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Isolation bearings for atmosphere project, Kolkata

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ABSTRACT: Atmosphere, a new age icon which adorns the skyline of Kolkata is a building project conceived to cater to the high life of its residents. Two 150m tall towers connected by a sky bridge are presently under construction. The most striking portion of the building is the sky bridge, 'Deya'. 'Deya' is a four storied structure connecting the towers from 32nd level onwards. This sky bridge rests on the cleverly conceived and designed EradiQuake® Isolation bearings. The static and dynamic actions and effects to be considered for the design and manufacturing of these bearings were complex. The genius of the bearings lies in its astute design and manufacturing which addresses these issues. This paper gives an account of the unique support system, its conception, design, testing and installation. Special emphasis has been laid on the features that make these bearings truly one of a kind.

1 INTRODUCTION

In 2011, a unique requirement arose that required the ambitious sky bridge to be rested on an adequate support system. 'Deya', the sky bridge is subjected to mammoth loading conditions requiring the support system to be robust. Although Kolkata is classified under zone 3 as per seismic zoning in India and is not likely to be threatened by massive earthquakes, tremors following the 2015 Nepal Earthquake were felt strongly all over the city. Such unforeseen seismic events could cause serious damage to the towers and as well as 'Deya'.

In summary, the supporting bearings had to accommodate both high static loads and dynamic actions while the bridge hangs at a height of 120m above ground level.

Figure 1. Artist's impression of Deya, Atmosphere

Figure 2. Artist's impression of Atmosphere

2 STRUCTURAL AND FUNCTIONAL REQUIREMENT OF THE SUPPORT SYSTEM

2.1 *Structural Requirement*

Four bearings, two on each tower are required to carry the sky bridge spanning a distance of 50m. The bridge houses multi-gym facility, spa, swimming pool, party deck, conference room, movie theatre, squash room and also a virtual golf course on the roof. So, it is a given that the gravity loads are high- in this case, 12000 Tons in all. Apart from the gravity loads, the bearings are required to transfer high horizontal forces from wind, seismic forces etc. The design load data is as shown in the Table 1.

Table 1. Design Parameters

Parameter (for each bearing)	Value	Units
Design Vertical Load in SLS	36,000	kN
Wind load in lateral direction	1,800	kN
Horizontal seismic force in longitudinal direction	3,600	kN
Rotation	0.02	radian
Movement in lateral direction (reversible)	250	mm
Movement in longitudinal direction (reversible)	200	mm

2.2 *Functional Requirement*

The two towers were not designed for the seismic longitudinal horizontal force of 3,600 kN on each bearing. They were designed for horizontal force of 1,800 kN in wind condition in the lateral direction. Hence, the support bearings, that were to be provided, were to bring down the seismic horizontal force to the level of wind horizontal force. The functionalities of the bearings apart from providing adequate support are:

i. Adequate lateral flexibility under gravity load.
ii. To dissipate energy in case of a seismic event.
iii. To restore the structure nearly to its original position after any earthquake.

3 CHALLENGES

The main challenges of proposing an adequate supporting system was manifold. The support system had to address critical concerns such as:

i. Providing a bearing system which would cater for such huge gravity load and be accommodated in the limited space over the towers.
ii. Providing a system that would reduce the lateral seismic forces to the level of wind.
iii. Providing a bearing system which was to adequately dissipate the energy produced during earthquakes.
iv. Restoring the bridge nearly to its original position after any seismic event, both in longitudinal and transverse direction.
v. To have a wind force restraining system in place which would not allow the large horizontal wind forces to trigger the isolation system for as this could lead to serviceability concerns.
vi. ‘Deya’, is supported on two different tall towers with different mass and stiffness distribution, and therefore out of mode relative displacements of the towers cannot be overlooked, which will cause rotation of the isolation support system in plan, i.e., about vertical axis.

4 SOLUTIONS

To accommodate the high static loads and its effects, a robust solution had to be in place. However, it was imperative to have a solution which would reduce the earthquake horizontal force to the wind force level for which the towers are designed. Therefore, a base isolation system was proposed. When base isolation systems are considered, popular solutions such as Elastomeric Isolators (Lead Rubber bearing and High damping rubber bearings) and Friction Pendulum bearings were a natural choice. However, these solutions were not viable because:

i. In case of elastomeric isolators, transferring design vertical loads as high as 36000 kN with horizontal movement of ±250mm simultaneously was a tall order to achieve.
ii. In case of Friction pendulum bearings, albeit a good plausible solution, the lack of space was the determining factor.

