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Developing the operation and maintenance strategy for the Padma Multipurpose Bridge

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ABSTRACT: Padma Bridge will form a strategic link in the infrastructure of Bangladesh. The bridge will form part of the Asian Highway Route A-1, whilst also opening up South-West Bangladesh for investment and development. The bridge will not only carry a major highway, provision will also be made for a railway which will be part of a dedicated freight link to India. With key utilities such as power lines, gas pipelines and telecommunications cables on the crossing, the bridge can truly be described as a multipurpose bridge and providing interruption-free operation will be critical for the various stakeholders. To ensure the smooth operation of the bridge in future, Design Consultant AECOM, has developed a comprehensive operation and maintenance strategy for the bridge.

1 INTRODCTION

1.1 *General principles*

Padma Multipurpose Bridge has been designed to have a life of 100 years. This design requirement does not however mean that the bridge will be serviceable for 100 years without maintenance. Regular inspections and maintenance will be required on the bridge to ensure that it fulfils this requirement and continues serviceable well beyond its design life.

Durability and ease of access have been two of the driving principles behind the design of the bridge. All materials and bridge components shown on the Construction Drawings and detailed in the Specification have been selected to be durable and require minimal maintenance.

Figure 1. View of Padma Multipurpose Bridge

1.2 *Requirements of stakeholders*

The bridge shall not simply be a highway bridge it shall also accommodate the following:

- A single track railway capable of handling passenger trains to a speed of 160km/h and freight trains to the Indian Railways Dedicated Fright Corridor (DFC) standard – 32.5 tonne per axle.
- High pressure gas transmission line. The pipe shall be 30 inches in diameter (760mm) and shall operate at 1135 psi (11.79MPa).
- Ducts for telecommunications cables and other future utilities.
- Possible power transmission line, although this utility finally may be located off the bridge as the electromagnetic field from the cable may have an impact on other installations unless a suitable insulation system is provided.

With so many functions for the bridge, the operational requirements for the bridge need to satisfy all stakeholders. Each of the stakeholders will need to be provided with access to their installations, and therefore the design has to take account of the various needs.

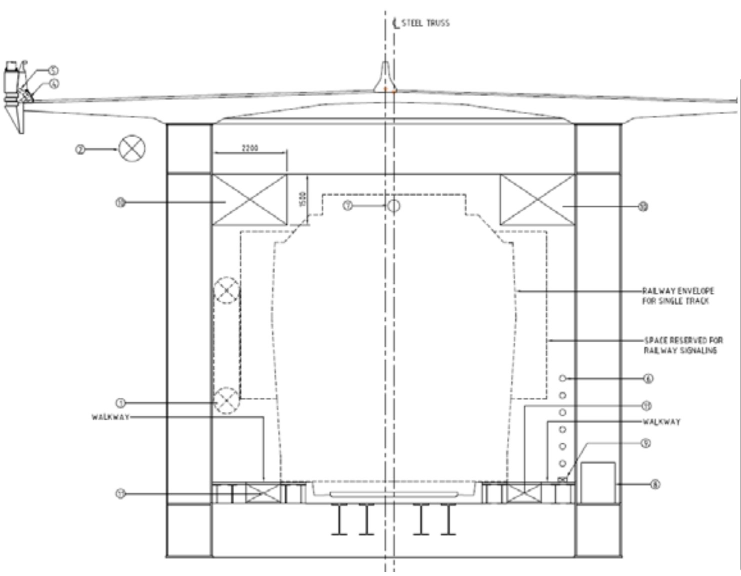
2 BRIDGE FORM

2.1 *Single level structure*

Previous studies had suggested a single-level bridge with the railway separating the two highway carriageways to be the preferred solution for the bridge. In such a scheme the deck width is increased to accommodate the combination of road and railway. Operational and emergency access to the railway can only be achieved from the fast lane of the highway. There is also less space to provide access walkways to each side of the railway.

