HIGH LOAD MULTIROTATIONAL BEARINGS FOR THE DULLES CORRIDOR METRORAIL PROJECT

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ABSTRACT

Phase 1 of the new Dulles Corridor Metrorail Project is nearing completion. The 3 mile long aerial portion of the line consists of more than 2700 precast concrete segments that were fabricated in an off-site facility on the Dulles Airport property. Since the owner, Washington Metropolitan Area Transit Authority (WMATA) has had problems with elastomeric and pot type bearings in the past, they wanted to use a high load multirotational bearing device with a proven track record on bridges all over the world. After a thorough review of the options disk bearings were selected for this critical portion of the Metro Line.

Disk Bearings were developed in the early 1970's as an alternative to pot and spherical bearings. With thousands of successful installations over the past 40 years, the key component of this device is the polyether urethane rotational element. Polyurethanes have tremendous compressive strength and outstanding weathering properties.

This paper will cover the development of the disk bearing and highlight several case histories on precast concrete bridges demonstrating the performance advantages of this innovative device.

Keywords: Bridge bearings, Polyether urethane, PTFE, Disk bearings, Dulles Metrorail, Segmental bridges

INTRODUCTION

The Dulles Corridor Metrorail Project is a two-phase 23 mile long extension of the existing 106 mile Washington, DC Metrorail System[1]. This extension will connect the Nation's Capital to Dulles International Airport through Tysons Corner. Construction of the first 11.6 miles is nearly complete and will include 5 stations. Phase 1 features 3 miles of aerial guideway, the majority of which consists of precast segmental concrete box girder bridges (Fig. 1). One of the main reasons for using this top down construction method was to minimize the impact on the congestion of the Tysons Corner area. The guideways consist of over 2700 precast concrete segments that were fabricated at an off-site facility by Rizzani de Eccher USA (Fig. 2). The segments were shipped to the site one at a time and lifted into place by an erection gantry or truss. The match cast 10 ft. long segments are coated with epoxy and then joined together prior to post-tensioning. Concrete compressive strength for the segments ranged between 6000 and 8500 PSI depending on location.

Fig. 1 Dulles Metrorail Aerial Guideway

Fig. 2 Dulles precast concrete segments

BEARING SELECTION

A project of this magnitude and visibility required a bearing device with a proven track record on concrete transit bridges. Washington Metropolitan Area Transit Authority (WMATA) has had problems with elastomeric bearings in the past. As the load and movement requirements increase, the height and plan area of elastomeric bearings increases commensurately. Molded under heat and pressure it becomes problematic to get a uniform cure throughout the cross section of the elastomer in the higher load ranges. Bond between the rubber and steel shims has also been a common failure mode.

Similarly pot bearing failures have been well documented in the past. A common failure mode has been the sealing ring being forced out of the pot area followed by the extrusion of the elastomer. WMATA was no stranger to this type of failure.

As a result the prime contractor, Dulles Transit Partners consisting of a joint venture team of Bechtel and URS, chose disk bearings for the majority of the project.

DISK BEARING DEVICE

Disk bearings were originally developed in the early 1970’s as a cost effective superior performance alternative to pot or spherical bearings (Fig. 3).

The key to the functionality of the disk bearing 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 -94° to +248°F (-70° to + to +121°C)[2]. 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.

