Howrah Bridge: A Milestone In Civil Engineering

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Abstract- *The Howrah Bridge has been serving the city of joy, Kolkata (previously known as Calcutta) by allowing the city to be well connected with the rest of the state and indeed the rest of the country since its inception to its formal inauguration in 1943. The bridge by itself is a marvel of Bridge Engineering and a milestone in probably all the fields of Civil Engineering- Structural, Geotechnical, & Transportation Engineering, all to serve the one purpose of improving communication and traffic conditions due to daily movement. The main purpose cum outcome of this research is to make a review of this extraordinary balanced-cantilever bridge, mainly from strict technical points of views and also from the social and economic factors that arise out of it. The structural configurations, foundation characteristics, construction techniques and maintenance issues have been extensively discussed. Relevant statistical facts relating to traffic volume on the bridge and related illustrations have been provided as and when required to verify some of the facts that has been discussed.*

Keywords- Balanced-Cantilever, Bridge Engineering, Construction Techniques, Foundations, Structural Configurations, Traffic Volume

I. INTRODUCTION

Howrah Bridge is a bridge with a suspended span over the Hooghly River in West Bengal, India. Commissioned in 1943, the bridge was originally named the New Howrah Bridge, because it replaced a pontoon bridge at the same location linking the two cities of Howrah and Kolkata (Calcutta). On 14 June 1965 it was renamed Rabindra Setu after the great Bengali poet Rabindranath Tagore, who was the first Indian and Asian Nobel laureate. It is still popularly known as the Howrah Bridge.

The bridge is one of four on the Hooghly River and is a famous symbol of Kolkata and West Bengal. The other bridges are the Vidyasagar Setu (popularly called the Second Hooghly Bridge), the Vivekananda Setu, and the newly built Nivedita Setu. It weathers the storms of the Bay of Bengal region, carrying a daily traffic of approximately 1,00,000 vehicles and possibly more than 1,50,000 pedestrians, easily making it the busiest cantilever bridge in the world. The third longest cantilever bridge at the time of its construction, the Howrah Bridge is currently the sixth longest bridge of its type in the world.

Table 1: Salient features of Howrah Bridge

General	
Coordinates	22.5851 °N & 88.3469 °E
Carries	4 lanes of Strand Road, pedestrians, & other vehicles
Crosses	Hooghly River
Locale	Howrah & Kolkata
Official Name	Rabindra Setu
Maintained by	Kolkata Port Trust
Characteristics	
Design	Suspension type Balanced-Cantilever type with Truss Arch
Material	Steel
Total length	705 m
Width	21.6 m with two footpaths of 4.6 m on either side
Height	82 m
Longest span	457.2 m
Clearance above	5.8 m
Clearance below	8.8 m
History	
Designer	M/s. Rendel, Palmer & Tritton
Constructed by	The Braithwaite, Burn & Jessop Construction
Construction start	1936
Construction end	1942
Opened	3rd February, 1943
Statistics	
Daily traffic	3,00,000 vehicles & 4,50,000 pedestrians
Toll	Toll Free on both ways

II. HISTORY

1862 proposal by Turnbull

In 1862, the Government of Bengal asked George Turnbull, the then Chief Engineer of the East Indian Railway Company to study the feasibility of bridging the Hooghly River. He had recently established the company's rail terminus in Howrah. He reported on 19 March, with large scale drawings and estimates, that

1. The foundations for a bridge at Calcutta would be at a considerable depth and cost because of the depth of the mud there.
2. The impediment to shipping would be considerable.
3. A good place for the bridge was at Pulta Ghat "about a dozen miles north of Calcutta" where a "bed of stiff clay existed at no great depth under the river bed".
4. A suspended-girder bridge of five spans of 401 feet (122 m) and two spans of 200 feet (61 m) would be ideal.

