ISOLATION BEARINGS FOR ARCH BRIDGE, MUMBAI COASTAL ROAD PROJECT

A. Santanu Majumdar
Mageba Bridge Products Pvt. Ltd.
Kolkata, India

B. Santanu Adhikary
Mageba Bridge Products Pvt. Ltd.
Kolkata, India

INTRODUCTION

The navigational span arch bridge of Mumbai Coastal Road Project (South), Package 2 consists of two steel arches, Left Hand Side (LHS) and Right Hand Side (RHS) arches, with largest length of 136 m. The arch bridges were designed with the assumption of using elastomeric bearings as the supports. Each arch is designed to be supported at 4 locations over elastomeric bearings. In most of the other spans of this project (both package 1 and package 2) considerably large elastomeric bearings (up to 1050 x 1050 x 298 mm) have been used, which might have prompted the designer to envisage elastomeric bearings for this span as well. The supports are required to be flexible supports so that the horizontal force transferred to the substructures are limited to certain values in different conditions. The challenge to provide the support system was not limited to addressing the gravity load of about 33,000 kN in ultimate limit state and accommodating static displacements and rotations of the bridge supports, but extends to the dynamic behavior of the bridges during seismic actions.

STRUCTURAL AND FUNCTIONAL REQUIREMENT OF THE SUPPORT SYSTEM

STRUCTURAL REQUIREMENT

The project specification specified 8 numbers of bearings, 4 under each arch. Each bearing was to carry a ultimate vertical load of about 33,000 kN. A rotation of 0.01 radian was to be allowed on each bearing. A longitudinal movement of ±209 mm (in extreme event) and transverse movement of ±155 mm (in extreme event) were to be allowed.

FUNCTIONAL REQUIREMENT

The two arches were designed with flexible bearings at the supports to reduce the seismic

Fig. 1: Artist's impression of the Arch bridges

Fig. 2: Arch bridges, MCRP

horizontal forces to be transferred to the substructures. They were designed considering elastomeric bearings at the supports. According to the project requirement, the bearings system should provide the following functional solutions:

1. Providing adequate lateral flexibility under gravity load to achieve the reduced force response
2. The bearings should have the horizontal stiffness values as close as to the design values
3. To restore the structure back nearly to its original position after events like an earthquake

CHALLENGES

HIGH LOAD AND LIMITED SPACE

The main challenge was to provide an elastomeric bearing which will cater for such a huge gravity load and that should be accommodated in the limited space over the towers.

ALLOWING HIGH ROTATION

The next challenge was to provide an elastomeric bearings which would allow a rotation of about 0.01 radian. The plan dimensions of the elastomeric bearings was becoming high thereby increasing the rotational stiffness. To reduce the rotational stiffness, the height of the bearings was becoming prohibitively high.

MANUFACTURING AND QUALITY CONTROL OF ELASTOMERIC BEARINGS OF HUGE SIZE

The size of the elastomeric bearings designed for this huge load, displacements and rotation, was coming out to be prohibitively large to be feasible to be manufactured in controllable quality.

SOLUTIONS

INTRODUCTION OF ERADIQUAKE® ISOLATION BEARING SYSTEM

All possible solutions of modern base isolation techniques were evaluated to define the support system of the bridges and finally a specially designed EradiQuake® Bearing system was adopted. EradiQuake® is a custom designed isolation bearing composed of a Disc Bearing