Hence, EradiQuake® Isolation systems were proposed. However, the 'Deya' would not rest on the simpler version of this Isolation system. These special bearings came with unique features which would overcome all the challenges listed above.

4.1 *EradiQuake® Isolation Bearing System*

EradiQuake® is a custom designed isolation bearing composed of a Disk Bearing and MER springs, which offers all the standard requirements of an Isolation system.

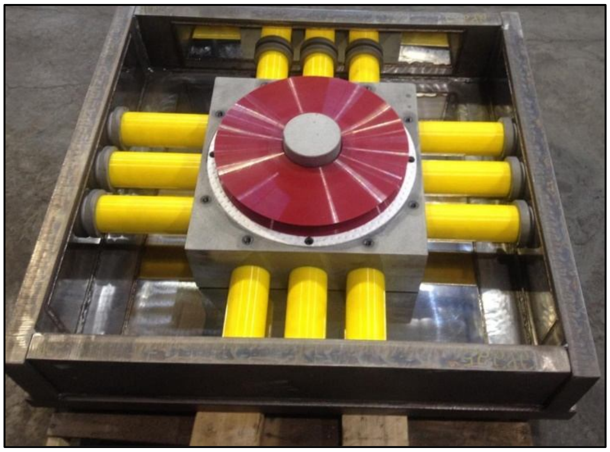

Figure 3. Assembled EradiQuake® bearing

Figure 4. Different parts of Eradiqauke® bearing

EradiQuake® System (EQS) is a state of the art Isolation Bearing System designed to minimize forces and displacements experienced by structures during an earthquake. 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. They also provide sufficient damping during a seismic event. These bearings essentially consist of:

i. Disc bearing: To transfer vertical load, horizontal force and to allow movement / rotation
ii. MER Springs: To convert the kinetic energy generated by the moving structure during seismic event into potential energy by compression of the springs
iii. PTFE/Stainless steel interface: To convert the kinetic energy generated by the moving structure during seismic event into heat energy respectively.

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

Table 2. Seismic Properties of the bearing

EQS	Avg DL	Avg Qd	Kd (kN/mm)	Kd (kN/mm)	Disp (mm)	Disp (mm)	Keff (kN/mm)	Keff (kN/mm)	F (kN)	F (kN)	DR	DR
Model	(kN)	(kN)	Long.	Trans	Long.	Trans	Long.	Trans	Long.	Trans	Long.	Trans
EQS3600(SI)	30000	450	6.8	5.4	200	250	9.0	7.2	1800	1800	0.16	0.16

Nomenclature

DL	Dead Load per bearing
Qd	Characteristic Strength, Friction Force
Kd	Post Elastic Stiffness, Spring Rate
disp	Estimated Seismic Displacement across Isolation Bearing
F	Peak Force
Keff	Effective Stiffness
DR	Equivalent Viscous Damping Ratio

4.2 *Special Features of the EradiQuake® Isolation System at 'Deya'*

4.2.1 *Reduction of seismic forces*

The proposed EradiQuake® bearings reduced the seismic lateral force which were twice the level of wind load to the same level. With this, the seismic lateral force could be brought down to the safe level at which the towers have been designed.

4.2.2 *Dissipation of energy during seismic event*

The transfer of seismic energy could be achieved by frictional dissipation between PTFE- stainless steel interface and spring (potential) energy by compression of MER springs.

