Quality assurance in design and construction

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Considerable emphasis was laid on the quality assurance in design and construction of the Jogighopa bridge. This paper enumerates the steps taken to ensure the desired quality at all stages of the project.

The Jogighopa rail-cum-road bridge is a massive structure consisting of 17 spans of 125 m, one span of 96.6 m and two spans of 32.6 m of through double-Warren type, double deck steel girders for rail and road, supported over 17 m x 11 m double-D type well foundations. On both approaches, there are long road viaducts and 16-18 m high embankments. Quality assurance in design and construction of such a bridge is obviously very vital for the safety and durability of the structure. The consequences of failure of such a structure needs no emphasis. It was therefore natural that thorough investigations preceded the detailed design and construction of this important bridge.

Basic studies

Rail India Technical and Economic Services (RITES) were engaged for conducting detailed site investigations and to suggest appropriate loading standards and structural arrangement along with preliminary design. Various basic studies done by the consultants are briefly described below.

River behaviour

A study of the river behaviour based on the old survey plans from 1911 onwards, lands at imagery, aerial photographs etc. indicated that geomorphologically, northern bank was vulnerable to erosion and the river showed a tendency to shift northwards after passing Jogighopa hills, lying on the upstream of the proposed bridge. The shift however was very gradual and with a suitably designed guide bund on north bank, it was found possible to halt the river shift to north. It was therefore important to conduct hydraulic model studies for the bridge and its guide bunds.

Hydraulic model studies

A river model covering a length of 10 km downstream and 35 km upstream of the bridge site for the width of the river contained between high bank / flood bunds was constructed by Central Water and Power Research Station (CWPRS), Pune. The hydraulic model studies confirmed the necessity of a guide bund on the north bank. It also tested the functioning of bridge for all adverse flow conditions. The model studies aimed at determining:

1. suitability of bridge site from hydraulic considerations of stable reach of the river

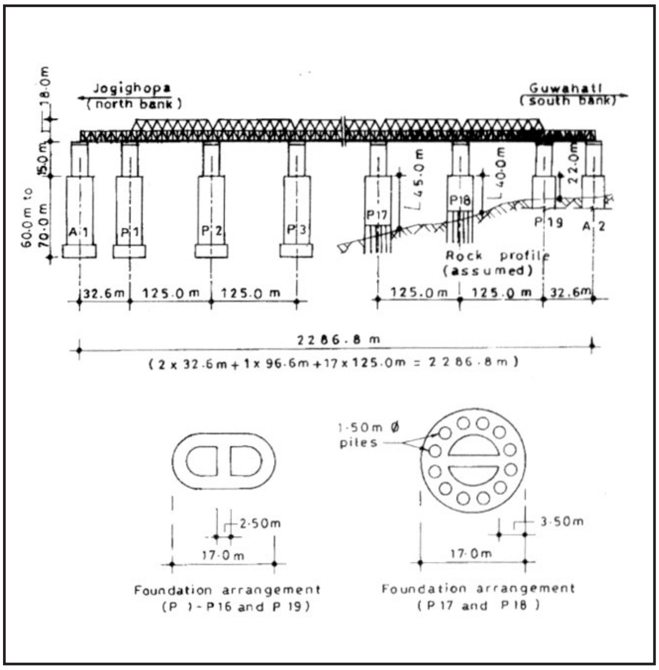

Figure 1. Details of the rail-cum-road-bridge on river Brahmaputra at Jogighopa

2. optimum orientation and waterway for the bridge

3. shape and length of guide bunds and other protection works

4. likely concentration of flow in any span for worst possible river course and to determine hydraulic parameters.

Geological studies

The north-eastern region of the country is quite sensitive from seismic point of view. Geological investigations were therefore carried out by Geological Survey of India, Shillong, which indicated that the area is subjected to frequent earthquakes and one of the major earthquake causing fault near the site is Dauki Fault Zone in Shillong Plateau. A geological study by photo-interpretation of satellite imageries done by the Institute of Photogramatic Interpretation, Dehradun indicated that structurally the river in the area followed an east-west trending lineament, characteristic of Archean crystalline rock formation. Geologically, it was found that the site was quite suitable for bridging and that a well designed structure could stand the test.

