IJCRT.ORG ISSN : 2320-2882

INTERNATIONAL JOURNAL OF CREATIVE RESEARCH THOUGHTS (IJCRT)

An International Open Access, Peer-reviewed, Refereed Journal

A GENERAL STUDY ON TWO MAJOR BRIDGES OF WEST BENGAL

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Abstract: Bridges are structures that connect two places or two points separated by natural bodies like sea, ocean, hills, etc. These bridges are mainly constructed for different vehicles to move on but even pedestrians can also use. In West Bengal there are many bridges but among them four major ones are: Howrah Bridge, Second Hooghly Bridge, Bally Bridge and Nivedita Bridge. All these four bridges serve as the lifeline for the entire state. This paper deals with the overview and case study of Howrah Bridge and Second Hooghly Bridge; their history, constructional details and materials, impact on social, economical and cultural life, etc.

***Index Terms*- Suspension Type Balanced Cantilever Bridge, Cable Stayed Bridge, Kolkata Port Trust, Hooghly River Bridge Commissioners.**

I. INTRODUCTION

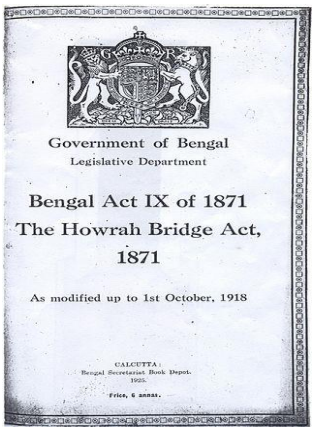
Bridges are one of the most important structures for any state or country. They act as lifelines for the state by connecting one place with other. The economy of the state directly depends on a good transport system and for ensuring good transport system; structures like bridges, flyovers, subways, etc. are required with good road connections. The concept of bridge is very old even it existed in mythological stories like Ramayana, where lord Ram and his banoor armies constructed a bridge made up of stones from India to Sri Lanka for fighting with Ravana, King of Lanka. Probably the earliest bridges were formed with fallen logs of trees across any water body, stepping stones, etc **[1].** The Arkadiko Bridge during the 13th century BC, in the Peloponnese of Southern Greece is probably one of the oldest arch bridges still in existence and known to present day people. Later on Romans were the first to construct bridges and some of them are still in existence like Alcántara Bridge, built over the river Tagus, in Spain. They also used one special kind of material for bridge construction called pozzolana, consisting of water, lime, sand, and volcanic rock at that time. Bridges made up of mortar and brick was constructed after the Roman era. Later on China also started constructing bridges made up of stones and wood like the Zhaozhou Bridge, built from 595 to 605 AD during the Sui dynasty. It is the world's oldest open- stone segmental arch bridge **[2].**

In India first ever known bridges were constructed by Mauryan dynasty as given in Kautilya's Arthasastra. Even during the Mughal time many bridges were constructed across rivers mainly for wars and trading. But the major construction of bridge in India was started during the British rule and actually it was then when people really understood the benefits and importance of a bridge for socio-econimical purpose **[2]**.

The East India Company when first came to India for trading, they found the necessities for construction of bridge in India for smooth transportation of goods and equipments from one place to another. And then the Howrah Bridge was constructed to connect the twin cities Calcutta (now Kolkata) and Howrah across the Hooghly river. After India got Independence in 1947 from British rule, Indian Government found the necessities of constructing another bridge across the Hooghly River so as to reduce some vehicle pressure from Howrah Bridge and also to reduce journey time and so the Second Hooghly Bridge was constructed.

II. HISTORY AND ORIGIN

As East India Company started trading in India movement along the Hooghly River got increased and hence a committee was appointed in 1855-56 to review alternatives for constructing a bridge across the river. Later it was decided that a newly appointed trust would be formed to manage it [3]. The Calcutta Port Trust was then created 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 [4].


