Challenges in Design and Construction of the World's Tallest Railway Bridge in Jiribam-Imphal New Railway Line

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Synopsis

The paper deliberates on the challenges of designing and constructing the World's Tallest Railway bridge of pier height 141m over river IRING in Manipur.

The site falls under highest seismic zone area of India (Zone-V). Due to the varying height and considerably high piers in seismic prone area, multimodal analysis is performed using peak ground acceleration (PGA) and acceleration response spectrum obtained from site specific seismic vulnerability study. Due to the pier locations on the steep slope of the hill, rigorous slope stability has also been ensured by rigorous analysis. For safety and stability against the high wind loads wind tunnel analysis had been resorted to. Fatigue analysis has been performed for the steel super structure as per the latest research findings.

1. Introduction :

Indian Railways intends to connect the capitals of the Manipur (Imphal) with Assam by railway link. The length of railway line in Manipur is about 111 km. The alignments of the railway lines pass through steep rolling hills of Patkai region, eastern trail of

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Himalaya, and as a result large number of tunnels and bridges need to be constructed. While the high mountains are penetrated by tunnel, the deep gorges between the mountain ridges are connected by tall bridges. The tallest of such bridges spans over a gorge at about 141m above its bed level with an overall length of 703 m a trail level. This bridge is stated to become tallest in the world from the point of view of pillar height surpassing the existing tallest of Mala-Rijeka viaduct on Belgrade-Bar railway line in Europe where the height of pillars is 139m.

With extensive study and discussion on possible alternative span arrangement of the bridges, considering the parameters like the length of span, type of span, location of the piers and construct ability it was finally decided that main super structures will be steel open web through type girders of 103.5 m span (c/c bearing). The piers are RCC hollow type with the tallest piers of141 m height. Other piers on the slope of the hills vary from19m to 98m height. The foundations are being designed with 1.5m diameter piles that penetrate into rock layers with maximum length of 30m.The critical issues of analysis and design involve preparation of site specific spectrum for seismic design of the bridge, rigorous slope stability analysis of the hill slopes on which the tall piers are standing, wind tunnel analysis to as certain the actual behavior of the structure in wind, fatigue analysis of super structure with the latest provision of fatigue. Apart from IRS (Indian Railway Standard), other codes like IS (Indian Standard), IRC (Indian Road Congress), AREMA (American Railway Engineering and Maintenance-of-way Association), UIC (International Union of Railway) and Euro code provisions have been taken into account.

The paper presents the challenges and techniques adopted for making this world Tallest pier bridge (Railway) as sustainable structures in a highly seismic zone at optimum cost.

In order to make this massive structure, the TAG/Expert Group for Best Techno-Economic Solution for Bridging Deep Gorges Hill Terrain Rivers has been formed.

2. Recommendations Of Tag :

- Technical Advisory Group(TAG) (total15 member) comprising of experts in the field of bridge design, Geo-Technical and Foundation Engg, Earthquake Engg, bridge construction etc. was constituted and they had made several observations
- The type of bridge and the span arrangement was finalised as per TAG deliberations
- Cost alone should not be the sole guiding principle for selection of a structure in such locations.
- Design should be governed by constructability, maintainability, durability and environmental conformity besides meeting functional requirements of the structure.
- The superstructure being on tall piers (>140 m) and these bridges being on remote location in the North East prone to subversive and extremist activities, they should be Simply Supported Steel Structures – open web girders.
- Because of better deflection response Concrete piers are more suitable and preferable. They are almost maintenance free and are therefore recommended for these four tall bridges.
- As piers are located on high approach slopes with the presence of fractured rocks, deep pile foundations are considered more suitable.
- Considering the general stability of the terrain, Raker piles may not be necessary.
- To follow appropriate IRS Codes for design. However where some aspects are not covered/not adequately covered by relevant IRS Codes, other codes like UIC, AREMA, BIS, IRC etc as well as some other well known international practices may be referred to. But at all times the design should conform to Good Engineering Practices.
- As the principal features of all four Major Bridges are similar, it should therefore be sufficient to adopt identical design parameters for all of them