In a single level bridge utilities are either located at the ends of the cantilevers or attached to the underside of the cantilevers or the structural girder. If placed at the ends of the cantilevers, the utilities will be accessible to the general public, which may have safety implications. If attached by hangers to the underside of the bridge, access for inspection and maintenance is more difficult.

2.2 *Two level structure*



ITEM No.	DESCRIPTION
1	THE HIGH-PRESSURE GAS TRANSMISSION LINE FROM THE GAS LINE IN MAWA ALONG THE EAST SIDE OF THE APPROACH STRUCTURE
2	ALTERNATIVE FOR 1
3	CORBEL FOR LIGHT POLES EVERY 37.5 m.
4	250 x 250 x 160 HAND HOLE FOR LIGHT POLE INSTALLATION
5	HIGHWAY LIGHTING POWER LINES IN BARRIER
6	FIBER OPTIC CABLES
7	ELECTRICAL LINE FOR FUTURE TRAIN ELECTRIFICATION
8	ELECTRICAL SUB-STATION FOR HIGHWAY LIGHTING
9	ELECTRIC SUPPLY LINE FOR HIGHWAY LIGHTING
10	400kV HIGH VOLTAGE TRANSMISSION LINE LOCATED 3 METERS FROM SMALL ELECTRIC AND DATA SERVICES
11	SPACE RESERVED FOR RAILWAY CABLES
12	LIGHTNING PROTECTION SYSTEM ON STREET LIGHT POLES AND RAILINGS SPACED AT 10-20m AS REQUIRED FOR GROUNDING TO PIERS, PILE CAPS AND PILES.

Figure 2. Cross section of a two-level Padma Bridge showing the accommodation of utilities

Figure 2 shows a two-level alternative cross section for the bridge. The highway runs on the upper level concrete slab with no direct connection to the railway or the utilities. The railway runs between the two truss planes at the same level as the lower chord. The railway runs on a concrete slab which is supported by four steel beams which connect to the lower cross beams. With this option walkways are provided to both sides of the railway, permitting both maintenance of the track and also acting as an emergency evacuation route.

The two-level bridge leads to a systematic means of arranging the utilities. Signalling and other cabling associated with the railway can be located beneath the walkways to each side of the railway. The high pressure gas pipeline can also be located alongside or beneath the railway walkways, and where necessary expansion loops pass under the railway. Telecommunications cables and any other utilities can similarly run alongside the railway, with easy access provided from the walkways.

It was concluded that from an operations and maintenance viewpoint the two-level structure is much preferred to the single level bridge. Combined with a lower overall construction cost, due to shorter approach viaducts and a lower deck weight, it was recommended that a two-level bridge be adopted.

2.3 *Concrete or steel deck*

Concrete bridges are perceived as having a lower maintenance cost than steel bridges, and therefore initial thinking suggested a concrete bridge to be the preferred option for Padma Bridge. There was however other considerations, in particular the effect of deck weight on the foundations. The poor ground conditions and severe environmental loading lead to a challenging foundation design and a relatively high proportion of the construction cost being in the foundations. In order to minimize the cost of the foundations, the weight of the deck needs to be reduced, and a steel deck is considerably lighter than its concrete equivalent.

In order to compare the steel and concrete deck options, the life cycle costs for the bridge were determined. Life cycle costs take account of the replacement of components, such as bearings and movement joints, and also general maintenance including the painting of steelwork. It was assumed that the first repainting would take place after 20 years and subsequent painting would take place at 10 year intervals thereafter. With a suitable paint system, these intervals are reasonable, if the paint system is applied correctly. The proposed paint system includes an inorganic zinc silicate primer, which acts to passivate the steelwork and gives very good durability.

The comparison of life cycle costs concluded that the steel truss bridge was not only the cheapest bridge based on construction costs it also came out to be the cheapest option over the whole life of the bridge.

2.4 *Selected scheme*

In summary the scheme design studies found that a two-level structure had many advantages from an operational viewpoint and a steel truss bridge was the most economic option. The two-level steel truss bridge (Figure 3) was consequently recommended as the basis for the detailed design phase for the project (Sham & Tapley, 2010).