Government of Bengal
Legislative Department

Bengal Act IX of 1871
The Howrah Bridge Act,
1871

As modified up to 1st October, 1918

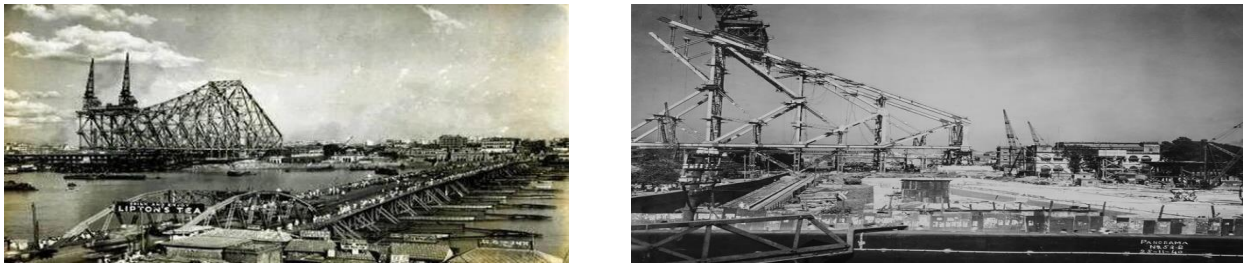
CALCUTTA:
Bengal Secretariat Book Depot.
1918.
Price, 6 annas.

(Fig No. 1: The Howrah Bridge Act [5])

It empowered the bridge governor to construct the bridge with Government Capital. Hence a contract was signed with Sir Bradford Leslie to construct a pontoon bridge over Hooghly River which would could be unfastened to allow marine vehicles and steamers to cross the river [5]. All the parts of these Bridge was brought from England and assembled in Kolkata and finally it was completed on 1874 and its total costs was around Rs.2.2 million at that time [4].

(Fig No.2: The Pontoon Bridge [6])

The bridge was then 1528 ft. long and 62 ft. wide, with 7-foot wide pavements on either side. But due to rapid increasing of load, the Port Commissioners started planning for a new improved bridge but construction of the new bridge got paused due to World War-1 (1914-918). In 1921 Mukherjee Committee was formed headed by Mr. R.N. Mukherjee regarding the construction process of the bridge. The committee recommended a suspension bridge of a particular type to be built across the River Hooghly and submitted its report to the New Howrah Bridge Commission which was set up in 1922 and in 1926 the new Howrah Bridge Act was passed [5]. The bridge was designed by one Mr.Walton of M/s Rendel, Palmer & Triton and its order for construction and erection was placed on to M/s.Cleveland Bridge & Engineering Company [6]. About 26,500tons of steels were required for construction and was ordered from England but the World War-II (1939-1945) broke out and eventually only 3000tons of steel was supplied to India. Then Tata Steel were asked to supply the remaining high tension steels and eventually they supplied 23,000 tons of steel with the use of higher percentages of copper and chromium for corrosion resistance named it as Tata Tiscom[7]. The fabrication and erection work was then awarded to Braithwaite Burn & Jessop Construction Company Limited (BBJ), a local construction firm of Howrah and finally after so many ups and downs, its construction was completed in 1943 and then it was open for the public [8].



(Fig No. 3: Construction of Howrah Bridge [6])

Due to increase in population, traffic and commercial works, Indian government thought of construction of another bridge to connect the twin cities across Hooghly River, hence the foundation stone for the Second Hooghly Bridge was laid by then Prime Mininster of India, Mrs. Indira Gandhi on 20 May 1972. The bridge took more than 22 years to complete with an approx. total cost of Rs.3.88 billion at that time. But out of the 22 years, construction of bridge was paused for seven years at the beginning and actually the construction began from 3rd July 1979 [9] and the bridge was opened for public on 10th October 1992. The bridge was designed by Schlaich Bergermann & Partner, and checked by Freeman Fox & Partners and Bharat Bhari Udyog Nigam Limited and like Howrah Bridge it was also constructed by Braithwaite Burn & Jessop Construction Company Limited (BBJ). This bridge is maintained and commissioned by Hooghly River Bridge Commissioners (HRBC). At the time of construction, it was the first cable-stayed bridge in India, the largest in Asia and the third largest in the world and the longest span bridge of this type in the world [4].