Seismological studies

In view of the high seismicity of the area, seismological studies were also important. The Indian meteorological department set up field stations to study present seismic activity. It suggested the frequency of likely intensities of earthquakes, for example, earthquakes of magnitude 6.5 to 7.5 on the Richter scale with 10 year and 7.5 to 8 with 100 year return period were predicted. Micro earthquake studies confirmed the site being in a sensitive environment with earth tremors originating closely with an effect of around MM VIII. The ground acceleration could be 250 cm / s2 and called for the provision of 0.2 g for the structure. The University of Roorkee conducted laboratory studies and gave the design criteria. The acceleration response spectra was developed which was used for detailed analysis and design of various components of the bridge structure.

Geophysical investigations

Considering the depth of foundations, subsoil investigations were necessary to determine the strata of subsoil and to determine various parameters for design of foundations, approach embankments and guide bund. In addition to the soil investigations carried out previously by various agencies in connection with earlier proposed road bridge and barrage in the near vicinity, 16 bore holes were done on the south bank in the rock zone from south abutment to pier 16. These holes extended 5-10 m inside the rock. Three bore holes, around 100 m deep were drilled in the central zone under water from pier 14 to pier 6. Another hole 100-m deep was done at pier location 3 on island. Five other land bore holes were made on north bank, ranging from 20 m to 60 m.

On the southern side the geophysical investigations were done by a CWPRS geophysical team using seismic refraction and electrical sensitivity methods to determine rock profile. Six bore holes each were done by AFCONS Infrastructure Ltd. also on pier 17 and 18, where sloping rock was met.

Design parameters were fixed accordingly for two categories.

1. where foundations would be wholly alluvial, that is Al to P16, P19 and A2.

2. where foundations would be on rock, that is, P17 and P18.

Design

The relationship between adequate investigations and appropriate design for the bridge projects needs no emphasis. With the data available from detailed investigations, design of bridge was finalised keeping in view the paramount importance of safety under the given conditions.

Hydraulic design parameters

The parameters for the design of the bridge are based on relevant codes and various investigations/studies carried out by RITES. The HFL, LWL and design discharge are based on gauge and discharge data maintained by Central Water Commission at their gauging sites at Jogighopa during 1955-57 and 1971 onwards. 50-years flood is normally considered adequate for waterway and 100 years for design of foundations but in the present case the bridge being across a very major river and involving high investment, the design discharge of 90,400 m^3 /s has been adopted for 250-year return period. The design intensities have been carried out based on model studies.

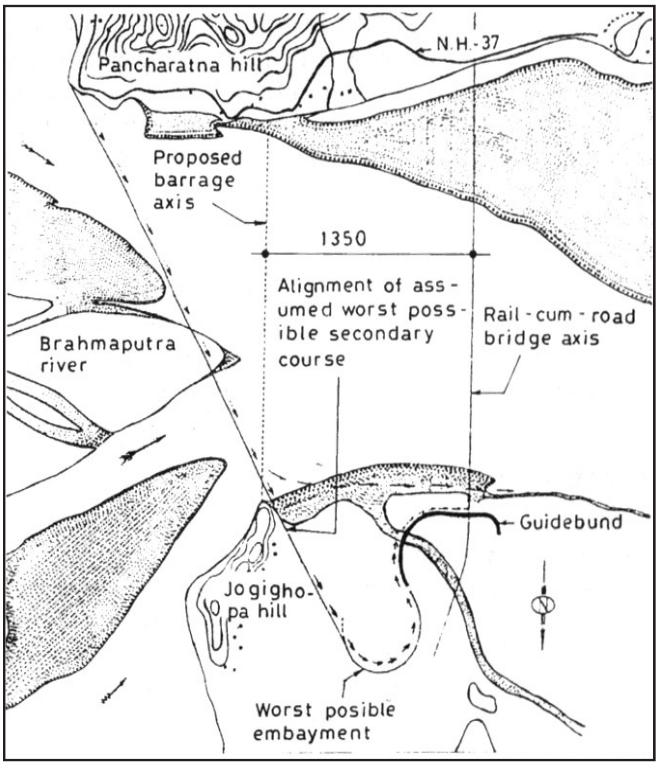

Figure 2. Hydraulic model for river flow conditions on north bank

Structural design parameters

The following codes have generally been followed for design of super structure and sub structure of this bridge.