- To use spans upwards of 100 M from those already used by IR as their logistics and structural behavior are well laid down and established.
- Provide a short shore or relieving span for making the span arrangement better and more effective from Good Engineering Practices.
- For lateral stability against wind load the girder has to be widened to provide adequate torsional rigidity.
- The area receives high annual rainfall (over 3000mm). Protection works have to be designed for such high rainfall due to very high run off velocity
- The top width of pier should be adequate enough to cater for special maintenance needs and launching.
- Apart from using STED software, slope stability analysis should be carried out by using Finite Element method such as PLAXIS software

3. **Superstructure:** The superstructure was considered to be a comparatively light structure considering the high seismic zone where more is the mass more will be the force in the substructure and foundation and will affect the slope stability of the hill. With this parameter in mind, RCC or PSC superstructure has been eliminated from the alternate bridge configuration study by the consultant.

   Among the different configurations of the tallest bridge ten options like, simply supported through type open web girder, continuous superstructure, steel cantilever arch, balanced canti lever arch and cable stayed options were considered.

   The guide line of seismic behavior of railway bridges published by IIT Kanpur in the year 2011 considers the simply supported super structure option preferable in view of the easier maintenance of the bridge. In the same light under present cases imply supported option has been adopted as the final choice by the consultant.

A maximum span length of 103.5m (c/c bearing) was considered as final option in view of allowable deflection of pier and as the same span had been successfully used by Railway.

The super structure members in the girders are of welded construction. All field connections are however riveted. The rear footpaths on both sides accommodated within the c/c of outer truss width which is 8.5m.

Substructure: The substructure was considered of three different types for alternate study– steel trestle type, RCC hollow cylindrical and RCC hollow tapered. As the heights of the piers are very high, the horizon tal deflection at the top of the pier is of considerable importance in view of the stability of the super structure and functional requirement. It was decided that the absolute deflection of the pier should be retained within H/500 subject to maximum value of 300mm in absence of any guide line given in any bridge code.

In light with the above, the different types of substructure was analyzed and the response to various load cases studied. It was found that the steel substructure is yielding much more than the RCC substructure under wind load case and the value of the deflection crosses beyond the allowable value mentioned earlier. Accordingly steel substructure option was discarded. Considering aesthetics and ease of construction, cylindrical hollow piers are adopted in the final design by the consultant.

All the bridges are designed for Broad Gauge single track carrying 25T maximum axle load. Spherical bearings have been envisaged for all the structures. The seismic restraint blocks are provided at the transverse direction to restrain the dislodgment effect.

4. Configurationof Bridge

According to the recommendations of the TAG, the bridge has been designed duly entrusting to the STUP Consultants.asper the design given by the consultant This bridge consists of eight spans

(1x69+5x103.5+1x69+1x28.0m) OWG/SS (SG); RCC pier, Piles). Following is the total detailed configuration of the Bridge.

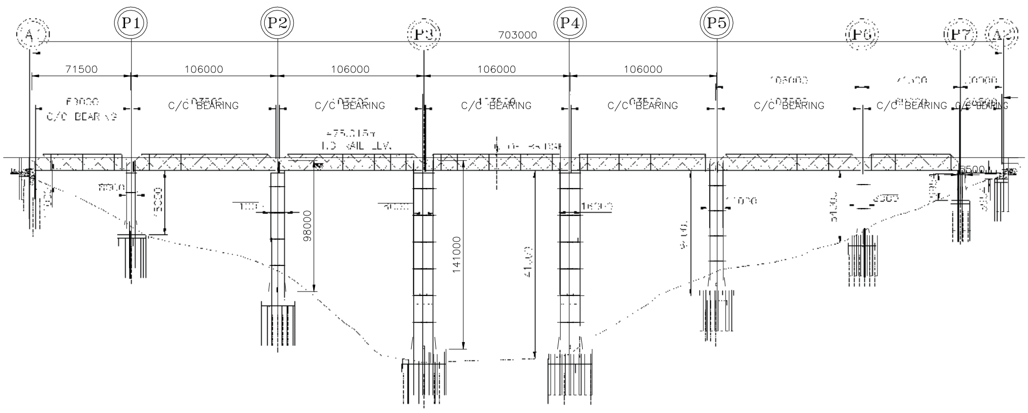
This mega bridge consists of two Abutment and 7nos of piers.