Pontoon Bridge

Fig. 1: Sir Bradford's Pontoon Bridge

In view of the increasing traffic across the Hooghly River, a committee was appointed in 1855-56 to review alternatives for constructing a bridge across it. The plan was shelved in 1859- 60, to be revived in 1868, when it was decided that a bridge should be constructed and a newly appointed trust vested to manage it. The Calcutta Port Trust was founded in 1870, and the Legislative department of the then Government of Bengal passed the Howrah Bridge Act in the year 1871 under the Bengal Act IX of 1871, empowering the lieutenant-governor to have the bridge constructed with Government capital under the aegis of the Port Commissioners. Eventually a contract was signed with Sir Bradford Leslie to construct a pontoon bridge. Different parts were constructed in England and shipped to Calcutta, where they were assembled. The assembling period was fraught with problems. The bridge was considerably damaged by the great cyclone on 20 March 1874. A steamer named *Egeria* broke from her moorings and underwent a head on collision with the bridge, sinking three pontoons and damaging nearly 200 ft. of the bridge. The bridge was completed in 1874, at a total cost of Rs. 2.2 million, and opened to traffic on 17 October of that year. The bridge was then 1528 ft. long and 62 ft. wide, with 7 ft. wide pavements on either side. Initially the bridge was periodically unfastened to allow steamers and other marine vehicles to pass through. Before 1906, the bridge used to be undone for the passage of vessels during daytime only. Since June of that year, it started opening at night for all vessels except ocean steamers, which were required to pass through during daytime. From 19 August 1879, the bridge was illuminated by electric lamp-posts, powered by the dynamo at the Mullick Ghat Pumping Station. As the bridge could not handle the rapidly increasing load, the Port Commissioners started planning in 1905 for a new improved bridge.

Plans for a new Bridge

In 1906 the Port Commission appointed a committee headed by R.S. Highet, Chief Engineer, East Indian Railway and W.B. MacCabe, Chief Engineer, Calcutta Corporation. The committee considered six options:

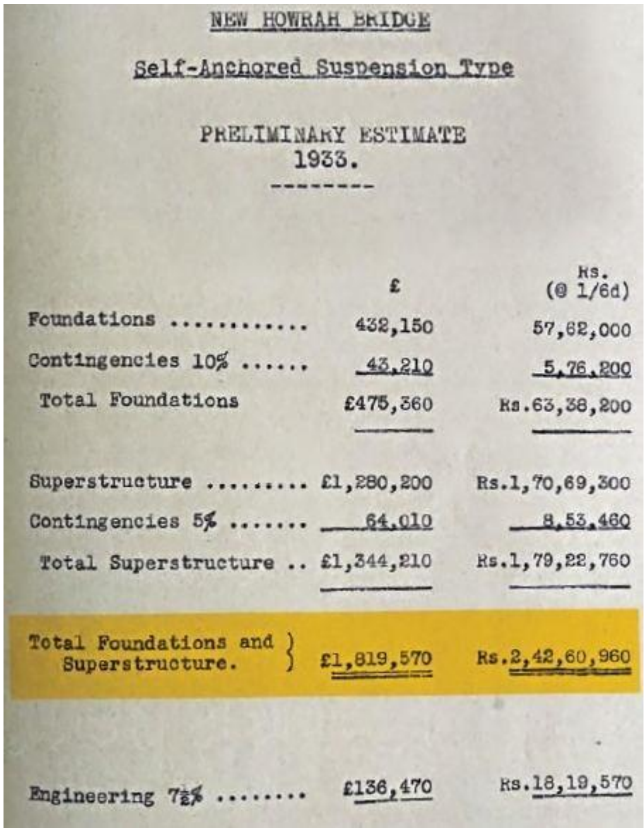
1. Large ferry steamers capable of carrying vehicular load (set up cost Rs. 9,00,000 & annual cost Rs. 4,38,000)
2. A transporters bridge (set up cost Rs. 2 million)
3. A tunnel (set up cost Rs. 338.2 million & annual maintenance cost Rs. 17,79,000)
4. A bridge on piers (set up cost Rs. 22.5 million)
5. A floating bridge (set up cost Rs. 21,40,000 & annual maintenance cost Rs. 2,00,000)
6. An arched bridge

The committee eventually decided on a floating bridge. It extended tenders to 23 firms for its design and construction.