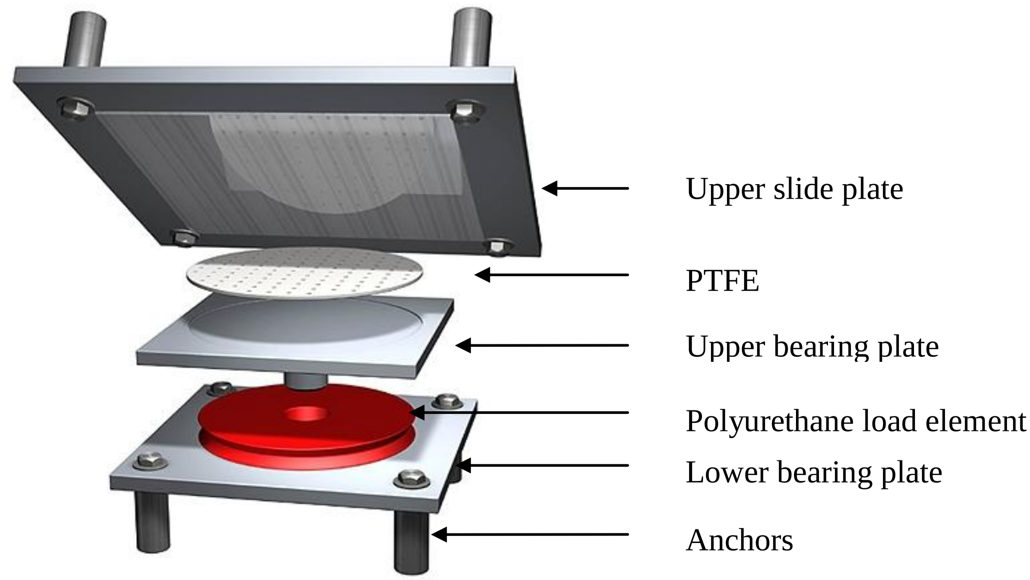

Fig. 3 Multidirectional disk bearing

Under the design load the polyurethane pad will deflect in the range of 10-15%. As the vertical load is applied the polyurethane pad expands, but the friction of the steel plate against the elastomer inhibits the expansion resulting in a bulging effect. This differential deflection gives the bearing the ability to distribute rotations regardless of the direction of orientation. The maximum allowable pressure in the rotational element is set by AASHTO at 5 ksi (35 M Pa). 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. This 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 the Dulles project there was very little room for large foundations so the disk bearings were the designer's preferred bearing choice.

In order to accommodate translation a Polytetrafluoroethylene (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 35 ksi (24 MPa) typically yield coefficient of friction values of 2% or less.

One of the first major structures to utilize disk bearings was the Pasco Kennewick Intercity Bridge over the Columbia River in the State of Washington. The Pasco Kennewick Bridge was the first cable stay bridge built in the 48 contiguous states. It is 2500 ft. (782 m) long with a 970 ft. (296m) main span. The disk bearings on this bridge range from 600 kips (12400 kN) to 2800 kips (2670 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 26 in. (660 mm) of movement. Likewise the disk bearings at the expansion joint also had to accommodate this magnitude of displacement. This was easily done by designing the upper slide plate long enough to provide this amount of movement. From the PTEF down the disk bearing design would be the same regardless of the movement.

Over 35 years later the disk bearings on the Pasco Kennewick Bridge are performing well and are still in excellent condition (Fig. 4).

Fig. 4 Thirty-five year old disk bearing on the Pasco Kennewick Bridge

Along with many notable highway bridges disk bearings have also been utilized on many concrete transit structures such as Seattle’s Sound Transit (Fig. 5), Atlanta’s MARTA (Fig. 6).Miami Dade’s Orange Line (Fig. 7) and Long Island Railroad’s Atlantic Avenue Viaduct (Fig. 8).

Fig. 5 Seattle's Sound Transit

Fig. 6 Atlanta's MARTA over I-85

Fig. 7 Miami Dade Orange line

Fig. 8 LIRR Atlantic Avenue Viaduct

DISK BEARING DESIGN

The disk bearings for the Dulles project ranged in vertical capacity from 115 to 610 kips. Rotations of up to 0.02 radians and displacements of up to 6.5 inches were required. Comparable elastomeric bearings for the high end of these loads and movement were over 2 feet square and up to 13 inches high which were deemed impractical. Horizontal loads were high due to the breaking force of the trains. The horizontal load on a disk bearing is transmitted to the substructure through a shear resisting mechanism (SRM) which is a high strength alloy steel pin that is machined to allow rotation but minimizes shear to the polyether urethane rotational element. The SRM feeds down through the lower bearing plate where it transmits loads to the substructure. For the Dulles project the SRM was sized to accommodate the high horizontal loads.

The anchoring detail of the bearings for the Dulles project was somewhat unique. Working closely with Corven Engineering out of Tallahassee the bearing manufacturer came up with a novel concept. The substructure anchor plate utilized conventional shear studs but the superstructure connection was a single pin design that didn't interfere with the complex concrete segment reinforcement (Fig. 9). The upper bearing plate and anchor pin were connected to the segment through a cast in place plinth. This eliminated complex detailing around the segment reinforcing and post-tensioning hardware.