The P1&P6 is with 36 nos of pile of 30.0m depth. The pile cap of size 20.5x205x2.5m.the pier pedestal of size 12. 25x12. 25x1.0m. the pier is 9.0m dia and 48.0m height.

The P2&P5 is with 49 no's of pile of 30.0m depth. The pile cap of size 24x24x3.5m. the pier pedestal of size 16.5x16, 5x12.20m. the pier is 12.0m dia and 98.0m height.

The P3&P4 is with 81 no's of pile of 22.0m depth. The pile cap of size 31.8 x31.8x4.2 m. the pier pedestal of size 24x24x2.0m. the pier is 16.0m dia and 141.0m height

The P7 is with 36 no's of pile of 30.0m depth. The pile cap of size 20.55 x20.55 m. the pier pedestal of size 12.25x12.25x0.5.0m.the pier is 7.50m dia and 19.0m height.



Elevation of the bridge

5. Salient Feature of Br 164

Span:		1 x 69.0 + 5 x 103.5 + 1 x 69.0 + 1 x 29.4 m Steel Girders
Total Length of Bridge	:	703 Meters
Total Nos. of Piles	:	411 Nos
Total Length of Piles	:	13,000 Meters

Height of Piers in Metres	:	P1-48m, P2-98m, P3-141m, P4-141m, P5-94m, P6-54m, P7-20m.
Diameter of Piers in Metres	:	P1-9m, P2-12m, P3-16m, P4-16m, P5-12m, P6-9m, P7-7.5m.

Estimated Material Consumption

Cement: 2,55,000 Qtls.

Reinforcement	:	0,000 Qtls.
Mild Steel Plates	:	22,000 Qtls.
Structural Steel	:	75,000 Qtls.

6. Construction material

As the bridge is located in the remote area of the country and inspite of the vicinity of the national highway in most of the bridge site, the general road condition is extremely poor and carrying the materials to 141m height in hill slopes is very difficult task. Due to very narrow and winding nature of the approaches. So high grade construction material cannot been visaged. M40 grade of concrete has been adopted considering the limitation of quality of aggregate, the individual chord lengths which are to be transported to the site are also limited and accordingly the joints in superstructure are determined. Since the stone quality available in the vicinity of Manipur is of sedimentary rock formation. So pakur metal has been used for piers for strength point of view. The sand being used for piers is from pakur region and for the piles and pile caps is of Dimmapur river sand is being adopted.

7. Erection Scheme of the Superstructure

Cantilever erection scheme is the one and only erection scheme which is feasible at the sites. The approaches of the bridges are thus studied particularly in view of the availability of space for laying the approach span for cantilevering of the other spans. The design of the superstructure is thus undertaken considering the erection condition forces in the members in addition to the other necessary forces.

8. Mobilization of machineries & infrastructure

1. In order to handle this mega bridge. Huge machineries have been planned/ mobilized.

2. Total 7 Nos of Hydraulic Rigs of varying capacities mobilized to the site work with great difficulties like long trailers which cannot negotiable in the that roads due to sharp curves, (SUNWARD-28, MAIT-HR-260-2Nos,IMT-220,SOILMEC-260, SUNWARD-25-2Nos)
3. Conventional rigs 18No's to supplement the Hydraulic Rigs.
4. Wagon Drills two numbers to drill micro piles in hard rock.
5. Rock agures,soil Augers.
6. Core Barrels with Diamond Rollers-2Nos.

Roads made to P7,P6,P5

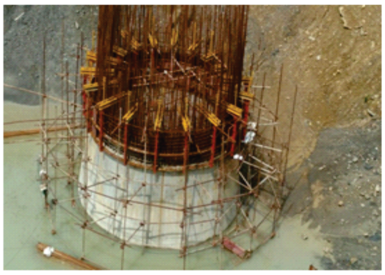
7. Batching plants-3 Nos
8. Crushing plant – 1No
9. Excavators - 12 Nos
10. Cranes 75T-1No, 50T-1No
11. Hydras-12T to 14 T-4Nos.
12. Transit Millers-12Nos
13. Concrete pumps-5No
14. Tippers –Required No's as per site requirement.