Figure 3. View of the preferred option: two-level steel truss bridge

3 MATERIALS AND COMPONENTS

3.1 *Deck steel*

With the design of the bridge based on British Standards, the grade of steel adopted has also been based on the British system. Initial sizing of the truss members was based on Grade S355, which is the most common grade of steel used in bridge works. In recent years higher grades of steel have been used on the construction of major bridges, such as the Rion – Antirion Bridge in Greece and Stonecutters Bridge in Hong Kong. Consequently a study was carried out to determine the effect of using a higher grade of steel, such as S420, on section sizes of the truss.

The studies suggested that the weight of steel could be reduced by about 14% for the higher S420 steel grade. At the same time steelwork fabricators around Asia were contacted to determine the availability and price differential for the higher grade of steel. Due to the large quantities of steel required for superstructure of the bridge, steel mills are willing to produce this particular grade of steel. The cost differential was not significant between the grades especially when the effect of the weight saving was considered on the piles. Consequently the higher grades S420M and S420ML have been adopted for the truss steelwork on the bridge. The steel has been designated as thermo mechanical control process steel (TMCP) to ensure weldability, high toughness and weldability, which ultimately should ensure the durability of the bridge over its life. Consequently the benefits of the higher steel grade extend beyond the initial construction, ensuring the bridge will remain strong and reliable for years to come.

To protect the steelwork, an effective corrosion protection system needs to be adopted for the bridge. Paint technology has advanced considerably in recent years, in particular with respect to the primer which acts to passivate the steel and therefore effectively halting the potential for corrosion of the steel. For Padma Bridge an inorganic zinc silicate primer has been proposed, with three further barrier coats, including a top coat of polyurethane.

3.2 *Prestressed concrete deck slab*

The concrete deck will be constructed from a series of precast concrete slabs which will be placed on the steel truss by means of a lifting frame. The concrete deck slab will act compositely with the steel truss, connections provided in the form of shear studs. The composite action will apply tensile stresses to the concrete slab and therefore the slab is post-tensioned by means of tendons grouted in the slabs.

The joints between the precast slabs will potentially be a natural point for the ingress of water and therefore it is critical that the joints are well formed. An epoxy adhesive will be applied in the joints between the slabs, with temporary prestress ensuring compression in the joint during application. A waterproofing membrane will be installed on top of the concrete deck slab. The waterproofing will be a sprayed polymer based membrane, either fast cure polyurethane or an acrylic based system. Such a system will be essential in protecting the slab joints and the prestressing tendons in the deck.

3.3 *Bridge components*

There are a number of bridge components. For many of the bridge components it is not possible to adopt the design life of 100 years specified for the main bridge. Consequently realistic and practical design lives are stipulated for these components:

- Bridge deck surfacing period to first re-surfacing:> 25 years
- Bridge bearings /seismic isolators period to first major maintenance/replacement: > 40 years
- Movement joints period to first major maintenance/replacement: > 25 years
- Corrosion protection period to first re-coating: >20 years
- Corrosion protection period between subsequent re-coatings:> 10 years
- Bridge maintenance gantry: >50 years

3.3.1 *Deck surfacing*

The selection of a suitable form of surfacing is an important consideration in the design of the bridge. The surfacing should be sufficiently thick to protect the bridge deck against the action of traffic, while the composition of the surfacing should be such that it is durable and susceptible to rutting due to expected heavy traffic loading.

In order to avoid rutting it is critical that there be an effective bond between the surfacing and the waterproofing membrane. This is particularly the case in tropical climates such as Bangladesh, where high temperatures and moisture make the application particularly onerous. It is also important to provide sub-surface drains for any water that collects between the membrane and the surfacing. There are two layers to the surfacing, a 60mm thick base course and a 40mm thick wearing course.

