also contain stop bars to limit longitudinal service movements. The remaining 14 fixed HLMDB at pier four, span four, carry 5330 kN of vertical load.

Figure 8. Polyurethane rotational element for a 25,780 kN HLMDB.

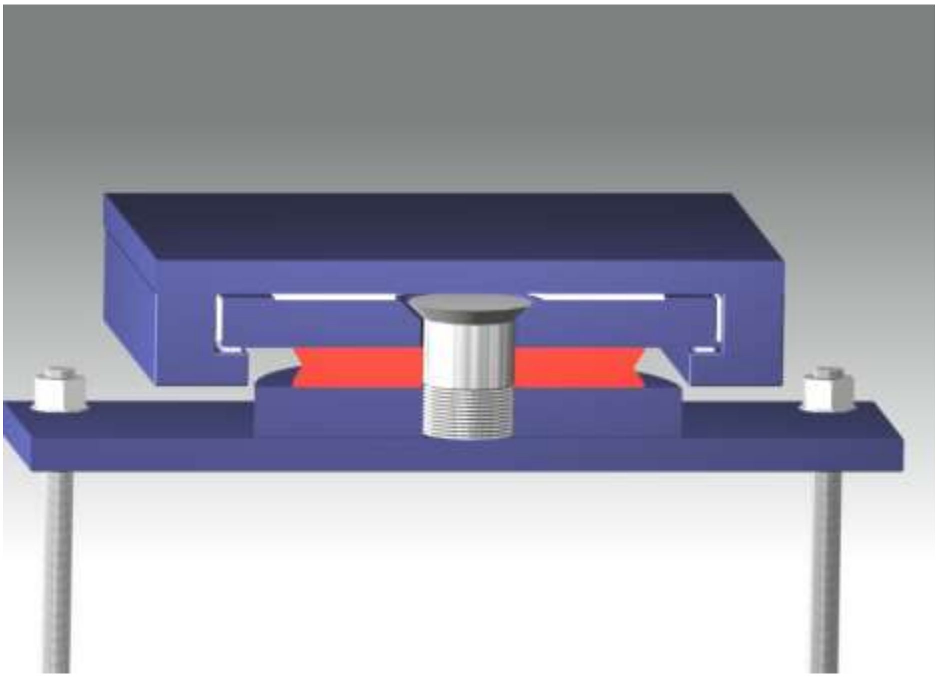

Figure 9. Uplift restraint HLMDB.

One of the other features that attracted the design team to HLMDB is the ease of replacement details Fig. 10. Most transportation design authorities require that bearings be designed so that they can be replaced with a minimal amount of jacking. This feature was utilized on this project on span 1 where the contractor needed to proceed with construction while the bearings for this location were being tested. The span was set on temporary supports. Once the production bearings were approved they were installed after the precast segments were already placed. The replaceability design utilizes a bolted in containment plate which keeps the bearing fixed in place. To facilitate removal the containment plate is unbolted and removed allowing the bearing assembly to be pulled out in one piece.

Figure 10. HLMDB installed on I-35W bridge showing containment plate.

Testing

Very few facilities in North America have the capacity to test bearings at such high loads as those required for the bearings at piers two and three of this bridge. The University of California at San Diego SRMD Facility was chosen for full-size testing of two disk bearings according to Section 18 of AASHTO LRFD bridge construction specifications, which included simultaneous horizontal and vertical proof load testing Fig. 11. The remainder of the testing required was completed by the fabricator at its own testing facilities, and all bearings met or exceeded the AASHTO LRFD testing requirements.