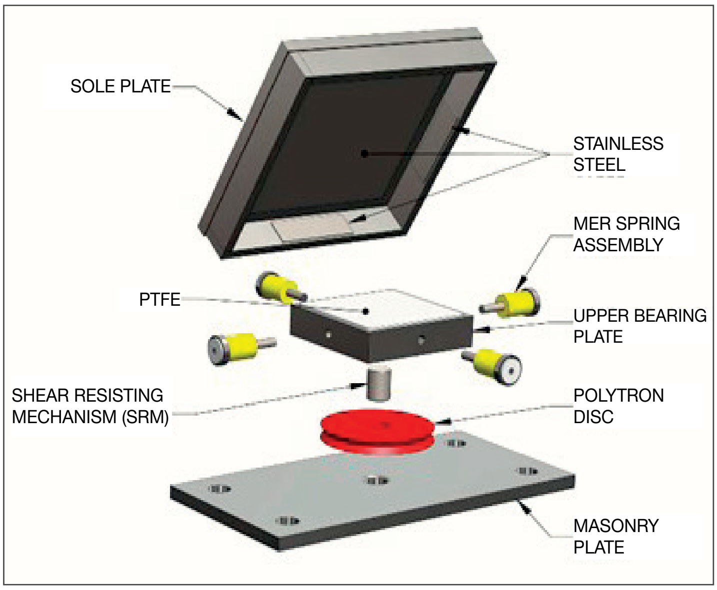

Fig. 3: Assembled Eradiquake® bearing

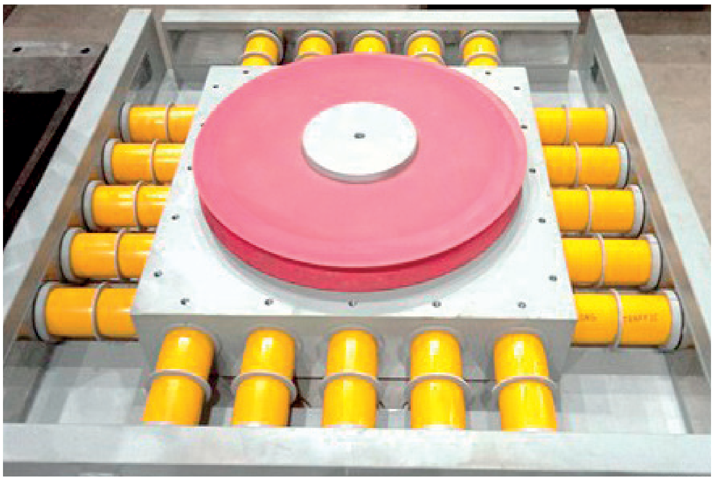

Fig. 4: Different parts of Eradiqauke® bearing

and MER springs, which offers all the standard requirements of an Isolation system.

EradiQuake® System (EQS) is a state of the art Isolation Bearing System designed to minimize forces and displacements experienced by structures during an earthquake. This isolation bearing, originally developed by R.J.Watson Inc., USA, is also recognized in AASHTO Guide Specification for Isolation Design. In addition to providing isolation to the structure, the EQS transfers the energy of a moving mass (kinetic energy), such as a bridge superstructure during an earthquake, into heat and spring (potential) energy. This is done via:

- Friction between Teflon/stainless interface
- Compression of the MER

The Seismic Properties of the proposed Eradiquake® bearings are as follows:

Table 1								
EQS	P,max (ULS)	Kd (kN/mm)	Kd (kN/mm)	disp (mm)	disp (mm)	disp (mm)	Keff (kN/mm)	EDC (kN-mm)
Model	(kN)	Long.	Trans	Long. (ULS)	Trans. (ULS)	Seismic	Seismic	Seismic
EQS23600 (LHS)	33,128	12.9	12.9	209	111	105	14.95	99,200
EQS17900 (RHS)	25,121	9.2	9.2	207	188	105	11.76	112,800

NOMENCLATURE	
P,max (ULS)	Maximum vertical load per bearing in ultimate limit state
Kd	Post Elastic Stiffness, Spring Rate
disp	Displacement Across Isolation Bearing
Keff	Declared effective stiffness at seismic displacement
EDC	Declared Energy Dissipated per Cycle at seismic displacement

PROVIDING FLEXIBLE SUPPORT TO THE STRUCTURE WITHIN THE LIMITED SPACE

The introduction of Eradiquake® bearings achieved the purpose of providing flexible support below the arches. The desired horizontal flexibility could be achieved by the MER springs. The dimension of the bearings could be kept within the limited space with the help of Polyurethane disc which has much higher load capacity.

ADEQUATE ROTATIONAL CAPACITY

The optimum rotational stiffness of the Polyurethane rotational disc provided the desired rotational capacity of the bearings.

DISSIPATION OF ENERGY DURING SEISMIC EVENT

The added achievement was the transfer of seismic energy by frictional dissipation between Teflon / stainless interface and spring (potential) energy by compression of MER springs which would reduce the actual movement of the structure during seismic event.

RESTORING THE STRUCTURE AFTER SEISMIC EVENT

The restoration of structure to its nearly initial position could be achieved by the release of spring (potential) energy of the MER springs in both longitudinal and transverse directions.