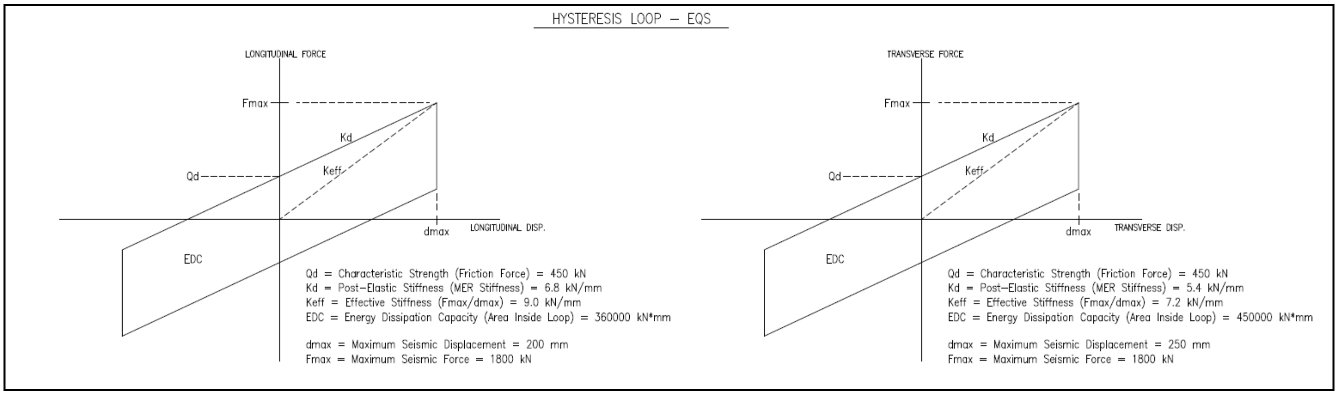

Figure 5. Hysteresis Loop - EQS

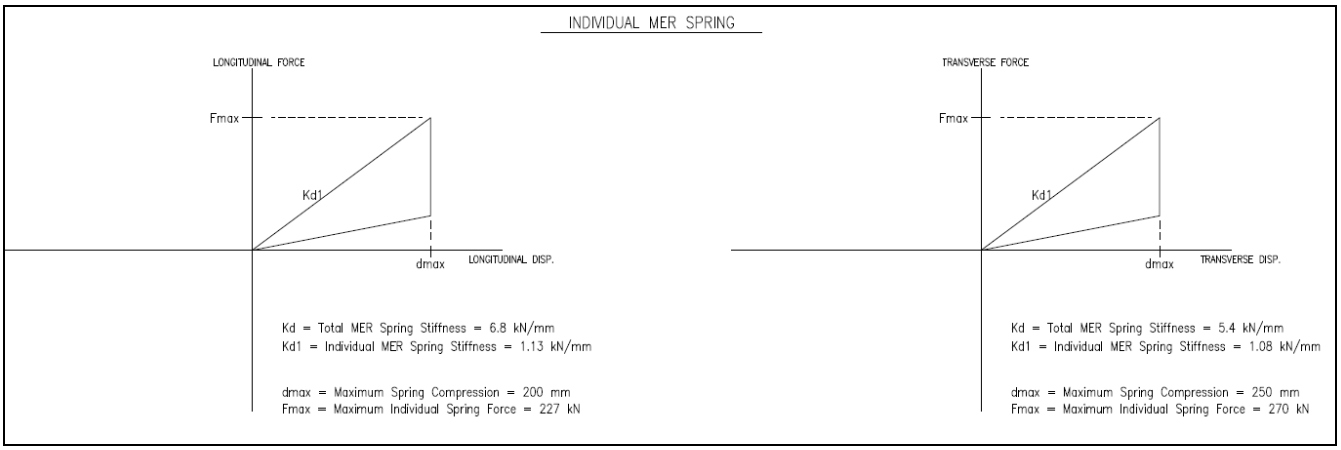

Figure 6. Individual MER springs

From the above diagrams and Table 2, it can be seen that the Energy Dissipation capacity of 360000 kN-mm and an equivalent viscous damping of 16% could be achieved by introducing this bearing system.

4.2.3 *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.

4.2.4 *Introduction of wind restraint fuses*

It is important that the isolation system is triggered only in case of a seismic event and not otherwise in the transverse direction. To this effect, the bearings were provided with adequate wind restraining systems or wind fuses in the transverse direction. If adequate restraint is not provided, then, the displacement in the bearings due to wind load can cause serviceability concerns. The Wind Restraints behave like fuses that break at horizontal forces of the order 1500 kN (force confirmed by Wind Tunnel Test) so that the bearings behave like perfect isolation bearings in any seismic event in the transverse direction also.