(Fig No. 4: Construction of Second Hooghly Bridge [12])

III. CONSTRUCTIONAL DETAILS

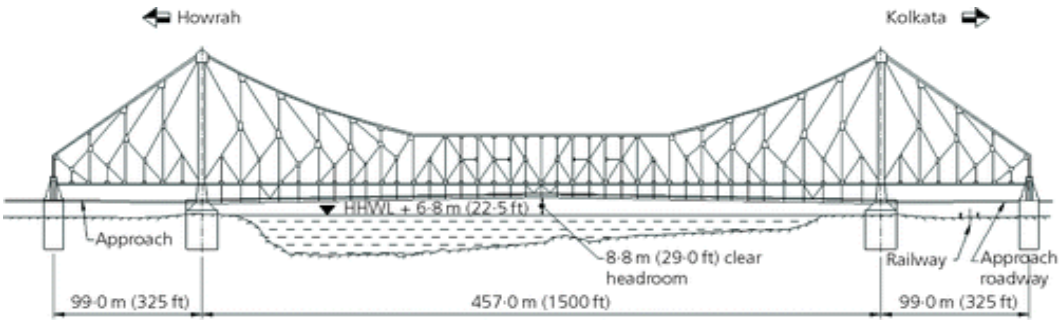
The Howrah Bridge was actually constructed as a replacement of the Pontoon Bridge which was designed by Sir Bradford Leslie, with a removable central section of 60 m for ships and steamers to cross over. It was opened to traffic in 1874 and served around 68 years although it was designed for only 25 years before it got finally replaced with the gigantic Howrah Bridge [6]. Howrah Bridge is a type of Suspension type balanced cantilever bridge having total length of around 705m with a longest span of around 457m [3]. The middle suspended span is around 172m, cantilever spans on both the sides around 143 m and anchor span on both sides around 99 m. After the end of World War-I when bridge construction got paused, a newly committee was formed chaired by Mr. R.N. Mukherjee with members nominated from the Port Commissioners and many internationally well-known engineers of that time. This committee played a major role in re-starting the bridge construction work in a proper way. This committee worked on feasibilities of different types of bridge that could be constructed and gave its findings on the following types of bridges [10]:

Single-span arch bridge: It got rejected on account of a high lateral thrust.

Suspension bridge: It also got rejected on account of longitudinal pull on anchorages as the soil conditions were not very suitable.

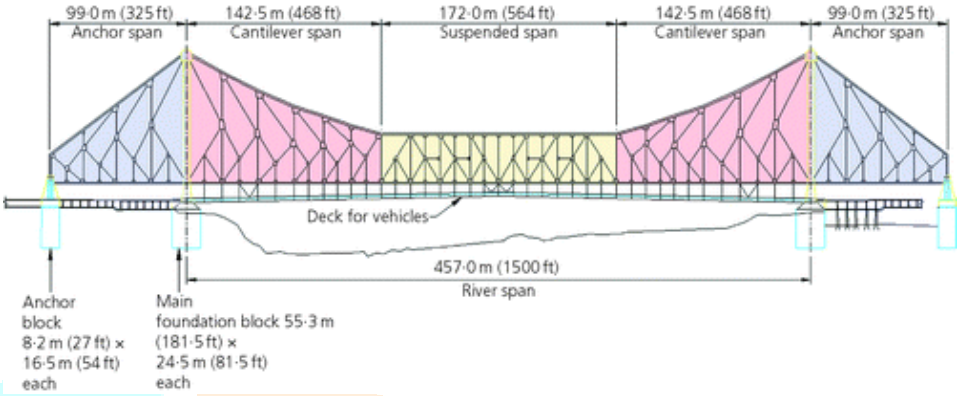
Pier and Girder Bridge: It was the most economical and easy construction but the bridge would affect the scouring and silting pattern of the river and influence the navigability of the river, and this was not acceptable and hence was rejected.

Floating bridge: It was rejected on account of its temporary nature and chances of collision with the river traffic like the previous Pontoon bridge.



