Overview of Enabling Works for Waterfront Structures—Design and Construction

K. Raja Rajan, D. Nagarajan, and T. Vijayakumar

Abstract Major bridges crossing mighty rivers must be constructed in flowing water. Constructing the sub-structure in water has been a challenging job for the contractor. Special construction techniques with marine fleets are to be adopted for waterfront construction. Enabling works like temporary piling platforms and cofferdams are used for pile and pile cap construction. Apart from this, enabling works like load out jetty to transport the materials from land to water; temporary walkway for access of workman to work location; temporary access bridge for construction vehicles movement; temporary liners for tower crane foundation; Concrete block to act as dead man anchor for barge movements are all required by the contractor for smooth functioning of the site as per construction schedule. Investment in enabling works by the contractor plays a significant role in the profit margin of the project, and of course, with utmost safety. Design of enabling works for waterfront structures involves hydrological data like afflux, bathymetry survey, current force, scour depth, and wave force to be taken cautiously for safe and economic design. The type of foundation and pile/well cap top level corresponding to water levels influence the construction scheme. The usage of geotechnical software like Wallap and Plaxis required for enabling work design to enhance the safety of the structure. Bathymetry and soil condition play a critical role in the design and construction of enabling works. Water Discharge quantity in the river along with water levels like low-water level, high flood level, and seasonal fluctuation of water levels has a great impact on the design of enabling works. Establishing enabling works for waterfront construction near an existing bridge is an additional challenge for the contractor. Along with the design, constructing the enabling works in water requires a special construction methodology and sequence of work. This paper provides insights into the design and construction of enabling works for waterfront construction.

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1 Introduction

To achieve a 5 trillion dollar Indian economy by 2025, India has decided to spend approximately 100 lakh crore on infrastructure projects over the next 5 years which will pave the way to an increase in jobs, ease of living, and improved infrastructure that will attract more investors toward our country. Capex amount shall be shared by the central and the respective state governments by 39% equally, and the rest 22% shall be by shared the private sector. At present, our country's growth is projected as 4.8% in the first half of FY20 and there may be a marginal increase in the second half of FY20 due to various economic disruptions within the country and globally by the pandemic effect. Current disruptions are only temporary, India will soon regain its growth and focus on infrastructure development. Out of 100 lakh crores, around 19% of the amount is planned to be spent on road projects in the upcoming 5 years.

Rivers are the lifeline of our Indian sub-continent. Bridges are always considered as the economy boosters of both connecting places due to increases in cash flows complementing each other economically. Both road and rail bridges connecting various parts of India pave for easy cargo transportation. The present government takes various steps to renew inland waterway transportation. Due to the increase in inland waterways transportation, there is a huge demand for long-span bridges. The engineering firm to which the authors belong has recently successfully completed the construction of the world's longest extra dozed cable bridge at Dhurgam Cheruvu Lake in Hyderabad. Few of the iconic bridges like Mondovi bridge at Goa, Narmada bridge at Bharuch were some of the project to exhibit the construction capabilities of their firm's river bridges construction. Currently, the same firm is carrying out construction works for the Mumbai Trans Harbor link project over the Arabian Sea, the Kachi Darga bridge project over the Ganga river, Second Ishwar Gupta Setu over the Hoogly river to specify a few of the ongoing river bridge projects.

Contractor competency is required for sub-structure construction in river bridges. Marine fleet's control will be of supremacy for speedy construction in water. A special construction method is required for waterfront construction. Many constraints like flash flood, monsoon season, workings in High tide level, etc., make the contractor plan meticulously the construction schedule. Investment in enabling works decides the contractor's profit in the project, so a detailed design of enabling works on waterfront construction is required by the contractor to maximize the profit with the utmost safety of the laborers and structure.

This paper provides an overview of temporary enabling works on waterfront structures from a contractor perspective for a typical bridge project rather than focusing on a single project. Various hydrological and design parameters have to be considered for designing the enabling works along with its construction methods have been discussed in this paper.

2 Hydrological Parameters (Project documents and reports on site-based data for waterfront structures xxxx)

Hydrological parameters are more critical to the design of the structure and for enabling works design. Many parameters like scour depth, afflux, current force, wind force on structure, water level variation, profile of riverbed, nearby existing structures, etc., shall be critical for enabling works design on waterfront construction (Nikonorov et al. xxxx).