Figure 7. MER springs in compressed position

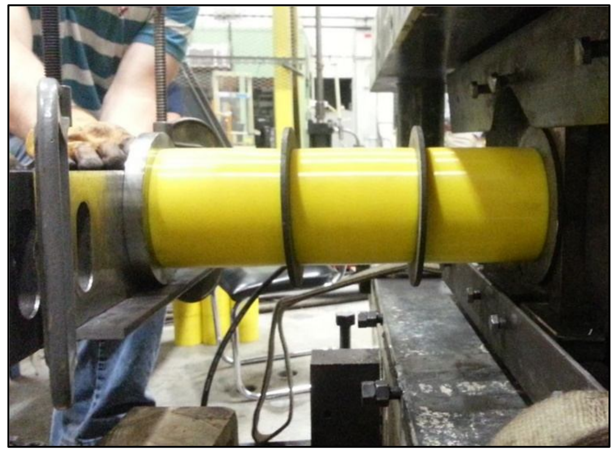

Figure 8. MER springs in relaxed position

Figure 9. Wind Restraints

Figure 10. Wind restrained installed in bearing

4.2.5 *Additional sliding surface to cater for rotation about vertical axis*

Additional sliding surface was provided over the rotational disc element to cater for a rotation of 0.02 radian about the vertical axis due to out of mode relative displacements of the two towers.

5 TESTING ON PROTOTYPE BEARING, ACTUAL BEARINGS AND ACTUAL MER SPRINGS

Upon manufacturing of the bearings, it was found that each bearing was mammoth sized. Finding a rig large enough to accommodate the bearing was a challenge in itself. To counter this problem, scaled down prototype bearings were manufactured and the following tests were conducted.

5.1 *Tests on Prototype Bearing*

Prototype tests are in accordance with AASHTO 2010 Guide Specifications for Seismic Isolation Design, Section 13.2.

i. One scaled prototype bearing was tested under vertical load equal to 1/8th of the dead load.
ii. Test displacements was ½ of the production bearing design displacement.

5.2 *Quality Control Tests*

i. Proof Load Test (AASHTO GSFSID 17.2.1)
ii. All bearings were proof load tested to 100% design capacity, due to force capacity of test equipment.
iii. Combined Compression and Shear Test (Qd) (AASHTO GSFSID 17.2.2) were conducted on all bearings.

5.3 *Stiffness Verification on Production MER Springs (Kd)*

i. A quantity of 9 (10%) of MER Springs were individually tested for design seismic displacement.
ii. Friction and MER spring data were combined for evaluation per AASHTO GSFSID 17.2.3.

5.4 *Wind Restraint System*

i. Restraint pin diameter adequacy testing: Single restraint pin was tested with various machined diameters to determine proper diameter to be used for production bearings.
ii. Single restraint pin was tested up to test equipment force capacity for breaking force testing. Once an acceptable restraint pin diameter was found, multiple pins were tested to failure up to a quantity of 5 simultaneously. If results of 5 combined restraint pins are not within tolerance, the pin diameter was to be further refined.
iii. Extrapolated restraint force capacity plus the Static Coefficient of Friction from combined compression and shear test was found to be within 10% of 1500 kN, i.e., the desired Breaking force.

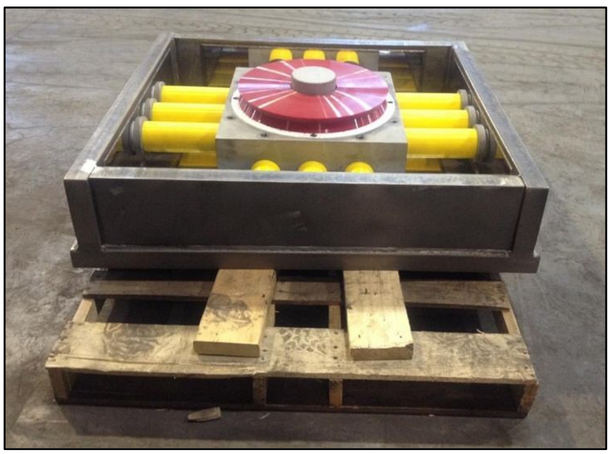

Figure 11. Prototype bearing

Figure 12. Tested Prototype bearing

6 LOGISTICS

The size of the bearing remained a challenge even while transporting the bearings. To illustrate, the size of the bearings were found to be larger than the container itself. Therefore, the bearings were shipped on flat rack containers instead of standard containers.

7 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. Pressure grouting were carried out through the vent holes present in the bottom anchor plates to ensure proper levelling of the anchor plates. The main bearings were then lifted from ground to the bridge level and placed over the already installed anchor plates. The bolts were then fastened with the threaded holes present in the anchor plates.