Planning & Estimation

The initial construction process of the bridge was stalled due to the World War I, although the bridge was partially renewed in 1917 and 1927. In 1921 a committee of engineers named the 'Mukherjee Committee' was formed, headed by R. N. Mukherjee, Sir Clement Hindley, Chairman of Calcutta Port Trust and J. McGlashan, Chief Engineer. They referred the matter to Sir Basil Mott, who proposed a single span arch bridge.

In 1922 the New Howrah Bridge Commission was set up, to which the Mukherjee Committee submitted its report. In 1926 the New Howrah Bridge Act passed. In 1930 the Goode Committee was formed, comprising S.W. Goode as president, S.N. Mallick, and W.H. Thompson, to investigate and report on the advisability of constructing a pier bridge between Calcutta and Howrah. Based on their recommendation, M/s. Rendel, Palmer and Tritton were asked to consider the construction of a suspension bridge of a particular design prepared by their Chief Draftsman Mr. Walton. On basis of the report, a global tender was floated. The lowest bid came from a German company, but due to increasing political tensions between Germany and Great Britain in 1935, it was not given the contract. The Braithwaite, Burn & Jessop Construction Co. was awarded the construction contract that year. The New Howrah Bridge Act was amended in 1935 to reflect this, and construction of the bridge started the next year.



NEW HOWRAH BRIDGE

Self-Anchored Suspension Type

PRELIMINARY ESTIMATE
1933.

	£	Rs. (@ 1/6d)
Foundations	432,150	57,62,000
Contingencies 10%	43,210	5,76,200
Total Foundations	£475,360	Rs.63,38,200
Superstructure	£1,280,200	Rs.1,70,69,300
Contingencies 5%	64,010	8,53,460
Total Superstructure ..	£1,344,210	Rs.1,79,22,760
Total Foundations and Superstructure.	£1,819,570	Rs.2,42,60,960
Engineering 7½%	£136,470	Rs.18,19,570

Fig. 2: The Preliminary Estimate for the New Howrah Bridge

Construction

The bridge does not have nuts and bolts, but was formed by riveting the whole structure. It consumed 26,500 tonnes of steel, out of which 23,000 tonnes of high-tensile alloy steel, known as Tiscrom, were supplied by Tata Steel. The main tower was constructed with single monolith caissons of dimensions 55.31 m x 24.8 m with 21 shafts, each 6.25 m^2. The Chief Engineer of the Port Trust, Mr. J. McGlashan, wanted to replace the pontoon bridge, with a permanent structure, as the present bridge interfered with North/ South river traffic. Work could not be started as World War I (1914–1918) broke out. Then in 1926 a commission under the chairmanship of Sir R. N. Mukherjee recommended a suspension bridge of a particular type to be built across the River Hoogly. The bridge was designed by one Mr. Walton of M/s. Rendel, Palmer & Tritton. The order for construction and erection was placed on M/s. Cleveland Bridge & Engineering Company in 1939. Again World War II (1939–1945) intervened. All the steel that was to come from England were diverted for war effort in Europe. Out of 26,000 tonnes of steel, that was required for the bridge, only 3,000 tonnes were supplied from England. In spite of the Japanese threat, the then (British) government of India pressed on with the construction. Tata Steel was asked to supply the remaining 23,000 tonnes of high tension steel. The Tatas developed the quality of steel required for the bridge and called it Tiscom. The entire 23,000 tonnes was supplied in time. The fabrication and erection work was awarded to a local engineering firm of Howrah: The Braithwaite, Burn & Jessop Construction Company. The two anchorage caissons were each 16.4 m by 8.2 m, with two wells of area 4.9 m^2. The caissons were so designed that the working chambers within the shafts could be temporarily enclosed by steel diaphragms to allow work under compressed air if required. The caisson at Kolkata side was set at 31.41 m and that at Howrah side at 26.53 m below ground level.