Current force: Any part of the temporary structure which is submerged in running water shall be designed to sustain the horizontal pressure due to the water current. The current force is calculated as per IRC 6. Current force is calculated from the deepest riverbed level or deepest scour level to high-water level. The velocity of water current is normally mentioned in the contract document, if not, the same has to be measured at the site. The resultant current force shall be added to the horizontal load and the capacity of the member shall be verified.

Wind force: Wind force is calculated as per IS 875–Part 3. Base wind pressure is selected based on the topography of the project location. The exposed area of temporary works like liners, sheet piles, etc., is calculated for wind pressure and the resultant force shall be added to the horizontal force. If there is variation between high-water level and low-water level, then the current force up to high-water level is to be calculated and wind force is to be calculated up to low-water level. Both the combinations shall be used in the design of enabling structures.

Afflux: Afflux means the rise of water level due to the obstruction of water flow by any temporary or permanent structure. For the permanent pier location, the client/permanent designer would have calculated afflux due to the pier and pile cap. But, as a contractor, for sub-structure construction, any temporary structures like piling platform or cofferdam shall be in place till construction, so afflux effect due to enabling works to be calculated. Afflux calculation is carried out as per IRS code (Bureau of Indian Standards xxxx). For afflux calculation, the entire obstruction area of all temporary structures like cofferdam, temporary walkway, load out jetty, etc., are to be calculated, and then the temporary rise in water level due to enabling works is to be estimated. Based on afflux readings only, the top level of enabling work is finalized so that no water intrusion is possible into the enabling structures work area. Normally, designers tend to fix the top level just above the high-water level, but due to the afflux effect, the increase in water height may lead to the entry of water into the work area. So the top level of enabling works to be finalized is based on high-water level plus the water level increase due to afflux.

Water level variation: Low-water level and high-water level are the two different water levels normally recorded as the hydrological parameter. The difference between these two levels is water level variation. The high water level provided might be the water level recorded during the floods. So, it is the contractor's responsibility to study the water level with respect to seasonal fluctuation. Based on the maximum water level, the top level of enabling works is to be fixed. For example, to fix the temporary walkway, the top level is to be fixed diligently with respect to the water

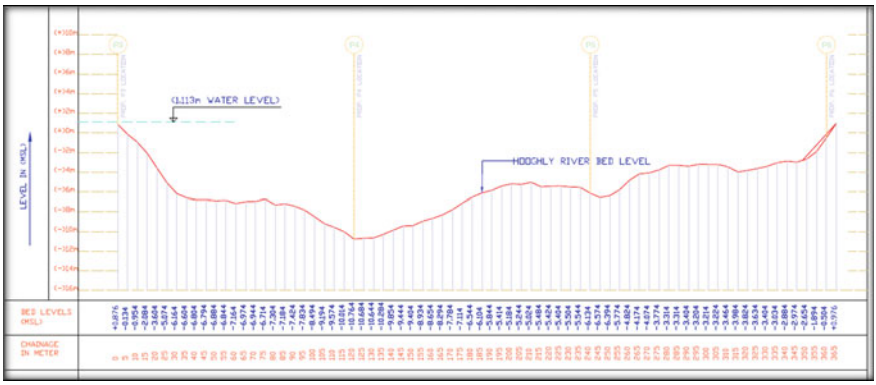

Fig. 1 Typical bathymetry of hoogly riverbed with pier locations

level for all season workings. In some cases, if the contractor wants to work during the off-monsoon season, then the contractor may take the advantage of low-water level, and the risk bounded is very high, since there may be an unprecedented delay or flash floods which is not in the hands of the contractor.

Profile of Riverbed: To know the profile of the riverbed, a bathymetry survey is to be carried out by the contractor. Sometimes the bathymetry shall be provided along with the contract document. Bathymetry is normally carried out at the center of alignment of the proposed bridge and at defined intervals in both upstream and downstream of the river. It is advisable to carry out the bathymetry survey up to the work area of the contractor so that the marine fleet's movement shall be decided based on the draft available. A typical riverbed profile is provided in Fig. 1 by a bathymetry survey which is carried out at the center of alignment.

Riverbed level variation is provided along the center line and pier marking is also provided for better understanding. The graph is plotted between change in ground level and chainage (i.e., from one side of the embankment to the other side). Water level and current force shall also be provided during the time of the bathymetry survey. Below fig shows a planned view of the bathymetry survey carried out at every 10m interval from one embankment to other embankments. Readings are taken every 10 m on either side of the proposed bridge and then the riverbed profile is developed.