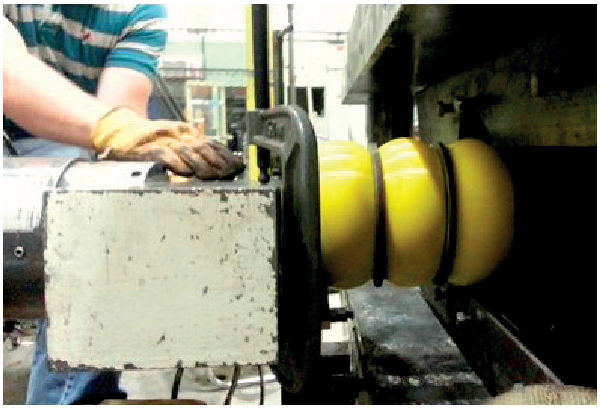

Fig. 5: MER springs in compressed position

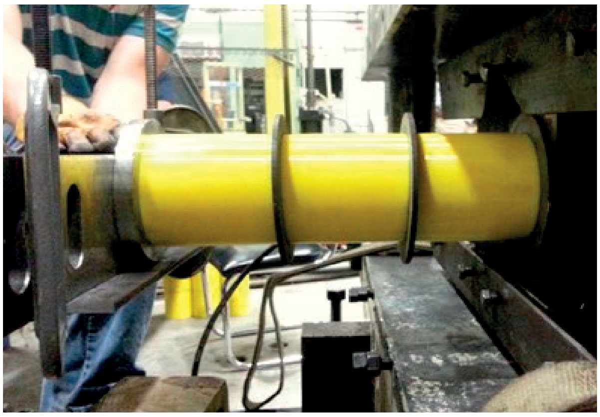

Fig. 6: MER springs in relaxed position

ADDITIONAL FEATURES

The bearings have been equipped with following additional features for enhanced life and performance:

- ROBO®SLIDE has been used as the sliding material. This is a special sliding material made of modified, ultra-high molecular polyethylene with reduced abrasion resistance and increased bearing capacity. It ensures high durability and service life contributing in low life cycle cost.

- No material prone to ageing has been used ensuring high durability/ service life contributing in low life cycle cost. The Polyether urethane rotational disc has excellent weathering properties when subjected to prolong exposure to seawater, fresh water, ozone and other deleterious chemicals.
- The urethane disc remains flexible within a wide range of temperature (-70°C to 121°C). Therefore, under normal atmospheric conditions there is no problem with the rotational element softening or crystallizing during temperature extremes.
- Simple and same connection detail for all bearing providing ease of installation.

ADVANTAGES OF ERADIQUAKE® BEARINGS

Some of the advantages of Eradiquake® isolation bearings over the other isolation bearings are mentioned below:

- A completely secured and fail-safe system compared to elastomeric isolators for high load application as there will be no reduction of loaded area due to horizontal displacement.
- Can be designed for different stiffness in longitudinal and transverse directions which gives higher design and optimization flexibility. This is not possible with Elastomeric Isolators or Friction Pendulum.
- Much higher life expectancy as there is no material prone to ageing.
- Unlike Friction Pendulum Bearings, there is no vertical displacement due to horizontal movement.

TESTING ON BEARINGS

The following tests were conducted on the actual bearings to evaluate the designed behavior of the bearings:

- Proof Load Test (AASHTO GSFSID 17.2.1)
- Combined Compression and Shear Test (AASHTO GSFSID 17.2.2).