1. Railways: IRS Bridge Rules 1982 ; IRS Steel Bridge Code 1962; IRS Concrete Bridge Code 1962; IRS Welded Bridge Code 1972; IRS bridge substructure code and BG Schedule of Dimensions.

2. Roadways: 1RC-5-1970 General features of design; IRC-6-1966 Loads and stresses ; IRC-24-1972 Cement Concrete (Plain and RC); IRC-22-1966 Composite constructions for road bridges; IRC-24-1967 Steel road bridges; IRC-78-1983 Foundations and substructures ; IRC-45-1972 Resistance of soil below the maximum scour level.

Salient features

Loading:

The bridge provides for two railway tracks and is designed for 'Modified Broad Gauge' loading. The road portion consists of two lanes and caters to loading as per IRC codes. Presently, however only a single railway track has been centrally provided with the provision of adding another track. Both the tracks when provided will be symmetrically placed.

Seismic effect:

In accordance with IRS bridge rules, dynamic analysis is necessary for seismic zones IV and V , for spans more than 120 m and where length of substructure from base of foundation is more than 30 m The dynamic analysis was also considered necessary due to proximity of fault zones producing earthquakes. The dynamic analysis was carried out by University of Roorkee and the final design caters to the recommendation thereof.

Impact of navigational force:

There are no clear cut stipulations regarding the impact of barges on piers and wells. Quality assurance requires consideration of data from studies available for similar projects under similar conditions. A provision of barge impact of 500 t has therefore been assumed, based on data available from Inland Water Transport Directorate and study carried out by RITES in connection with design of an earlier bridge on river Brahmaputra at Tezpur.

Other features

Liquefaction studies were carried out by University of Roorkee for design of high approach banks and guide bunds under sandy subsoil conditions to safeguard against failures under seismic effect and these recommendations were adopted in design.

Special foundation system was evolved for two piers on south bank, catering to the unique conditions during earthquakes and scour. At these locations, sloping rock was encountered at a depth more than that permissible for pneumatic sinking and yet within zone of scour. The design consisted of 17-m diameter circular wells combined with 12 piles of 1.5 m diameter passing through steining and anchored 10 m inside rock to specially cater to undampened seismic forces.

An aseismic structure has also been provided on each pier to take care of the situation of superstructure being over thrown off the bearings under severe earthquake conditions. The arrangement broadly consists of two posts embedded in pier caps. Another attachment is connected to bottom of girders. In the event of excessive lateral movements during earthquakes, this attachment would be prevented in its movement beyond a limit by the posts embedded in the pier cap, thus restricting the lateral movement of the girder.

Sturdy roller and rocker bearings and state-of-the-art expansion joints for the road have been adopted to give smooth riding surface on road and to cater to the movements under various loading conditions.

Many of the structural failures can be attributed to improper detailing and design which do not adequately address the issues pertaining to constructibility. Keeping in view this element of quality assurance (QA), various components of girders were designed with weldable steel conforming to IS:2062 and HTS conforming to IS:961 - 1975. HTS rivets were used for HTS members and all junctions of HTS and MS members. This reduced the size of member and rivet holes giving larger area for tension. Reinforcement comprises of high yield strength deformed (HYSD) bars according to 1S:1786 - 1979.

Design checking and review

Design review helps in detection of omissions, ambiguities and inadequacies of the design, thereby substantially reducing contract modifications and failures. This aspect was well taken care of in the following manner.

1. The superstructure was designed by RDSO after ascertaining design spectra based on dynamic analysis conducted by University of Roorkee and proof checked by STUP Consultants Ltd. Sufficient time was given for the design to ensure that quality of design did not suffer.

2. The substructure for normal conditions were designed by N. F. Railway. The proof checking was done by GILCON on behalf of the substructure contractors.