At a few project sites, due to high scouring action, the profile of the riverbed changes from season to season. Some depositions from the upstream sides also get settled and change the profile of the riverbed. Contractors have to keep a record of changes in bed profile in order to maneuver the marine fleets and also to establish the enabling works (Fig. 2).

Scour Depth: It is one of the most significant factors which triggers the failure of the foundation of river bridges. Scour depth is defined as the erosion of soil at the riverbed. Scouring increases as the velocity of the water increases (Pizzaro et al 2020). It also depends upon the type of soil, effective diameter of the soil, and design discharge of the river. From IRC 78 (Bureau of Indian Standards xxxx), the below formula is used to estimate the scour depth.

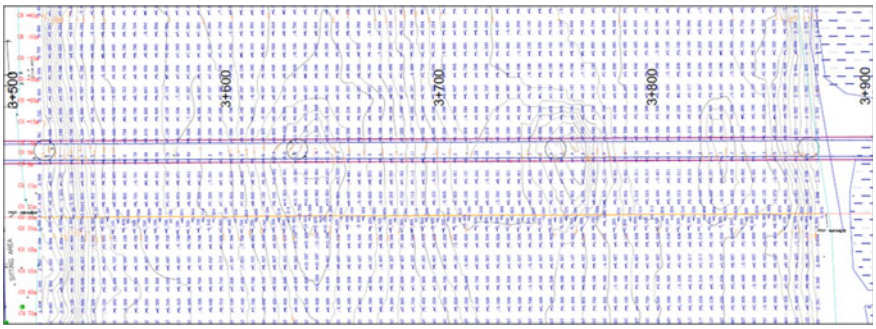

Fig. 2 Typical bathymetry of hoogly river in plan with respect to alignment

$$d_{sm} = 1 \cdot 34\left(\frac{Db^2}{k_{sf}}\right)^{1/3}$$

For enabling work design, the design discharge has been taken only for the last 5 years. Whereas, for the permanent design of the bridge, the design discharge would have been taken for 100 years. Since the enabling works are temporary, the last 5 years discharge value is referred to for estimating the scour depth. Silt factors and other parameters referred from the geotechnical interceptive report. For enabling works, scour depth is calculated from the recorded high-water level and multiplied by a factor of 2 as per IRC 78 code (Bureau of Indian Standards xxxx). The reason for choosing the last 5 years' discharge is to optimize the enabling work quantity and as well as accounting scour depth to some extent. Every time, bathymetry survey cannot be taken to monitor the bed level, so the easy way to have an observation on scour depth is just by checking the sound frequently. Sound readings provide a handful of data to the contractor for the planning of enabling works. Adopting the permanent pile scour depth for enabling work may not be feasible and economical.

3 Cofferdam

Cofferdam is a temporary watertight structure used for the construction of a pile cap. If the bottom of the pile cap is above the high-water level, then possibly cofferdam may be eliminated. Whereas if the pile cap bottom is below water level, then a cofferdam is the only solution to construct a pile cap. Many designers are matching the top of pile cap level to low-water level, so the requirement for cofferdam is increasing among contractors. To have a good architectural view, the pile cap is designed to be underwater or below bed level, whereas if the navigational channel is provided, then the possibility of the marine fleet may hit the pile cap which is below water. Further arrangements are to be provided for the pile cap which is present in the navigational channel.

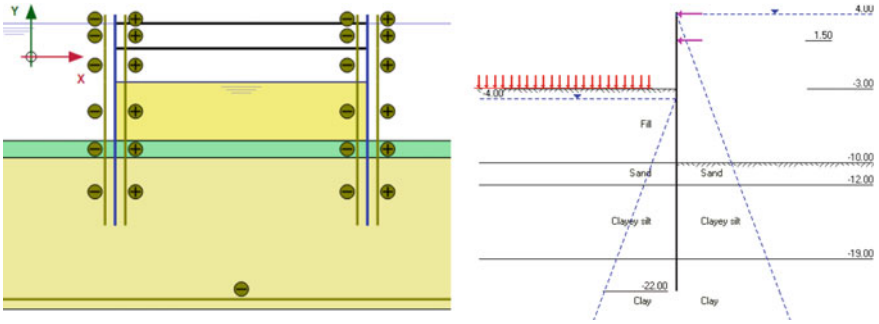

Fig. 3 Cofferdam design by PLAXIS and WALLAP software

Cofferdam is a steel structure with a steel sheet pile or steel liner depending upon the depth of water. Different types of sheet piles like U-piles, Z-pile, combinations of H-beam and Z-pile, double wall sheet pile, etc., are available from various standard sheet pile vendors. If the water depth is more, then the possibilities of steel liners shall be worked out. Structural steel struts are provided within the cofferdam as intermediate supports. Cofferdam design is usually carried out with the two available geotechnical software called PLAXIS 2-D and WALLAP. Based on bending moments, the section and grade of the sheet pile are chosen, and based on strut forces, structural steel members are fabricated and installed, global factor of safety is ensured with sufficient embedment depth. Filling may be considered inside the cofferdam till the pile cap bottom level (Fig. 3).