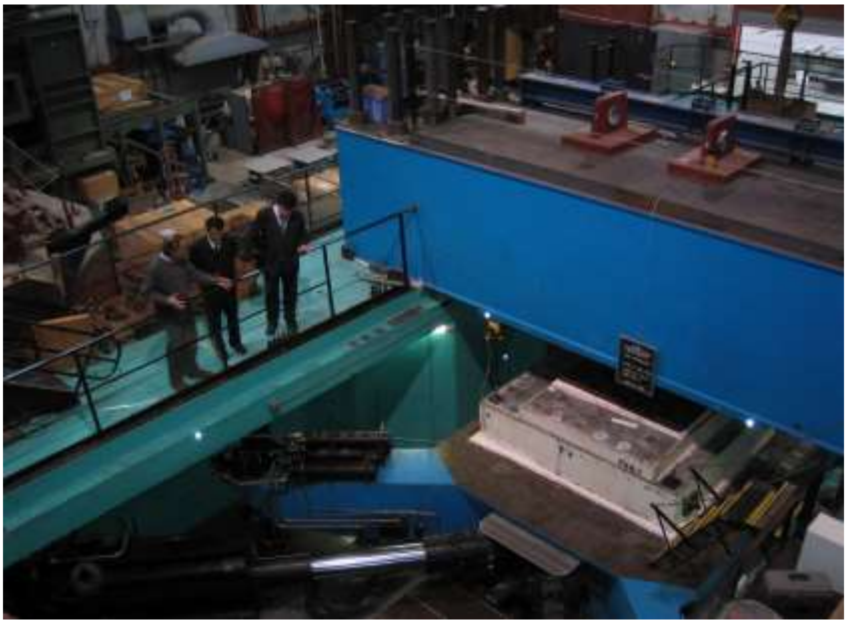

Figure 11. HLMDB undergoing testing at SRMD test facility.

Figure 12. Hoover dam bypass bridge.

The bearing requirements for a fast track, high profile project such as the St. Anthony Falls Bridge (I-35W) in Minneapolis were numerous. Rotational capacity, high vertical and horizontal loads, uplift restraint, ease of replacement and a history of long term performance were just some of the features required for this project. HLMDB met all of these requirements and provided the Minnesota DOT a cost effective solution.

Hoover Dam Bypass

Another example of a HLMDB installation is on the Hoover Dam Bypass Fig. 12. The bypass project includes a new four-lane, composite deck arch bridge with a North American Record main span of 323 meters. The spandrel columns on top of the arch rib and at the approaches have an average span of approximately 40 meters.

The contracting team of Obayashi Construction and PSM Construction was awarded the contract to build the Hoover Dam Bypass with the help of the consulting engineers, TY Lin International, HDR, and Jacobs Engineering Group. The engineers chose HLMDB in order to meet the challenging performance specifications for the bearings on the new Colorado River Bridge.

At the abutments, the HLMDB were installed in early 2008. There are eight guided expansion disk bearings designed for vertical service loads of 1,850 kN to 2,415 kN. The horizontal load capacity is 538 kN, the maximum longitudinal displacement for the abutment bearings is approximately 460 mm, and the bearings are designed for a maximum rotation of ±0.022 radians. A special feature of the abutment bearings is a permanent elastic expansion restraint mechanism consisting of polyether urethane springs with a longitudinal restoring stiffness of 23 kN in each direction over a movement range of 125 mm. The abutment bearings were also provided with temporary restraints to lock them in the set position until after the erection of the superstructure (Fig. 13). There are a total of three guided expansion HLMDB and one non-guided expansion HLMDB located at piers one and 15. The vertical service load for the HLMDB at these piers is 11,054 kN, with a horizontal load capacity of

1,126 kN. The bearings are designed for approximately 440 mm of longitudinal movement, and a maximum rotational capacity of ±0.027 radians.

Figure 13. Hoover dam abutment HLMDB.

The remaining 12 HLMDB are installed on piers 7-12 over the arch. They consist of four fixed and eight guided expansion disk bearings with a vertical service load ranging from 9,706 kN to 9,951 kN. The horizontal load capacity will be 1,708 kN and these bearings are designed for approximately 130 mm of total movement, and a maximum rotational capacity of ±0.027 radians.

Figure 14. Test frame at lehigh university.

Due to the large vertical and horizontal load requirements, two of the pier bearings were sent to the ATLSS facility at Lehigh University in Bethlehem, Pennsylvania for proof load testing as required by the contract specifications (Fig. 14). This involves testing them up to 150% of the design vertical load. The abutment bearings were tested at the R.J. Watson, Inc. test machine. All bearings met or exceeded the contract requirements.

Conclusions

The use of HLMDB is a cost effective method of accommodating loads, movements and rotations on bridges of all types. Field inspections have revealed that HLMDB are a long term and maintenance free device. HLMDB can be easily modified to accommodate high horizontal loads, uplift restraint and seismic forces. These features have resulted in HLMDB being used on structures such as the Pasco Kennewick, I-35W, Hoover Dam Bypass and many other signature bridges around the world.

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