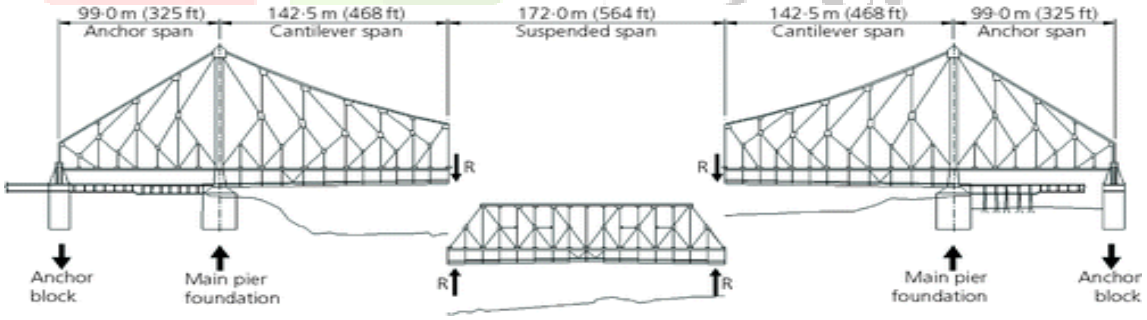
(Fig No. 5: Final Adopted Design of the Howrah Bridge [6])

Balanced cantilever bridge: It will allow the construction of the main girder clear of the river, which could carry huge commercial traffic. By cantilevering the span from the anchored span, the river traffic will also not get affected. This option also ensured that the foundations were mainly subject to vertical loads [7]. Finally Committee recommended for a cantilever bridge with suspended girders and submitted its report to the New Howrah Bridge Commission and the bridge configuration which was finally adopted for construction in 1935 was very close to the recommended type of bridge made by the committee [10]. A global tender was called and hence the construction was started. At that time loading standards as per Indian conditions was yet to be developed and in the absence of any code and loading standards it made the work a bit difficult. Usage of high-strength steel was decided, for reducing the weight of steelwork, based on the previous experience of Chelsea Bridge. With the adoption of a cantilever bridge, unhindered navigation provision was attained. The original concept was to make the central suspended span as hog-backed, but was changed to parallel chord members in the final design, from the aesthetic point of view.



(Fig No. 6: Structural Arrangements of the Howrah Bridge [6])

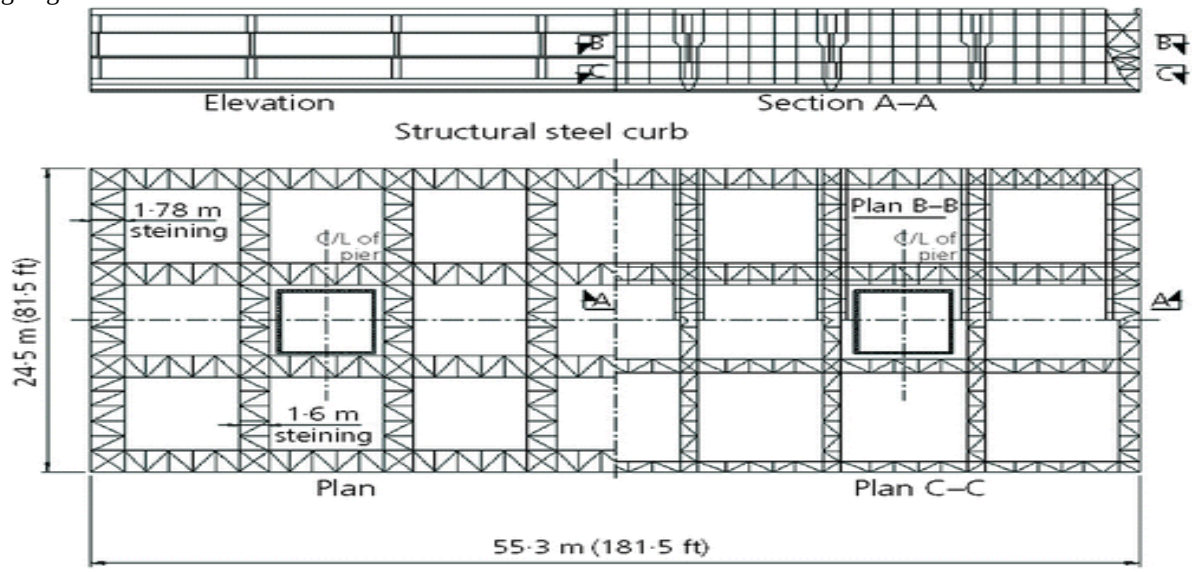
The truss for the cantilever arm and anchorage arm is a subdivided K type which helped in the reduction of the slenderness effect of the large vertical, and the suspended span is a subdivided N type. The width of the deck is 21·640 m along with a footpath of 4·5 m on either side. The carriageway is equivalent to six lanes as per the current code, IRC: 6-2017 (IRC, 2017), although it was planned when there was no IRC codes. The deck system consists of a grillage of cross-girders and stringers. The deck has eight articulation-type joints with slab seal expansion joint, together with two main expansion joints with a double-slab-seal-type joint at the junction of the suspended span and cantilever arm. There are 26 pin-joints which ensure a perfect truss behavior. The link member between the cantilever arm and suspended arm is pinned at both ends, and the vertical member at that joint is also pinned to allow rotation during expansion [6]. The bridge consists of two main towers with two posts each with K-bracing system between them. The saddles are located at the top of the posts, with pin joints for the upper chord and diagonals for the main trusses. The main bearing at the towers are between the lower chords of the anchor and cantilever arms.