3.3.2 *Bridge bearings and seismic isolators*

The bridge articulation system should be designed to be robust and durable. Initial studies on the bridge suggested a system based on sliding bearings and shock transmission units (STUs) would be most suitable. In the case of an earthquake the STUs lock-up evenly distributing the load to the bridge piers. Such a system would however require 320no. STUs, each of which would require regular inspection and maintenance. An alternative scheme based on seismic isolation was also investigated. This system uses friction pendulum bearings. Friction pendulum bearings use the characteristics of a pendulum to lengthen the natural period of the isolated structure so as to reduce the input of earthquake forces. The damping effect due to sliding mechanism also helps mitigating earthquake response. Since earthquake induced displacements occur primarily in the bearings, lateral loads and shaking movements transmitted to the structure are greatly reduced. The friction pendulum bearings are less susceptible to wear and damage than the STUs. The reduction in load applied to the substructure during an earthquake is also beneficial to the long-term durability of the structure. For the revised scheme, according to AECOM's analysis, plastic hinges will no longer form in the bridge piers during a seismic event and thus repair works to the bridge should be less extensive.

3.3.3 *Movement joints*

For Padma Bridge the movement joints will be located at piers which is generally the preferred location from an inspection and maintenance viewpoint. For the highway the joints will be the modular type, consisting of a number of steel beams laid in the transverse direction with rubber strips installed between them. The movement joints have been designed to move in such a way that the gaps between the steel beams expand and contract evenly. Uneven forces will be produced within the joint system if debris or strayed objects are trapped in the rubber strip, and the conditions of the rubber strips shall be thoroughly checked during inspections.

In the design provision has been made for a railway. Joints in the rails will be required at the same intervals as the joints between the bridge modules. The design of the bridge has been such that the displacements and rotations of the bridge at joints are within set limits suitable for railways. These continue to be met during earthquakes and ship collision events, although additional inspections will be carried out of the joints following such occurrences.

3.3.4 *Deck drainage*

Gullies are provided at regular intervals along the bridge, with a spacing not exceeding 25m. The actual spacing is determined on the basis of rainfall not exceeding 120mm/hour, which should satisfy all but the worst cyclone at the bridge site. The rainwater will discharge directly to the river, with suitable down pipes ensuring that no staining of the deck soffit will occur.

4 INSPECTION REQUIREMENTS

4.1 *General requirements*

The bridge has been designed with ease of inspection and maintenance as a paramount feature. Access will be provided by walkways alongside the rail track with stair connections to the top slab and piers at regular intervals.

A dedicated team of engineers and inspectors will be required to inspect the bridge on a regular basis. The team will refer to the Operation and Maintenance Manual prepared on completion of the bridge. There will be four fundamental levels of inspection:

- *Visual Inspections* - conducted by inspectors on a six month cycle. The inspections are intended to identify any faults that may appear so that, either a further more detailed inspection be carried out, or immediate repair works take place.
- *Close Visual Inspections* – more detailed inspections carried out by engineers on a two-year cycle. For close visual inspections the engineers must be within touching distance of any surface/component to be inspected. The inspection is intended to identify any faults, which can then be included in the maintenance programme.
- *Principal Inspections* – an engineer will carry out a Principal Inspection at a minimum interval of six years. The engineer will examine materials, equipment, installations and components in details. It may require the use of specialist equipment.
- *Special Inspections* – to be carried out over the whole bridge by engineers following a major event – cyclones, severe flooding (with potential for deep scour) and earthquakes.

The Operation and Maintenance Manual produced at the completion of construction will identify key areas for inspections and outline the exact period between inspections for each component. Components such as the friction pendulum bearings and movement joints will have a shorter cycle time than the main bridge structure due their susceptibility to damage.

4.2 *Foundations*

The foundations of Padma Bridge have been designed to be robust and durable do not require frequent inspection (Sham, Yu & De Silva, 2010). The steel piles have been designed with a sacrificial layer of steel to ensure that the structure of a pile is not affected by corrosion. The most onerous locations for such corrosion will be in the splash zone and inspection can be conducted in this area during periods when the river level is low.

The piles are subject to highest loading during seismic events and in the case of ship impact. Consequently the bridge should be subject to "Special Inspections" following such events, and if damage is suspected, underwater inspections may be required using remote underwater cameras. It should however be noted that the bridge has been designed without plastic hinges being formed in the foundations during a seismic event and therefore inspections should be just a precaution, repair work should not be necessary.