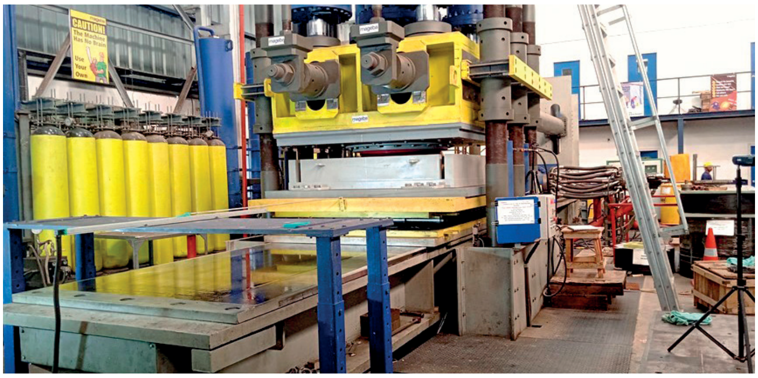

Fig. 7: Bearing testing in Dynamic Testing Machine

Fig. 8: Bearing testing

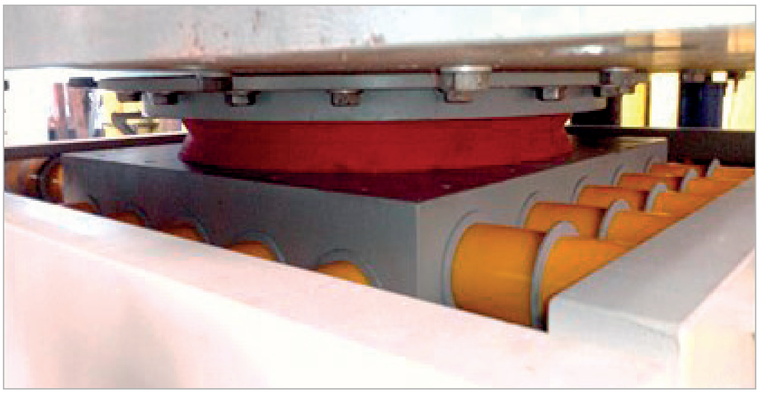

Fig. 9: Bearing testing

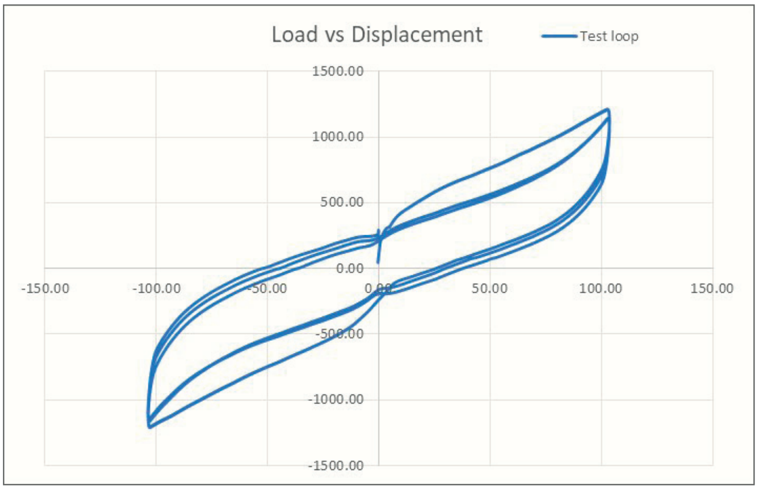

Fig. 10: Force-displacement diagram of EQS17900 (RHS) - test for seismic movement

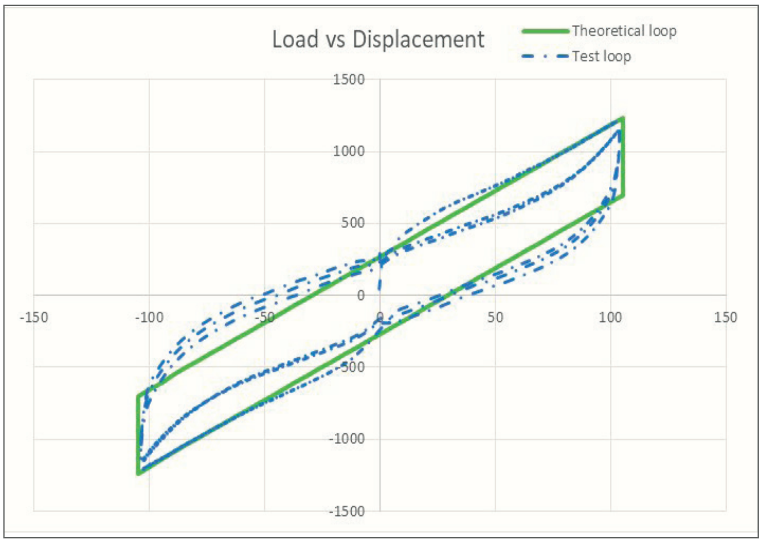

Fig. 11: Force-displacement diagram of EQS17900 (RHS) – comparison with theoretical loop