One night, during the process of grabbing out the muck to enable the caisson to move, the ground below it yielded, and the entire mass plunged 2 ft., shaking the ground. The impact of this was so intense that the seismograph at Kidderpore registered it as an earthquake and a Hindu temple on the shore was destroyed, although it was subsequently rebuilt. While muck was being cleared, numerous varieties of objects were brought up, including anchors, grappling irons, cannons, cannonballs, brass vessels, and coins dating back to the East India Company. The job of sinking the caissons was carried out round-the-clock at a rate of a foot or more per day. The caissons were sunk through soft river deposits to a stiff yellow clay layer 26.5 m below ground level. The accuracy of sinking the huge caissons was exceptionally precise, within 50–75 mm of the true position. After penetrating 2.1 m into clay, all shafts were plugged with concrete after individual dewatering, with some 5 m of backfilling in adjacent shafts. The main piers on the Howrah side were sunk by open wheel dredging, while those on the Kolkata side required compressed air to counter running sand. The air pressure maintained was about 40 lbs per square inch (2.8 bar), which required about 500 workers to be employed. Whenever excessively soft soil was encountered, the shafts symmetrical to the caisson axes were left unexcavated to allow strict control. In very stiff clays, a large number of the internal wells were completely undercut, allowing the whole weight of the caisson to be carried by the outside skin friction and the bearing under the external wall. Skin friction on the outside of the monolith walls was estimated at 29 kN/m^2 while loads on the cutting edge in clay overlying the founding stratum reached 100 tonnes/m. The work on the foundation was completed by

November 1938. By the end of 1940, the erection of the cantilevered arms was commenced and was completed in midsummer of 1941. The two halves of the suspended span, each 86 m long and weighing 2,000 tonnes, were built in December 1941. The bridge was erected by commencing at the two anchor spans and advancing towards the center, with the use of creeper cranes moving along the upper chord. 16 hydraulic jacks, each of which had an 800 tonnes capacity, were pressed into service to join the two halves of the suspended span.

The entire project cost Rs. 25 million. The project was a pioneer in bridge construction, particularly in India, but the government did not have a formal opening of the bridge due to fears of attacks by Japanese planes fighting the Allied Powers. Japan had attacked the United States at Pearl Harbor on December 7, 1941. The first vehicle to use the bridge was a solitary tram.

The bridge is regarded "the gateway to Kolkata, as it connects the city to the Howrah Station".

III. DESCRIPTION

Specifications

When commissioned in 1943, Howrah was the 3rd-longest cantilever bridge in the world, behind Pont de Québec (549 m) in Canada and Forth Bridge (521 m) in Scotland. It has since been surpassed by three bridges, making it the sixth-longest cantilever bridge in the world in 2013. It is a suspension type balanced cantilever bridge, with a central span 460 m between centers of main towers and a suspended span of 172 m. The main towers are 85 m high above the monoliths and 23 m apart at the top. The anchor arms are 99 m each, while the cantilever arms are 143 m each. The bridge deck hangs from panel points in the lower chord of the main trusses with 39 pairs of hangers. The roadways beyond the towers are supported from ground, leaving the anchor arms free from deck load. The deck system includes cross girders suspended between the pairs of hangers by a pinned connection. Six rows of longitudinal stringer girders are arranged between cross girders. Floor beams are supported transversally on top of the stringers, while themselves supporting a continuous pressed steel troughing system surfaced with concrete. The longitudinal expansion and lateral sway movement of the deck are taken care of by expansion and articulation joints. There are two main expansion joints, one at each interface between the suspended span and the cantilever arms, and there are others at the towers and at the interface of the steel and concrete structures at both approaches. There are total 8 articulation joints, 3 at each of the cantilever arms and 1 each in the suspended portion. These joints divide the bridge into segments with vertical pin connection between them to facilitate rotational movements of the deck. The bridge deck has longitudinal ruling gradient of 1 in 40 from either end, joined by a vertical curve of radius 1,200 m. The cross gradient of deck is 1 in 48 between kerbs