4.3 *Access equipment*

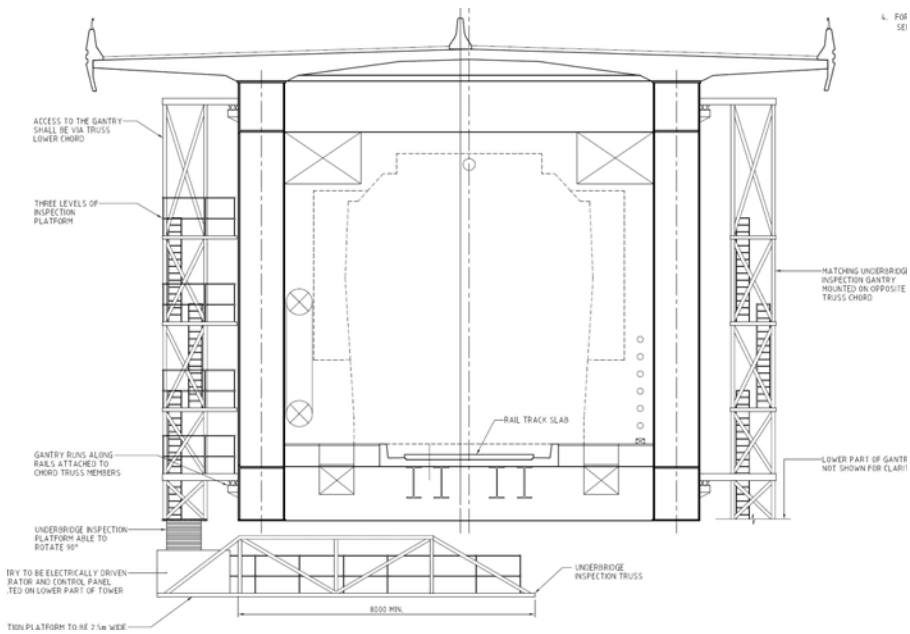


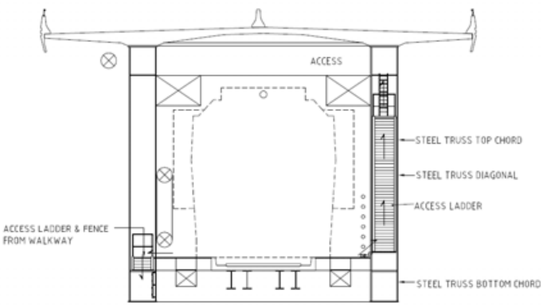
Figure 4. Bridge inspection gantries are provided to inspect and maintain the sides and underside of the bridge.

Two maintenance gantries (Figure 4) shall be provided for access to the sides and underside of the bridge. The access gantries shall be mounted on rails attached to one side of the superstructure truss. The gantries shall be designed to travel the length of the bridge and articulate a platform under the lower chord of the steel truss in each span providing access for under bridge inspection and maintenance.

Features of each gantry include:

- Tower used to inspect sides of truss is approximately 13m high with ladders and three levels of platforms.
- Driving system for the gantry is mounted on the tower. The gantry is guided along rails attached to the upper and lower chords of the truss. An electric generator provides the power.
- The lower platform is 2.5m wide and approximately 10m in length. The entire width of the underside of the bridge can be inspected, with access being provided by either the north or south gantry. The platform can be rotated through 90° so that the gantry can pass bridge piers.
- Maximum payload for a gantry is 2 tonnes, with the flooring designed for 150kg over a 500 x 500mm area.