Cofferdam construction will be in marine mode. A vibro hammer is used to drive the steel sheet pile. The selection of a Vibro hammer depends upon the requirement of centrifugal force and amplitude based on the soil strata. Vibro hammer shall have sufficient capacity to drive the sheet pile till the designed founding level. Barges Dead Weight Tonnage (DWT) shall be calculated considering crane, Vibro hammer, compressor, etc., and suitable size and capacity of the barge to be brought at the site. Movement of barges shall either be by using a tow boat or with the help of a winch tied to a dead man's anchor.

4 Piling Platform

Piling platform is a temporary structure that is erected in the pier location over temporary liners. Temporary liners are positioned carefully between the proposed permanent piles. The friction capacity of driven liners is not to be affected during the permanent piling process. Over the temporary liner, using structural beams and panels, a temporary platform is erected. This platform is used for rig movement to all piling positions. Floating barges are used to stack the permanent liners, reinforcement cage, and Vibro hammer. It is economical and safe to have a crane over a floating

barge rather than on a piling platform. If the crane is to be mounted on a piling platform, then accordingly, the platform is to be designed and it may require more operational space. Platform to be designed for base pressure of piling rig and live loads foreseen over the platform. Temporary liners to be designed for the vertical load from the platform adding to the current force, wind force, and scour depth if any shall be accounted. Bracings on either side are to be provided between temporary liners.

Piling rig or A-frame shall be used to bore the pile. If a piling rig is proposed, then the piling rig shall be mounted over the piling platform. Transportation of the piling rig from the floating barge to the piling platform needs marine specialist assistance (Fig. 4).

Many factors like piling rig weight, water level, current flow, inclination of platform for marching piling rig, etc., are to be taken care of while transporting the piling rig. Feeding of materials during the piling process shall be over floating barges. Bored soil shall be stacked over a barge or platform and then disposed of as per contractual requirements. The entire platform shall be removed after the completion of the piling procedure. Floating barges, Vibro hammers, and cranes shall be used for erecting and dismantling the temporary piling platform.