3. A Technical Advisory Group was constituted consisting of experts from Railways, ministry of surface transport (MOST), construction firms and from various other organisations. It deliberated on the design parameters and the design submitted by Dr A.S.Arya for special foundations of piers 17 and 18.

Construction

Construction is the most demanding and difficult phase of quality assurance, as it is during this phase that the design and specifications are put to the final test in terms of constructibility, design performance and cost effectiveness. Some of the common lapses which affect the quality of construction are as follows :

1. Quality is often compromised to meet the schedule.

2. Construction is not supervised at appropriate technical levels.

3. The engineers and supervisors of contractor and client lack knowledge of certain specialised tasks.

4. Rectification is not done and slack quality standards are accepted.

Safeguards for ensuring quality

The day-to-day supervision on the project was done at a fairly high level by a team of assistant engineers/ executive engineers and deputy chief engineers. Periodical meetings between contractors and Railways were held to discuss progress, quality and to sort out problems. The high profile project also helped in keeping the field staff motivated to maintain high quality standards. QA plans were drawn in advance in consultation with contractors and inspection agencies, which included testing of raw materials, procedural aspects and acceptance tests for the end products.

Selection of agency

The QA in construction begins right from selection of the agency. QA at the tendering stage should entail a good prequalification system for contractors. On all major works, the contractors were prequalified on the basis of their organisational capacity, inventory of tools, plant and equipment, their financial capacity, past experience etc. Pre-bid meetings were held with prequalified contractors to discuss various tender conditions and were improved upon where necessary.

Selection of raw materials

The main items comprise of steel, cement and quarry products. 30,000 t HT steel for super structure was rolled by the Steel Authority of India Limited specially for the bridge. Nearly 80,000 t good quality high grade cement was procured departmentally in a phased manner. Around 15,000 t MS structurals and HYSD steel was also procured departmentally from major steel manufacturers. The sources of quarry products like boulders, coarse aggregates and river sand were identified in advance after necessary chemical and physical tests. The stone quarries were taken on lease to ensure uniform and controlled quality. It was considered prudent to control source of supply to ensure uniform tested quality throughout the work.

Concrete

Once the sources of coarse and fine aggregates, cement and steel are controlled, the most important aspect which affects durability is the quality control during mixing, placing and compaction of concrete. The quality of the cover to reinforcement also has a very important role to play in ensuring a durable structure.

The following general procedure was adopted for quality assurance.

1. Determine suitable mix design (grade of concrete used varied from M25 to M40). There was a review of the concrete at intervals to account for loss of strength of cement due to aging and also if there was change in source of supply of other ingredients.

2. Sources were identified in advance and ingredients tested on the basis of need.

3. Plants and equipment were clearly specified in contract conditions. Automatic batching plants and concrete pumps were used. On such large project where each pour may be of the order of 500-1000 m^3, these plants and equipment were essential to avoid unnecessary construction joints.

4. Inspection of placement / curing : Introduction of pour card for every concreting operation which documented the location and lift number of concrete, identification of mixer, grade of concrete, date/ time of concreting. The concreting started only after shuttering, reinforcement and concreting arrangements were found to be acceptable by the assistant engineer. The pour card also informs about trial mix and assessment of quantities of the aggregates, cement, w / c ratio and water content after adjustment of natural moisture content in coarse and fine aggregates. The concreting starts only after pour card is signed by the assistant engineer.

5. Laboratory testing : Apart from routine slump tests for workability and consistency during and after concreting, one sample consisting of three cubes for every 50 m3 of concrete was collected and tested for 7 to 28 days crushing strength, for confirmation and revision of mix, if necessary.

Steel work

For assurance in the quality of fabrication, well equipped fabrication shops like Braithwaite, Burn & Jessop Construction and Bharat Wagon and Engineering were selected for the fabrication of steel work. Detailed quality assurance programme (QAP) was developed before start of work. RITES inspected the shop fabrication. The erection was inspected by railway authorities. Sample features of the QAP are broadly given below :-

Raw materials

Steel plates structurals

1. 100 percent visual examination for identification and correlation with manufacturer's test certificate.
2. 100 percent check for physical condition for example pitting, corrosion , rusting, rolling defects etc.