4.4 *Internal access to truss members*



Cross Section of Deck Showing Access Points

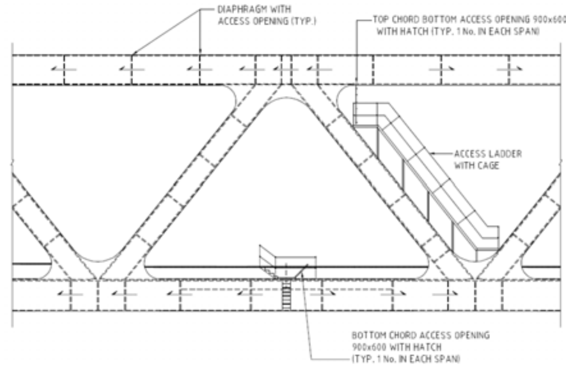


Figure 5. Access to Internal Members of the Steel Truss

The steel truss members are hollow and with many members being 1.6m in depth it is important to provide internal access not just during construction but also for inspection and maintenance purposes during the life of the bridge. Figure 5 shows the access arrangement to the internal voids of the truss members. The openings are 600 x 900mm. Openings are provided through the diaphragms so that maintenance staff are able to walk the length of the bridge through the upper and lower chord members.

4.5 *Walkways and staircases*

Access to the bridge will be by means of stairways on the transition piers, the piers at the interface of the main bridge and the approach viaducts (see Figure 6). Alternatively access can be provided along the railway itself, although the use of the railway for such functions will impact operations.

Two intermediate piers in the river will also be provided with staircases to pile cap level. This access is primarily intended for emergency use, evacuation of a train, but could be utilised as an access for inspection and maintenance.

Figure 6. Transition Pier between Main Bridge and Approach Viaduct will be used as access and also as an emergency evacuation route.

5 MAINTENANCE

The regular inspection programme will identify faults as they develop and also highlight areas where components and protective coatings require replacement due to age and gradual deterioration. It is important that the maintenance authority should maintain a database of faults and repairs carried out. The database should also highlight any areas, that during design and construction, have been identified as being particularly sensitive to damage and deterioration.

5.1 *Steel truss members*

The external surfaces of the truss are protected by from corrosion by robust painting system. There will however be perforations at locations where items are attached to the bridge: supports for the gas pipeline, telecommunications ducts, architectural lighting etc. and the inspection and maintenance regime should check any leakage through these holes.

With a railway running on the lower deck, the members supporting the railway will be particularly prone to the effects of fatigue. The latest knowledge in weld details has been applied in the detailed design and for the connection between the railway support beam and the lower cross girder high strength friction grip bolts have been used. Further assurance will however be required through a robust inspection and maintenance regime.

The surfaces of steel members, both external and internal, will be checked for rust and flaking. Immediately following completion of the bridge defects in the application of the paint system may lead to some local deterioration of the paint system, leading to local patch repairs. Over a longer period of time the outer barrier layers of the paint system will deteriorate, although the steel itself should not be adversely affected due to the primer coat. It is however expected that after at least 20 years, the paintwork system, and certainly the barrier layers will need replacement.

5.2 *Concrete surfaces*

Concrete surfaces can deteriorate in a number of ways:

- *Discoloration* may be caused by mould growth or corrosion of embedded steelwork or reinforcement. Depending on the degree of the staining, action should be taken to repair the defective work.
- *Cracks* which can be classified into three categories:
  - (i) Dead cracks – caused by some event in the past which is not expected to recur. A long as within design limits and no growth in either length or width is recorded, no action needs to be taken. If the width is excessive (>0.2mm) crack sealing should be implemented, with an epoxy resin.
  - (ii) Live cracks – do not remain constant in width but open and close usually with changes in temperature or loading. Such cracks are more difficult to seal.
  - (iii)Growing cracks – increase in width over a period of time because the loading causing the growth is continuing. The reasons for such cracks could be corrosion of reinforcement, concrete shrinkage or creep. It is important that the cracks are monitored and observed over a period of time, and action taken if the crack width becomes excessively wide.
- *Spalling* in concrete can occur when cracks formed, within the concrete, have extended to the surface. The reason for the spalling should be investigated before any repairs are carried out. Spalled concrete should be retained for further testing.

5.3 *Miscellaneous steelwork*

Handrails, walkways, access ladders, stairways and hatches shall be checked for loose nuts, security, signs of corrosion and surface deterioration. If any maintenance or repair to the miscellaneous steelwork becomes necessary then it should be carried out with minimum delay to avoid further deterioration.