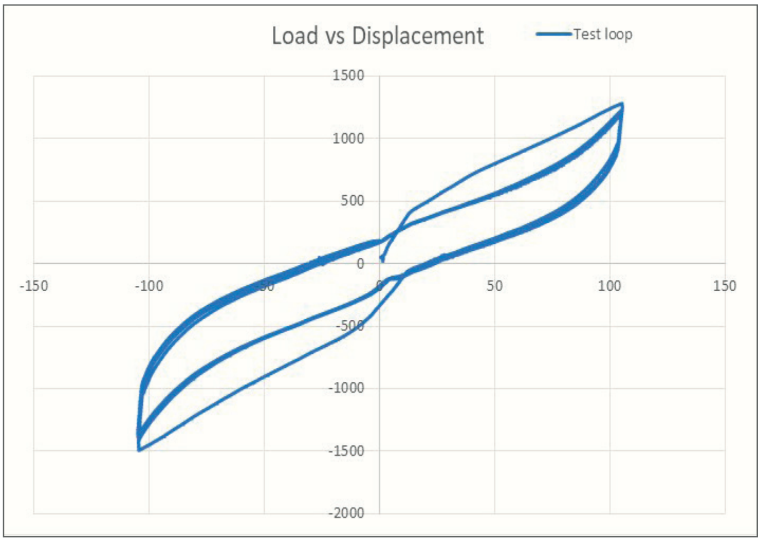

Fig. 12: Force-displacement diagram of EQS23600 (LHS) – test for seismic movement

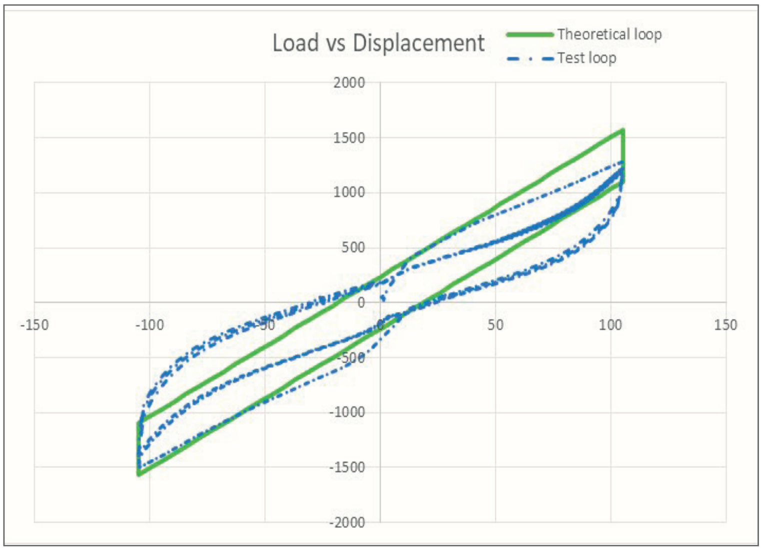

Fig. 13: Force-displacement diagram of EQS23600 (LHS) – comparison with theoretical loop

The comparison of test properties with respect to the design properties are shown in the table below:

Table 2				
Bearing	Keff, design (kN/mm)	EDC, design (kN-mm)	Keff, test (kN/mm)	EDC, test (kN-mm)
EQS17900 (RHS)	11.76	112,800	11.41	107,960
EQS23600 (LHS)	14.95	99,200	12.72	98,870

INSTALLATION

The bearings were supplied with bottom anchor plates with shear studs welded on the bottom anchor plates. The bottom anchor plates were installed over the pedestal and the pedestals were cast. The main bearings were placed over the already installed anchor plates. The bolts were then fastened with the threaded holes present in the anchor plates.

Fig. 14: Installed bearings

CONCLUSION

Specially designed EradiQuake® Isolation bearings used in this project are not only the larger of their kind but also are equipped with many unique features required to meet the unprecedented structural demands. This system not only provided the requisite isolation to the arch bridges by reducing seismic lateral force to the desired level and dissipating seismic energy, but is also well equipped to give requisite degrees of freedom including high rotation demand. The bearing system also addressed the limitation of space issue. Hence, it can be concluded that the specially designed Eradiquake® seismic isolation system provided to this project meet all the complex demands of this special structure.

Due to the isolation requirements, it was necessary to incorporate large modular expansion joints capable of accommodating substantial movement in both the longitudinal and transverse directions. This requirement has been effectively met by implementing mageba TENSA®MODULAR joints.

Fig. 15: Reference pictures

REFERENCES

1. AASHTO 2010 Guide Specifications for Seismic Isolation Design
2. Eradiquake® Product Brochure, RJ Watson INC.