(Fig No. 7: Cantilever Behavior of the Howrah Bridge [6])

These bearings are supported on the pedestal extensions projected out from the main posts. The posts are rectangular in cross-section and consist of three main vertical webs with transverse vertical diaphragms dividing them into eight compartments. The lower lateral bracing members are attached with large gussets to the main bearings. The transverse members between each pair of bearings transmit the lateral and longitudinal forces to the main towers [7]. During the foundation design it was estimated that around 30000T downward compression load will come at the main piers and 13500T upward tension at the anchorage points and the two piers and anchorage at both ends will take half each [6]. From the detailed description of the soil strata below the bed of foundation it showed that both banks (Howrah side and Kolkata side) of the river have a clay layer with stiff clay at about 25-30m below the ground level [6]. On Howrah side it was around 26.5m and Kolkata side it was around 31.6m [7]. On Kolkata side it also had a sandy stiff layer of soil between soft clay and stiff clay which caused problem during construction [6]. With the various soil parameters and loading values, foundation of the main towers were constructed with single monolithic cassions 55.31 x 24.8m with internal connecting criss-cross walls creating 21 chambers measuring about 6·1sq.m each, which went down to 26·5 m at the Howrah side and 31·6 m at the Kolkata side penetrating into a stiff clay layer. The external steining walls were 1·78 m thick, and the internal

steining walls were 1·6 m thick for providing a sufficient number of dredging shafts to give effective control along the major and minor axes while providing ample weight in the monolith shell, during sinking, to overcome skin friction and cutting edge resistance [6].



(Fig No. 8: Plan of Main Pier of Foundation [6])

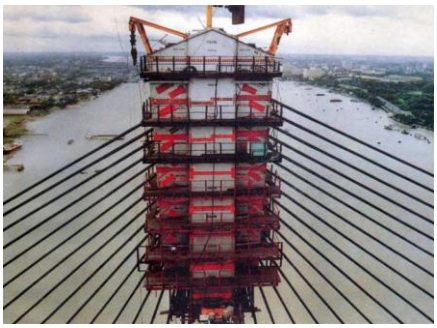
During the construction period, maximum load came on the foundation and therefore this downward load was reduced with uplift of the superstructure through the anchorage. As per the analysis and design, the dead load of each anchorage should exceed the maximum uplift by not more than 50% but as the uplift of the superstructure was located at two pints with a distance of about 23m below the main truss and foundations were very deep enough[7], so a single large monolithic cassion for the anchorage was not required hence two separate monolithic cassions of size 16.4 x 8.2m [5] was constructed for the anchorages along with two dredging shafts which was later tied with a tie beam [6]. Wind frames were designed to take the lateral wind load reactions of the superstructure, and these frames at the anchorages are situated on the central axis of the bridge. The entire project cost was around Rs 25 million at that time and is considered to be a landmark in bridge construction field of India [11].