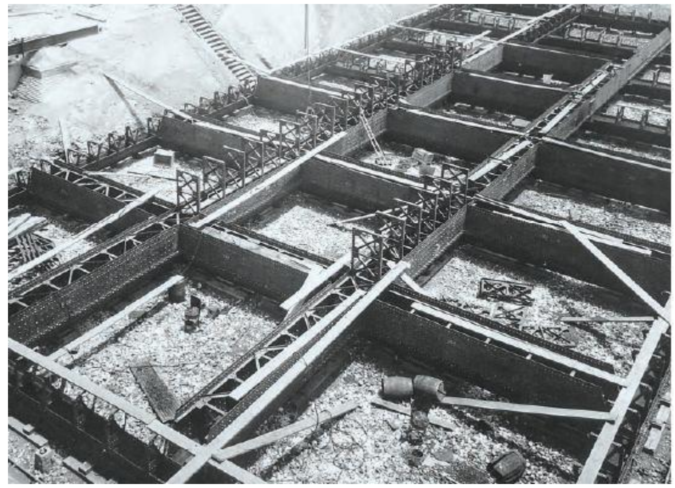


Fig. 3: Constructions of Foundations in progress

Fig. 4: Constructions of Abutments in progress

Fig. 5: Constructions of Superstructure in progress

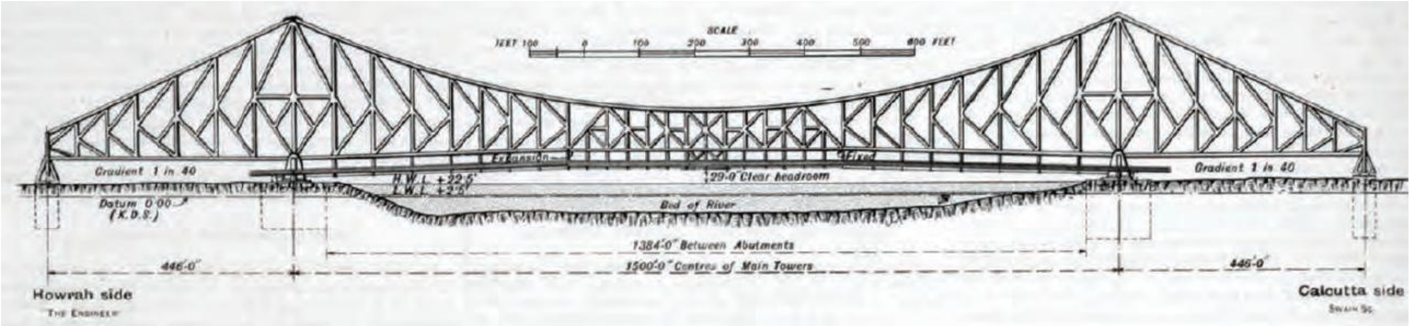


Fig. 6: Side Elevation of Proposed New Howrah Bridge

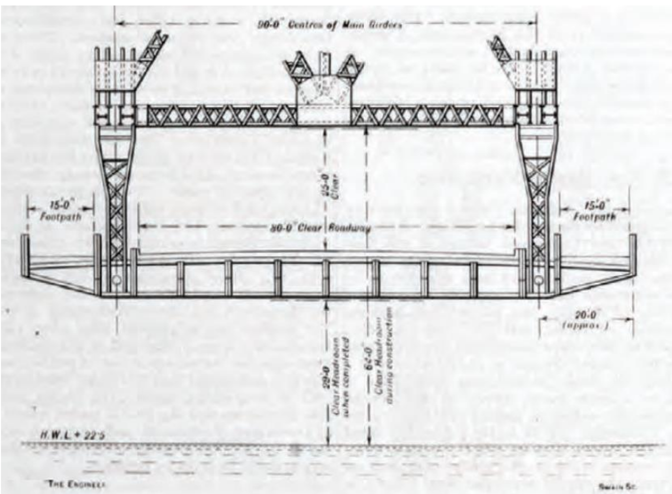


Fig. 7: Cross-Section of Proposed New Howrah Bridge

Fig. 8: General view at Anchorage showing lateral windframe and anchorage links

Traffic Volume

The bridge serves as the gateway to Kolkata, connecting it to the Howrah Station, which is one of the four intercity train stations serving Howrah and Kolkata. As such, it carries the near entirety of the traffic to and from the station, taking its average daily traffic close to nearly 1,50,000 pedestrians and 1,00,000 vehicles. In 1946, a census of the daily traffic was taken, which counted 27,400 vehicles, 1,21,100 pedestrians and 2,997 cattle. The bulk of the vehicular traffic comes from buses and cars. Prior to 1993, the bridge also carried trams. Trams departed from the terminus at Howrah station towards Rajabazar, Sealdah, High Court, Dalhousie Square, Park Circus and Shyambazar. In 1993, tram services on the bridge were discontinued due to increasing load on the structure. However, the bridge still