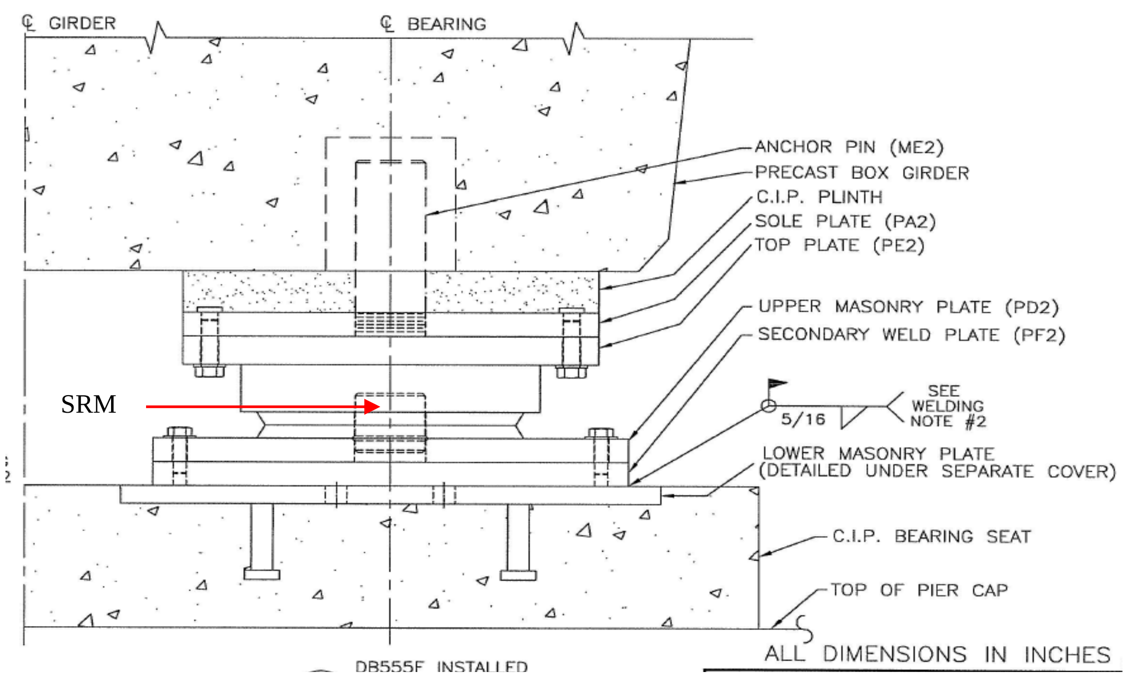

Fig. 9 Bearing Connection Details

In addition to the 1254 disk bearings that were supplied on the Dulles project 40 spherical bearings with vertical load capacities of up to 960 kips and rotations of up to 0.055 radians were manufactured for spans greater than 140 feet. This was a standard requirement for WMATA structures.

Another mandatory feature on the disk bearings for the Dulles project was a design that allowed for ease of replacement should that ever become necessary. A common detail that was used features bolted accessible connections to the upper sole and lower masonry plates (Fig. 10). A provision for the jacking equipment also needed to be made at the piers and abutment. The removal procedure would be to jack the structure enough so that the dead load is relieved from the bearing device. The accessible upper and lower bolts are then drawn out which allows the bearing to be removed in one piece. This method allows the bearing to be removed with a minimal amount of jacking and labor.

Fig. 10 Disk bearing with replaceability detail

DISK BEARING MANUFACTURING

The manufacturing specification for the bearings on the Dulles project required that the manufacturer have 10 years experience in high load multirotational bearings and be certified by AISC. The bearing details minimized welding predominantly utilizing bolted connections. Inspection of the manufacturing process was provided by Bechtel engineers.

All exposed steel surfaces were coated with a paint system in accordance with the contract documents. Partial disassembly of the bearings was required prior to the painting process in order to achieve proper part coverage.

DISK BEARING TESTING

The testing specification for the bearings on the Dulles Metrorail project was rigorous with 54 production bearings being tested overall. Random samples of production bearings were tested at the manufacturers facility on a test frame with a vertical capacity of 2 million pounds (Fig. 11). The proof load test required each test bearing to be loaded to 150% of the rated vertical capacity while simultaneously being rotated 0.02 radians for one hour. The bearings were than disassembled and inspected for any signs of damage. All of the bearings tested passed the proof load test.

Fig. 11 Test frame used for the Dulles project

For expansion bearings a friction test was conducted in accordance with the AASHTO Standard Specifications for Highway Bridges Section 18.[3] This test required expansion bearings to be run through 100 cycles of displacements at design load with the friction values to be measured at the end of the testing. The testing speed is 2½ inches per minute and the friction of the last cycle has to be lower than 3%.

After the friction testing the bearings were disassembled and inspected for excessive wear. Once again all of the bearings tested for friction properties on the Dulles project passed the test.

CONCLUSIONS

Bridge bearings represent a small portion of the overall cost of the structure, however they are a vitally important component in the design. Properly functioning bearings allows for the loads, rotations and movements of the superstructure and distribute these forces to the substructure without any excessive stress or damage to these elements. The selection of disk bearings for the majority of the bridges on the Dulles Metrorail project was based on the outstanding performance history of the device on applications all over the world (Fig. 12).

Fig. 12 Disk Bearings supporting the concrete segments on the Dulles Project

The design, manufacture, testing and installation of the disk bearings on this project were conducted in a streamlined manner that resulted in minimal delays and kept the construction team on schedule for this landmark project.

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