3. 100 percent cross sectional measurements;
4. Ultrasonic test on 30 cm grid for thick plates>25 mm conforming to IS:2062 and acceptance as per ASTM-A435.

Fastners Rivets

1. 100 percent visual examination or verification with manufacturer's certificate and acceptance as per IS:1929, IS:1148 and IS:1149.
2. Bend and flattening test, dimensional check as per sampling plan by RITES and acceptance as per IS:1929.

Bolts, nuts, drifts

Same as that for rivets as per IS:1363 (bolts) and IRS:M4 Class III/IV (rivets) by the fabricator /RITES.

Paints and primers

1. 100 percent visual examination as per relevant IS:102 and IS:2339 by the fabricator and RITES.
2. Sample testing for humidity, corrosion, scratch hardness, pigment content and drying time by RITES as per IS : 1027 and 2339.

Manufacture

1. Jigs, fixtures, template: 100 percent examination and measurements as per IRS B1-79 and verified by RITES.
2. Cutting, cleaning painting: 100 percent visual check and 100 percent measurements for and dimensional accuracy.
3. Wire flux: 100 percent manufacturers test certificate as per IRS M-30 (wire flux) and IRS M-29 for electrodes; suppliers to be on RITES approved list.

Fabrication

1. Rivetting: 100 percent visual examination / measurement by Go/No Go gauges for fit up, dimensions and drilling as per IRS B1-79.
2. After rivetting: 100 percent hammer test and by gauges for soundness, deformed eccentric heads etc. as per Appendix V of IRS B1-79.
3. Pre-welding: Preparation and approval of welding procedure. Only certified welders are engaged, acceptance given jointly by Railways and RITES with macro etching test as per IS:1181.

Post welding:

1. 100 percent gauge measurement of size of weld; defect/profile of weld
2. 100 percent dye penetration test for all welds and 100 percent radiographic non-destructive test for all butt welds as per IS:482-1967.
3. Final offer as per erection mark, shop paintings and marks:
4. 100 percent visual specified checks for rivets and welds; 100 percent dimensional measurements;
5. 100 visual examination for surface finish, lettering /marking as per DODL; 100 percent measurement for thickness of paint.

Erection

The following checks were done for erection :

1. Shop erection of half span for camber measurements and proving of jigs and fixtures.
2. Camber measurement during and after erection of a span and comparison with required camber.
3. Ensuring erection sequence, matching, fitting and proper connections for further erection.
4. 100 percent check on field rivets and rivetting.

Bearings

Similar quality assurance plan was also drawn both for fabrication of bridge bearings, consisting of welding of steel structurals and forging of rollers. Some of the broad features of the QAP are given below :

Raw materials

All plates were tested for physical and chemical tests as per IS:961. The inspection agency was to ensure freedom from defects such as cracks, surface flaws, laminations and imperfect edges.

Forging

Raw material of forging had to be as per IS:1875 with minimum reduction ratio of 1.8:1.

Mechanical and chemical tests were conducted on test piece (per heat) as per IS:2004 C1.3. Rollers were tested ultrasonically after loading them, to ensure freedom from natural cracks under loaded condition.

Finished bearings

Each component of finished bearings were dimensionally checked as per drawing and prescribed tolerances for proper fitting of bearing components, smoothness of machining etc.

Vertical load test was conducted on bearings in assembled condition and test load applied for specified time. Bearing surface was painted with white lead as per IS:134 and tallow IS:887. All bolts/ nuts were thoroughly cleaned and dipped into boiled linseed oil according to IS:77. Oil bath was checked for free movement of rollers and leak proofness.

A QAP for similar other components of the bridge were also drawn and implemented.

Conclusion

The project organisation laid great emphasis on establishing a quality culture in the supervisory staff, both of the Railways and contractors. A well equipped field laboratory was also established at site and special workshops were organised for training of staff from time to time. Quality requirements were clearly defined in the beginning to avoid confusion. All these measures, have made it possible to achieve very good quality in all components of the project.

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