10. Challenges faced during the execution so far:

- There were no Approaches to A1, P1, P2, A2, P7, P6, P5 locations. The Hill slopes were cut and approaches made to these locations to facilitate the machinery and manpower to reach these locations.
- Movement of heavy machineries like Hydraulic Rigs, Heavy cranes in steep Hill slopes and ghat roads. The machineries were dismantled and brought to site and re erected the ghat roads were widened at several Hair pin bend locations. These machinery movements were escorted with special security upto place of working.
- Initially availability of heavy Hydraulic Rigs was a big issue. Supporting agencies help has been taken in mobilizing of 7Nos of hydraulic Rigs to this Bridge site where 411nos of piles to be drilled.
- At P3- the Hydraulic rigs theory totally failed due to boulder studded strata. The conventional Rigs 18 no's were mobilized for piling. At P-3 most of the piles were done by conventional Rigs, soil augers, rock augers heavy chisels.
- Huge ingress of water at P-3 & P4 locations which in the River bed.
- The slopes of P5,P4, P2 were slipped due to heavy monsoon during the year 2016-17.
- Several vehicles were fallen down from hill slopes due to slippage of roads.

- The service roads were concreted to facilitate the vehicles to ply in the monsoon also.
- Frequent bandh and blockades large scale insurgency hampered the progress.
- Local issues which can't be described on paper.
- P2 the piling has to be done in hard sand stone, the Hydraulic Rigs could not able to drill the boring. the micro piling using the Wagon drill has been resorted and each bore hole 6 to 8 micro piles were drilled to facilitate the hydraulic rig to have gripping and completed the boring.
- Under water concreting using Tremie for concreting.
- Concreting of tallest pier (141m) height is next to imposible,to overcome this twin lift has been deployed and being used.
- Special grouts were designed at site to attend the any patch work.
- Procurement of pakur metal during monsoon has become hurdle due to landslides and unfavorable road conditions.
- Non availability of skilled labour and procuring them from outside Manipur state is difficult due to ILP issues in the state.

The substructure work is likely to be completed by December 2016



11. Use Of Slip Form Technology

In view of the High rise structures i.e. 141m height piers Slip form Technique has been envisaged at this work site. This Vertical Slip form allows concrete to be erected as monolithic without cold joints structure, while reducing overall project duration. Lift arrangements for carrying 1.0m^3 of concrete. This also facilitates labour carrying also.

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A slip form consists of a framework of horizontal walers and vertical yokes. The slip form panels are connected to each other on inside of the waling. Each side of slip form is connected to vertical yokes that keep panels in position. The jacks for lifting of form are installed on horizontal crossbeam between yokes. When slip form is lifted, all the jacks are activated simultaneously. Hydraulic driven jack 3 T capacity at every 1.5m have been erected for easily slipping, the slip form panel is 1.3 meters high and made up of steel plates.

VIEW OF- P1

The concrete is placed in 100 to 250 mm thick layers whenever the freeboard height is sufficient. The slip form rate is adjusted so that initial set in concrete occur between 200 to 400 mm above bottom of the panel. The slipping of 2.50m to 3.0 m is achieved in 24hours cycle time.

13. Conclusion

Due to the criticality of the terrain, tall and varying height of the piers, large length of the bridge, and position of the piers on the hill slopes and the presence of severe most earth quake zone the construction of the above bridge is critical in all respect. The construction methodology of the bridge, transportation of the materials particularly in view of the winding approaches, the limitation of the size of the fabricated steel chord of the superstructure and erection of the superstructure besides large scale insurgency and bandh and blockades, poses very high challenges. During the execution all the above issues has been taken in to consideration with due importance to each issue and an effort has been made to achieve safe and sound structures with optimum cost which will serve the railway connections to Imphal which is remote area of the North-East part of India.