(Fig No. 9: Deck Grillage system of the Howrah Bridge [6])

Construction work of the Second Hooghly Bridge was started from 3rd July 1979, although its foundation stone was laid by Mrs. Indira Gandhi in the year 1972. It is a type of Cable stayed bridge with a total length of 823m joining Howrah and Kolkata. This bridge is built with steel pylons of 127m high and consisting of 121 cables in a fan arrangement. The deck is made up of RCC with two carriageways and it is 457m long over the main span. The two side spans are supported with parallel wire cables of 182.88m long. The total width of the bridge is 35m with 3 lanes in each direction and a 1.2m wide footpath on each side [12]. The Pylons are designed as free standing portals, made up of 4×4 m steel boxes with riveted connection, provided with expansion joints to allow 400mm horizontal expansion at the free ends. Fixed end slab seal type expansion joints were also used for horizontal expansion of the joints. The total structural steel used for construction of the bridge is around 13,200T [13].

The bridge was designed by Schlaich Bergermann & Partner and was constructed by The Braithwaite Burn and Jessop Construction Company Limited (BBJ). The Hooghly River Bridge Commission (HRBC) was responsible for the commissioning operations of the bridge. Design of this bridge was little different from any other bridge. Normally the bridge designs are done with live load composite construction but this bridge was designed with the dead load design concept and side span concreting was done with support provided by the intermediate trestle. The deck is designed with a grid structure of girders having one set of girders at the end and another set in the middle, which are again braced by girders spaced at an average distance of at 4.2m centre to centre [12]. For construction of the main span of bridge, a 45T capacity deck crane was used to lift the pylons on the two side spans of the bridge; one set on the Kolkata side and the other is on the Howrah side. The six pylons on the Kolkata side of the bridge were installed using cranes of 75 MT and 50 MT while a single 50 MT crane was used on the Howrah side. The deck of the bridge is connected to the end piers by bolts embedded in the pier chambers and the anchorage of the pylon with the base of piers was done using dywidag rods, duly

anchored in the piers [9]. Cables were erected from the four pylon heads with the help of 32 MT hoist frames. The hoist frames were mounted on top of each pylon.



(Fig No. 10: Cables of Second Hooghly Bridge [12])

The cables were manufactured at Usha Martin Industries in Ranchi and transported to the construction site. These cables were lifted with a 2T tower crane fixed inside the pylons and were stressed with jacks which were imported from Vermac, Bangkok along with male/female strand sockets. The main bridge span was erected by a desk erection crane from both sides as cantilever erection. The erecting cables from the pylon head held the cantilever grid as the construction proceeded and the temporary bracings were erected for the lateral stability. As dead load composite concept of design was used so the concreting of the deck slab followed the four panels of steel work [4]. The Wind Tunnel Test with a prototype of this bridge was also been conducted in Indian Institute of Science, Bangalore. To ensure stability against lateral movement bearings were installed in vertical and horizontal directions, with grouted collars in four segments at the two end piers and horizontal bearings at the two middle piers [12]. And finally the bridge construction was completed and opened for traffic from October 1992. The total constructional cost of the bridge was around Rs. 3.88 billion at that time [12].

(Fig No. 11: Construction of Second Hooghly Bridge [12])

IV. HISTORICAL IMPORTANCE

The Howrah Bridge and the Second Hooghly Bridge serves as the lifeline for the City of Joy; Kolkata. Both the bridges connect Kolkata with Howrah (together known as Twin City). From historical point of view both the bridge have its own importance. The Howrah Bridge is one of the oldest bridges on India and is considered as an iconic structure and created a land mark in the bridge construction field of India. This was the third-longest cantilever bridge at the time of its construction and now it is the sixth-longest bridge of its type in the world. Its construction was completed way back in 1943 and still now it is standing as it was back then and constantly serving the city. It is a bridge without a single bolt connection and is constructed with only rivet connection. This bridge marks as a famous symbol of Kolkata and West Bengal for the entire world. It weathers the storms of the Bay of Bengal region, carrying a daily traffic of approximately 100,000 vehicles and possibly more than 150,000 pedestrians thus making it the busiest cantilever bridge of the world [3]. As the population and commercial activity grew more and more in West Bengal, particularly in Kolkata being the capital city of the state, and also serving as the gateway for Northeastern regions, the only link bridge between Howrah and Kolkata was subjected to high traffic congestion. Hence, another gigantic and iconic bridge was built across the Hooghly river to connect the twin cities; the Second Hooghly Bridge whose construction was completed in the year 1943. This bridge provides a direct connection between Kolkata Port with NH6 linking Bombay & Madras, as well as NH2 for Delhi and NH41 for Haldia Dock carrying almost about 100000 vehicles per day [14]. At that time of construction it was the first cable-stayed bridge in India, largest in Asia and the third largest in the world. It is also considered as the longest span bridge of this type in the world with a span of 457.2m with a capacity to run more than 85,000 vehicles per day [12]. The total length of Howrah Bridge is 705m and Second Hooghly Bridge is 823m. In the absence of any Codal guidelines during Howrah Bridge construction, engineers had to develop loading standards at that time that could cover the nature of traffic in future which now almost meets the present recommendation of IRC which actually demands a great appreciation for the engineers at that time. The engineers were also very careful about the development of the approaches, which had land constraint but still manage to provide a vertical gradient for the manual and cattle-driven vehicles by careful land usage. This has ensured the crossing to be used by the huge number of passengers which is very helpful now during the busy