continues to carry much more than the expected load. A 2007 report revealed that nearly 90,000 vehicles were plying on the bridge daily (15,000 of which were goods-carrying), though its load- bearing capacity is only 60,000. One of the main reasons for the overloading was that, although vehicles carrying up to 15 tonnes are allowed on the structure, vehicles with 12-18 wheels and carrying loads up to 25 tonnes often plied on it.

From 31 May 2007 onwards, overloaded trucks were banned from crossing the bridge, and were redirected to the Vidyasagar Setu instead. The road is flanked by footpaths (4.6 m wide), which are thronged with pedestrians.

Table 2: Traffic Flow for fast moving Heavy Vehicles

Year	Trams	Bus/ Van	Trucks
1959	13%	41%	46%
1986	4%	80%	16%
1990	3%	82%	15%
1992	2%	80%	18%
1999	---	89%	11%

Table 3: Traffic Flow for fast moving Light Vehicles

Year	Two-Wheelers/ Autos	Cars/ Taxis
1959	2.47%	97.53%
1986	24%	76%
1990	27%	73%
1992	26%	74%
1999	20%	80%

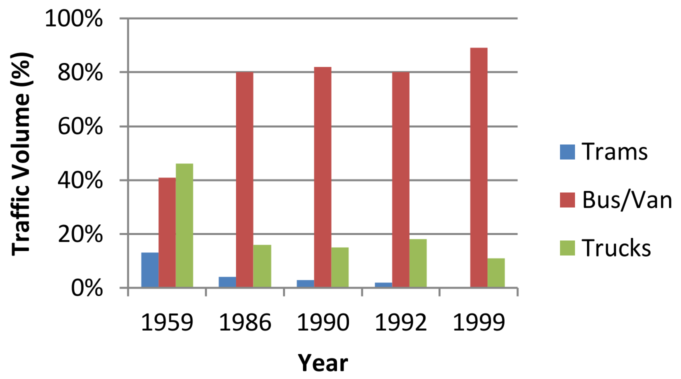


Fig. 9: Traffic Flow for Fast moving Heavy Vehicles

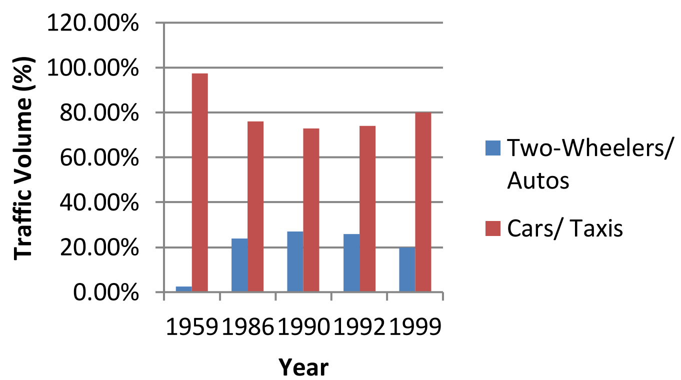


Fig. 10: Traffic Flow for Fast moving Light Vehicles

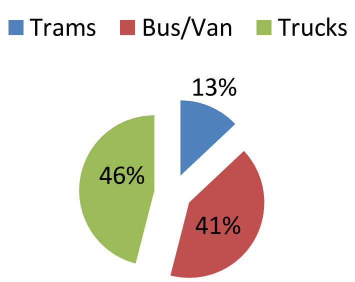


Fig. 11: Share of various types of Fast moving Heavy Vehicles along Howrah Bridge (1959)