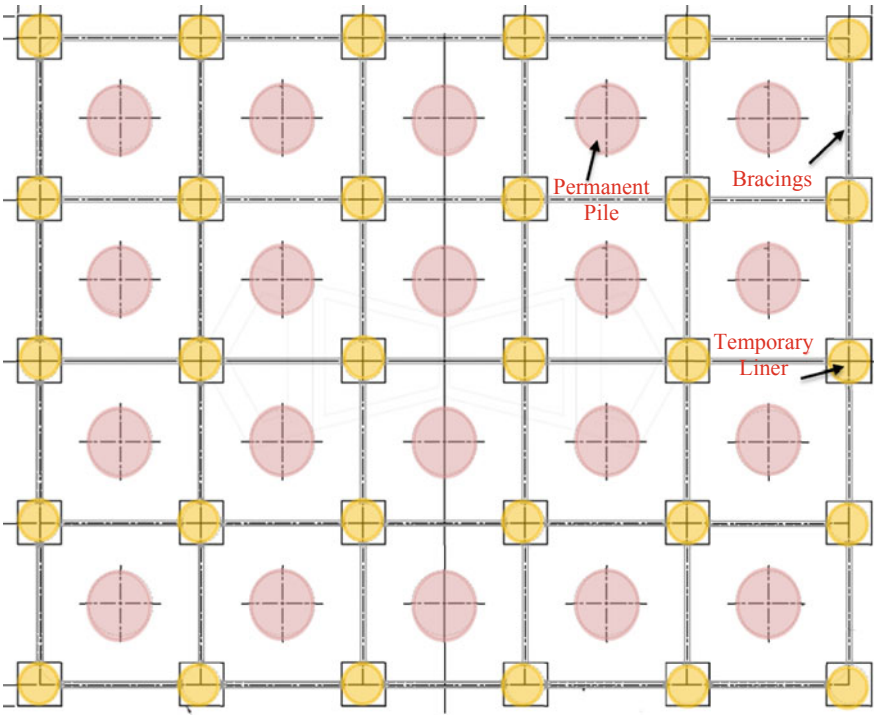

Fig. 4 Plan View of permanent piles and temporary liners for piling platform

5 Temporary Access Bridge

A temporary access bridge is built along the alignment for the entire river crossing stretch. This facilitates the construction equipment movement, labor movement, material movement, etc., from the land portion to the respective pylon/pier position. The temporary access bridge is supported by liners and structural beams with steel or precast concrete panel. The width of the temporary access bridge depends upon the volume of the work to be carried out within the given time schedule. Top level of the temporary access bridge depends upon the high-water level. This temporary access bridge shall be accessible for all monsoon periods. Standard IRC loading is taken for the design of temporary access bridge. This temporary access bridge can be built by moving the piling gantry to drive the liners and service crane to erect the superstructure panel.

6 Load Out Jetty

Load out jetty is a temporary structure used to transfer materials from land to water. Load out jetty comprises temporary liners over which a gantry will be erected to transport the materials. The capacity of the gantry is to be determined based on the forecast of the weight of materials to be shifted till the completion of the project. Load out jetty shall be spanned between land and water so that the gantry can lift the material from the trailer and load it over the barge. Gantry used to travel on rail beam which will be supported by liners at definite spacing. Liners are to be braced to resist the lateral forces.

The Riverbed profile is to be analyzed before setting up the load out jetty. A sufficient draft shall be available for decking the barge in the load out jetty. If sufficient depth is not available, then local dredging is to be carried out to ease the barge movement. Due to seasonal variation, the chances of deposition of sand are very much possible, which has to be monitored frequently. Some fender-type arrangement may be provided to the liners which are located on the waterside, so that direct collision of the barge on the liner can be avoided (Fig. 5).

7 Temporary Walkway

Temporary walkway is used as access for laborers and engineers to reach the work location across the river. Normally, the width of the temporary walkway shall be 1.5 to 2 m which allows access only for man movement and not for any vehicle movement. This is called a lifeline for a contractor till the completion of the project and the same shall be accessible during all monsoon seasons. By installing this temporary walkway, it will largely reduce the barge or small boat movement for

Fig. 5 Typical photograph showing temporary walkway and load out jetty

labor transportation. Adding to the labor movement, small pipelines are laid over this temporary walkway for bentonite and concrete transportation. These pipelines are connected at the embankment and with a pumping motor, bentonite and concrete are pumped to the desired location.

Temporary walkway is designed such that it stands on a single liner at definite spacing connected by a beam or truss over liners. If water depth and current velocity are more, then the single liner may not be feasible, and the contractor left with the option of a double liner or a larger diameter liner. Liner to be designed for lateral forces and to be ensured that there will not be any direct collision by marine fleets. High possibility of the barge hitting the liner is possible, and the contractor is to take care of the same. If any navigational channel is present, then a temporary walkway is to be provided accordingly matching the navigation span.

8 Summary

This technical paper has brought the overview and significance of temporary waterfront structures in bridge construction projects and highlights the hydrological parameters clubbed with the design of enabling works. The construction aspect of temporary waterfront structures has also been briefed and discussed. Design and construction aspects of major enabling works like piling platform, cofferdam, temporary access bridge, temporary walkway, load out jetty which is envisaged in a typical river bridge project has been discussed to bring the contingency in enabling works design.

9 Conclusion

Regarding Temporary Waterfront structures from the contractor's perspective, the following points may be noted:

- Scour depth shall be calculated for enabling works by taking discharge for limited years to economize the temporary structure. Scour depth shall be monitored frequently by maintaining the records of soundings at pre-defined locations.
- Sufficient data like water level, flash floods, and riverbed profile are to be collected from the nearest Port office and the same records are to be maintained till the completion of the project.
- Profile of riverbed to be ensured before planning for temporary waterfront structures. Marine fleet movements feasibility to be carried out with bathymetry.
- Current force, wind force, afflux, scour depth, and other hydrological parameters are to be considered in designing the enabling works.
- Cofferdam, piling platform, Temporary walkway, load out jetty to be designed considering all hydrological parameters and for the foreseen loadings.
- Top level of enabling works is to be decided based on water level variation and afflux calculation. Care is to be taken such that water shall not enter the work area.
- The usage of the temporary walkway and temporary access bridge for a project is based upon the location of the project and the time schedule of the project.
- Movement of marine fleets is to be carried out with marine specialist, and direct collision is to be avoided with temporary waterfront structures.

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