hours of local suburban trains. But incorporation of wide pedestrian corridors is unusual for bridges in the country, which also indicates the visionary wisdom of the engineers [6]. Both Bridges have showed the possibilities that India actually has in the field of construction. Today's Howrah Bridge is almost similar to the recommendation of the Mukherjee Commission, headed by Mr. R.N. Mukherjee. Around 23000T of specially made high tension steel (Tiscrom) was supplied by Tata Steel during construction of Howrah Bridge [1] and the cables of Second Hooghly Bridge was brought from Usha Martin Industry of Rachi [4].A local constructional firm from Howrah, The Braithwaite Burn and Jessop Construction Company Limited (BBJ) completed the constructional works of both the bridge. Both the Bridges are now standing tall without any serious damage and constantly serving the city. Even the girder repair work of the Howrah Bridge during 2005-2006 was done by BBJ.

V. SOCIAL AND CULTURAL IMPORTANCE

Both Howrah Bridge and Second Hooghly Bridge plays a huge important role from social and cultural point of view. These two bridges serve as landmark of the state for the whole world. The Howrah Bridge is also popularly known as "Rabindra Setu" named after the great Poet and Writer Kabiguru Rabindranath Tagore, who is the first Indian and Asian Nobel laureate. The Second Hooghly Bridge is also popularly known as "Vidyasagar Setu" named after the famous Educationist Reformer Pandit Ishwar Chandra Vidyasagar. Both the names, "Rabindra Setu" and "Vidyasagar Setu" are symbols that represent the culture and heritage the entire state of West Bengal. The first vehicle to cross over the Howrah Bridge was a tram, another symbol of heritage of Kolkata. But unfortunately from 1993, trams were stopped from using the bridge, and the route was discontinued as the bridge might not be able to take the heavy load of trams in light of increased traffic and pedestrians [11]. The view of Vidyasagar Setu from Princep Ghat is a major spot of attraction for the photographers. The economy of the state is very much dependent on both the bridge. Kolkata is the capital of West Bengal and people coming from the opposite side of the Hooghly River have to use the bridge every day. Most of the intra-state express trains and super-fast trains have final destination in Howrah Railway Station so all the tourist and people coming from outside the state have to avail the bridge to go to other parts of the state. The resembles of both the bridge have been found in various poems and stories of different authors. Presently the state the dministrative head office of West Bengal, "Nabanna" is also located in Howrah and one of the leading universities of the world, Indian Institute of Engineering Science and Technology (i.e. BESU) is also located in Howrah which actually increased the demand and necessity of both the bridges to another level. World famous Indian Botanical Garden is also situated in Howrah. The entire Howrah Bridge is now decorated with multi-coloured led lightings, spot lights with some sound system which is inaugurated by Prime Minister Shri Narendra Modi, in the presence of Chief Minister of the state Miss Mamata Banerjee and Governor of the state Shri Jagdeep Dhankhar on January 2020. These bridges have been featured in many famous Indian movies like Do Bigha Zamin, Neel Akasher Neechey, Calcutta 71, Barfi, Gunday, Kahaani, etc. Even many flim makers from outside India like Richard Attenborough's, Florian Gallenberger, Roland Joffé, etc. have featured Howrah Bridge in their movies. A movie named "Howrah Bridge" was made by one of the famous Indian director Shakti Samanta in the year 1958. The Howrah Bridge even also featured in Garth Davis' Academy Award-nominated 2016 film Lion[5].