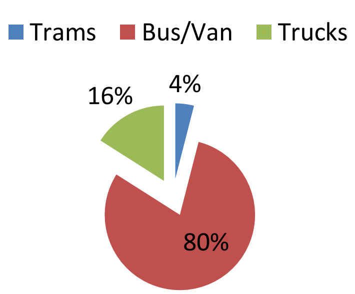


Fig. 12: Share of various types of Fast moving Heavy Vehicles along Howrah Bridge (1986)

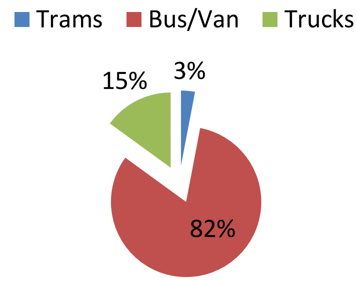


Fig. 13: Share of various types of Fast moving Heavy Vehicles along Howrah Bridge (1990)

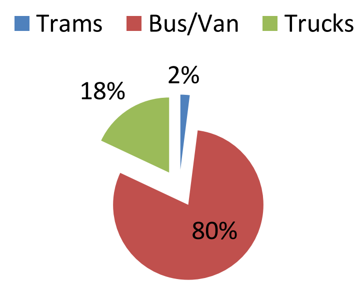


Fig. 14: Share of various types of Fast-moving Heavy Vehicles along Howrah Bridge (1992)

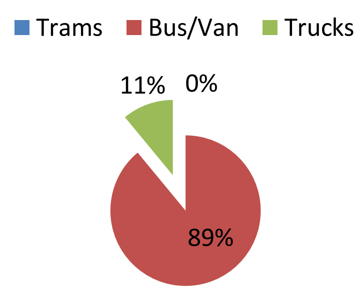


Fig. 15: Share of various types of Fast moving Heavy Vehicles along Howrah Bridge (1999)

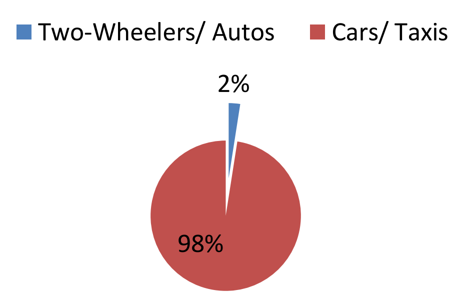


Fig. 16: Share of various types of Fast moving Light Vehicles along Howrah Bridge (1959)

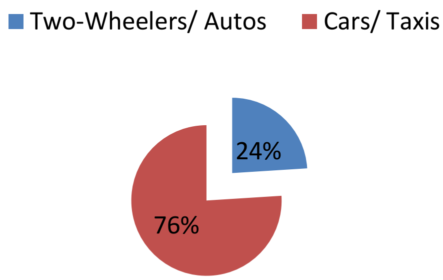


Fig. 17: Share of various types of Fast moving Light Vehicles along Howrah Bridge (1986)

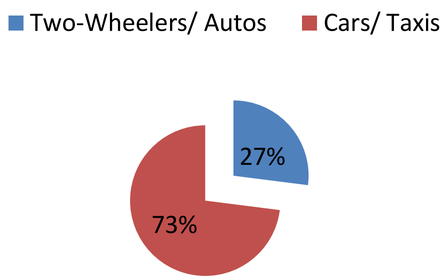


Fig. 18: Share of various types of Fast moving Light Vehicles along Howrah Bridge (1990)

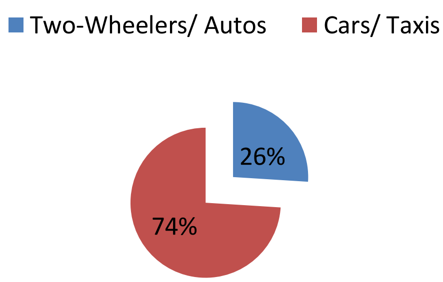


Fig. 19: Share of various types of Fast moving Light Vehicles along Howrah Bridge (1992)

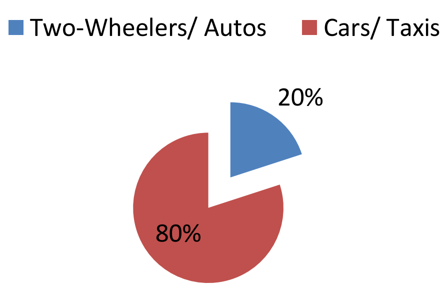


Fig. 20: Share of various types of Fast moving Light Vehicles along Howrah Bridge (1999)