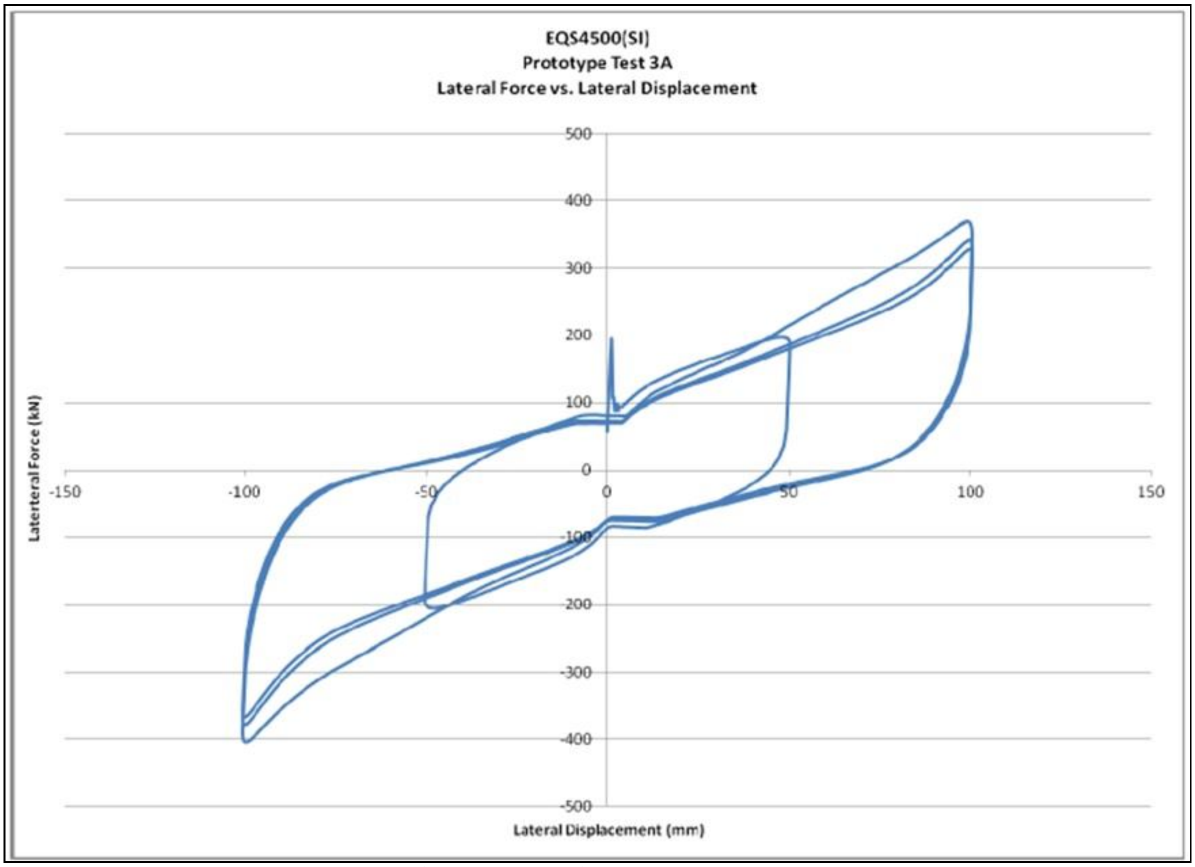

Figure 13. Force-displacement diagram of prototype test for longitudinal seismic movement