(Fig No. 12: View of Howrah Bridge and Second Hooghly Bridge at night [17])

VI. PRESENT STATUS OF MAINTENANCE AND TRAFFIC VOLUME SCENARIO

Both the Bridges carry huge amount of traffic load daily. In a census made in 1946 the count of the daily traffic amounted to 27,400 vehicles, 121,100 pedestrians and 2,997 cattle and now it has been increased to nearly 1.5 million pedestrians and 1 million vehicle each day, probably the world's busiest cantilever type balanced suspension bridge [4]. Since after its full construction, Howrah Bridge have never undergone high damage except on 2005 when the funnel of a private cargo vessel M.V. Mani got struck underneath the bridge during high tide causing damage to the girders and stringers of the bridge. Many cross girders were even got broken. As the damage was serious, so Kolkata Port Trust opted help from Rendall-Palmer & Tritton Limited, the original consultant on the bridge from UK and the total cost of repair of the bridge was around Rs.5 million at that time and nearly 8tones of steel were required for the repair work which was purchased from SAIL [3]. Around Rs27.3million rupees was spent for the maintenance purpose of the bridge in 2005 which included painting of the entire bridge, laying of cable line, 700 lights, a new control tower, sub-station, etc. All these maintenance work of Howrah Bridge is mainly done by the Kolkata Port Trust. The articulation joints at deck level of the Howrah Bridge were also renovated in 2008 [15]. Many parts of the bridge got damage of corrosion because of bird droppings and human spitting. Even due to rush driving, accidents took place which also caused some damage. Hence 6 high-tech CCTV cameras were installed to monitor the entire structure [4]. The Original Expansion Joints of the Howrah Bridge also got damaged hence they were also replaced

using a set of reinforced elastomeric slab seal type expansion joint [16]. An inspection made by The Port Trust officials in 2011 found that spitting had reduced the thickness of the steel hoods protecting the pillars from 6 to less than 3 mm since 2007. The hoods are of high importance as the hangers need them at the base to prevent water seeping into the cross-girder and hanger junction [4]. As time passed, traffic volume and human movement on Howrah Bridge increased as it is very close to Howrah Railway Station, hence overloaded trucks were redirected to Vidyasagar Setu from 2007 onwards and as a result of which traffic congestion became a major problem for the Vidyasagar Setu. The Hooghly River Bridge Commissioners (HRBC), an autonomous body under the Transport Department, Government of West Bengal planned to build two oneway-exit and entry–ramps in Vidyasagar Setu to get relieve from the traffic congestion. The lightning on the Vidyasagar setu has also been increased with various colourful Led lamps and the bridge now looks very colorful in the night. The outer casing of the cables that holds the Vidyasagar Setu requires repair and maintenance as reported by an inspection team to the HRBC. For annual maintenance of the bridge, a team was formed which included experts from the Civil Engineering Department of Bengal Engineering and Science University (BESU), officials of Consulting Engineering Services and others. HRBC has even consulted with Schlaich Bergermann & Partner, the German company that designed Vidyasagar Setu, to suggest a maintenance plan of the entire Vidyasagar Setu [4].

VII. CONCLUSION

The importance of both the Bridges are immense for the state as well as the country from all the aspects. Both the Bridges are the symbol of the Indian possibilities and empowerment in the construction field even during the 19th Century. Structurally both the bridges are worth to study for any engineer. The amount of technology and science used for construction of both the bridge even in the 19th century is really something to wonder against all the odds. Even after recent earthquakes and cyclones like Aila, Amphan,Yash, both bridges are unharmed and standing tall. The more people do research about both the bridge, more surprising and relevant information comes out. Thus from all the aspects it is worth for studying both the bridge. But as both Bridges are getting old day by day and population is also increasing rapidly, hence proper annual maintenance of both the bridge is required. And we being responsible citizen of the country should not do anything that will harm the glory and heritage of the bridge.

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