Fig. 21: Daytime View of Howrah Bridge

Fig. 22: Underside of the Bridge Deck

Maintenence

The Kolkata Port Trust (KoPT) is vested with the maintenance of the bridge. The bridge has been subjected to damage from vehicles due to rash driving, and corrosion due to atmospheric conditions and biological wastes. On October 2008, 6 high-tech surveillance cameras were placed to monitor the entire 705 m long and 30 m wide structure from the control room. Two of the cameras were placed under the floor of the bridge to track the movement of barges, steamers and boats on the river, while the other four were fixed to the first layer of beams — one at each end and two in the middle — to monitor vehicle movements. This was in response to substantial damage caused to the bridge from collisions with vehicles, so that compensation could be claimed from the miscreants.

Corrosion has been caused by bird droppings and human spitting. An investigation in 2003 revealed that as a result of prolonged chemical reaction caused by continuous collection of bird excreta, several joints and parts of the bridge were damaged. As an immediate measure, the Kolkata Port Trust engaged contractors to regularly clean the bird droppings, at an annual expense of Rs. 5,00,000. In 2004, KoPT spent Rs. 6.5 million to paint the entirety of 2.2 million m^2 of the bridge. Two coats of aluminium paint, with a primer of zinc chromate before that, was applied on the bridge, requiring a total of 26,500 litres of paint. The bridge is also considerably damaged by pedestrians spitting out acidic, lime-mixed stimulants. A technical inspection by Port Trust officials in 2011 revealed that spitting had reduced the thickness of the steel hoods protecting the pillars from six to less than three millimeters since 2007. The hangers need those hoods at the base to prevent water seeping into the junction of the cross-girders and hangers, and damage to the hoods can jeopardize the safety of the bridge. KoPT announced that it will spend Rs. 2 million on covering the base of the steel pillars with fibre-glass casing to prevent spit from corroding them.

On 24 June 2005, a private cargo vessel *M V Mani*, belonging to the Ganges Water Transport Pvt. Ltd, while trying to pass under the bridge during high tide, had its funnel stuck underneath for three hours, causing substantial damage worth about Rs. 15 million to the stringer and longitudinal girder of the bridge. Some of the 40 cross-girders were also broken. Two of four trolley guides, bolted and welded with the girders, were extensively damaged. Nearly 350 m of 700 m of the track were twisted beyond repair. The damage was so severe that KoPT requested help from M/s. Rendall, Palmer & Tritton Limited, the original consultant on the bridge from UK. KoPT also contacted SAIL for 'matching steel' used during its construction in 1943. For the repair, which cost around Rs. 5 million, about 8 tonnes of steel was used. The repairs were completed in early 2006.

IV. CONCLUSION

Thus, to conclude this theoretical discussion, we can obviously state the importance the Howrah Bridge holds in lieu of the city of Kolkata and its surrounding areas. The Bridge is of paramount importance for the city to function efficiently as communication itself is a cornerstone on which Kolkata and Howrah are based. Besides, the magnificent Rabindra Setu also adds beauty to the Kolkata skyline and attracts huge number of tourists to the city which keeps it ticking from an economic and commercial point of view. Thus it is really necessary to understand the requirements of the bridge and maintain its viability to serve the population of the region.

Structurally, Howrah Bridge is a marvel and an epitome of uniqueness in architecture and design. The volume of construction work that was needed to erect this monumental structure is worth studying whose construction was full of great engineering challenges for the builders in those days. The engineering study of Howrah Bridge thus provides ground for engineers to go on and build similar types of structures all over the world. Though balanced-cantilever bridges are generally not built these days due to the huge amount of material and time requirement, it still is worth studying from the durability concept of bridges and provides areas where maintenance techniques can be developed.

Thus, if we see from all these different aspects, it is worth studying about the Howrah Bridge in intricate details, an earnest and petite example being this discussion.

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