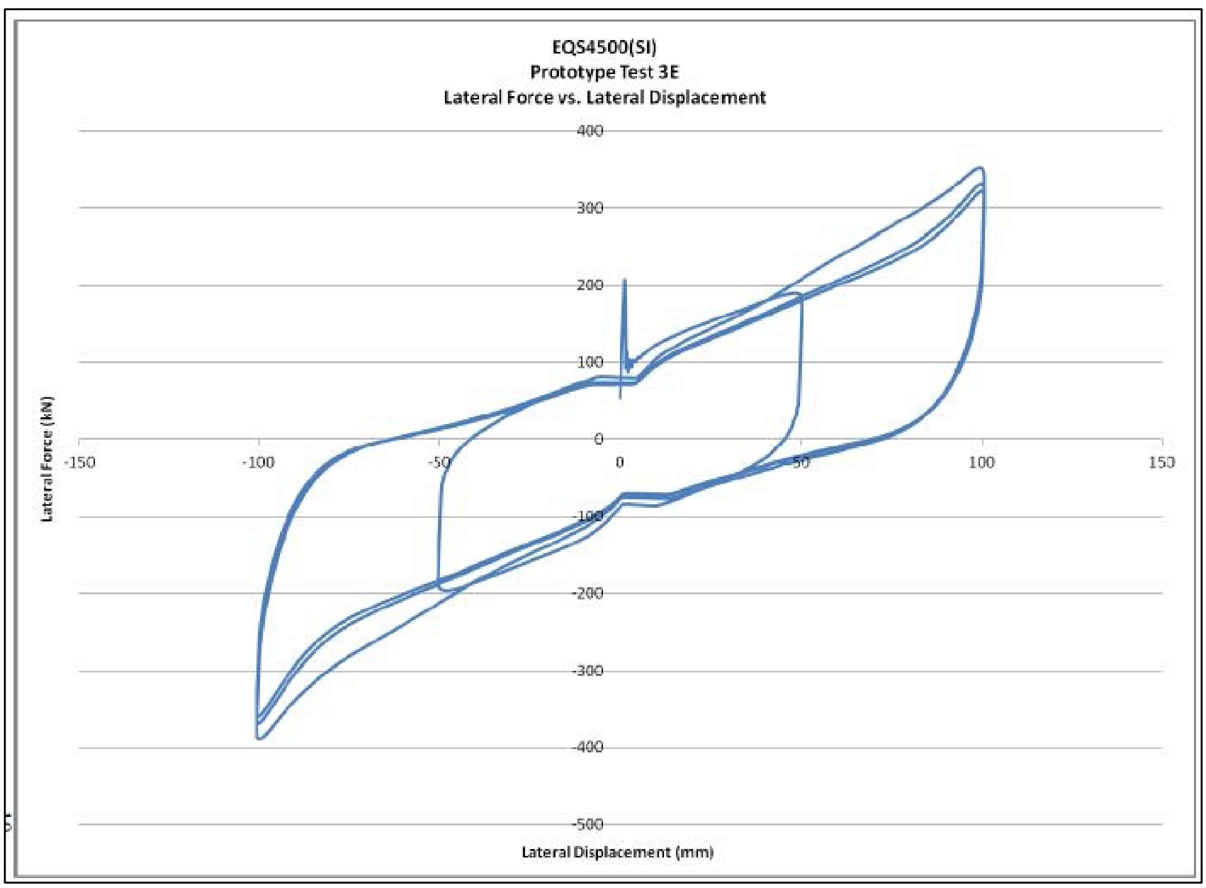

Figure 14. Force-displacement diagram of prototype test for transverse seismic movement

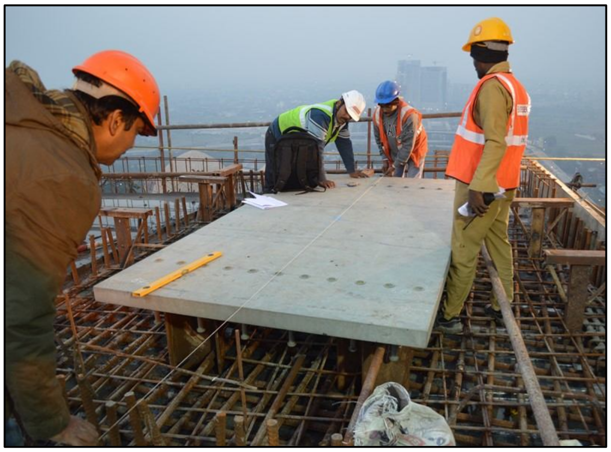

Figure 15. Placement of anchor plate

Figure 16. Pressure grouting below anchor plate

Figure 17. Lifting of bearing of approx. wt. 15T

Figure 18. Placement of bearing over anchor plate

8 CONCLUSIONS

Specially designed EradiQuake® Isolation bearings used in this project are the largest of their kind. They are equipped with the unique features required to meet the unprecedented structural demands. This system provides the required isolation and energy dissipation and accommodates required degree of freedom. This bearing system simultaneously addresses the serviceability issue as well and also deals with the space constraint effectively. Hence, it can be concluded that these specially designed, one of a kind EradiQuake® seismic isolation system provided to this project successfully meets all the complex demands of this special structure and is a milestone in its own right in the field of 'earthquake engineering'

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