5.4 *Geometry survey*

The geometry of the bridge shall be surveyed at regular intervals, and particularly after a major event, such as an earthquake, deep scour due a major flood or a ship collision. Anomalies in the geometry, if identified in a reliable survey, tend to reveal distress or defects which shall be thoroughly investigated in order that remedial actions can be formulated and taken.

6 OPERATIONAL REQUIREMENTS

6.1 *Severe weather*

The rigid and robust design of the bridge should ensure that the bridge can operate for both road and rail traffic in bad weather conditions. For severe weather conditions, measures will have to be taken to restrict traffic, and if necessary, close the bridge.

In strong winds, the first action to be taken will be to restrict the bridge to high-sided vehicles (container trucks and buses). On other bridge a typical threshold sustained wind speed is 70km/h with gusts regularly exceeding 85km/h. For trains a similar speed will be adopted on the bridge, although the closure of the railway is more likely to be dictated restrictions in force generally for the railways.

6.2 *Prohibited vehicles*

The basic operational philosophy for prohibited vehicles will be to detect the vehicle before it enters the bridge approach slip roads as once the vehicle is on the slip roads it is unlikely it can be stopped before reaching the bridge. Prohibited vehicles will include dangerous goods, overweight vehicles and wide loads. In certain circumstances such vehicles may be escorted across the bridge.

Prohibited vehicles will need to be detected by patrol staff based at the start of the slip roads.

6.3 *Abnormal loads*

Padma Bridge has been designed to accommodate abnormal loads up to the classification of 45 units of HB load under BS 5400 Part 2. The movement of abnormal loads will need to be planned in advance with the bridge authority. The movement of abnormal loads is normally timed at times of low traffic flow and when heavily laden freight trains are not planned to cross the bridge.

6.4 *Traffic incidents*

The term traffic incident is used to describe vehicle breakdown and traffic accidents, either vehicle to vehicle or vehicle to structure. Detection of traffic incidents will normally be by bridge surveillance staff. After an incident has been detected, patrol and recovery vehicles will be dispatched to the incident location by the operational controller of the bridge. Depending on the nature of the incident emergency services (police, fire, and ambulance) will also be called.

The operational controller will also need to make decisions on whether to implement partial closure of the bridge, for example single lane or complete carriageway.

6.5 *Operation of the railway*

The railway envelope in the lower deck provides for a single track railway across the bridge. With railway only being single track, strict procedures will need to be followed with respect to the timing of trains crossing the bridge. To maximise the usage of the bridge by trains, fixed periods will be provided for trains travelling in each direction.

The bridge has been designed for passenger trains travelling at speeds up to 160 km/h. It has also been designed to the requirements of a Dedicated Freight Corridor (DFC) under Indian Railway standards. The DFC loading is one of the most onerous rail loadings in the world. The rail envelope has also been designed for double stacked containers and possible future installation of overhead electrification lines.

6.6 *River traffic*

The bridge is intended to provide the minimum inconvenience possible to passing river traffic. The bridge piers have been designed to withstand collision from a 4000DWT vessel. This vessel is larger than all the vessels listed in the Ship Register for the river and also future coal handling ships which may travel along the river.

With spans of 150m, the horizontal clearance between piers is greater than 130m, substantially more than the required clearance of 76.2m. A vertical clearance of 18.3m to Standard High Water Level is provided by the superstructure of the bridge, an additional allowance of 400mm for the effects of global warming on the levels of the river.

7 CONCLUSIONS

The Padma Multipurpose Bridge will provide an essential link in the transportation infrastructure of Bangladesh. It is consequently very important that the bridge is able to operate for many years, with the minimum of maintenance. To this end the design of the bridge has only used the most durable components, which can be inspected and maintained with ease and in safety. The operational procedures for the bridge have been developed to ensure that there will be minimal disruption to traffic during periods of maintenance and during severe weather conditions.

ACKNOWLEDGMENTS

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