BD Deck 1: A New Precast, Pre-stressed Concrete Panel Bridge Deck System

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MAY, 2017

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In partial fulfillment of requirements for the degree of

Bachelor of Science in Civil Engineering

Under the Supervision of

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AHSANULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

MAY, 2017

DEDICATION

TO OUR
PARENTS, FAMILY AND TEACHERS

APPROVED AS TO STYLE AND CONTENT
BY

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DECLARATION

We hereby declare that the work performed in this thesis for the achievement of the degree of Bachelor of Science in Civil Engineering is "***BD Deck 1: A New Precast, Pre-stressed Concrete Deck Panel***". The whole work is carried out by authors under the guidance and strict supervision of **Dr. Enamur Rahim Latifee**, Associate Professor of the Department of Civil Engineering at Ahsanullah University of Science and Technology (AUST), Dhaka, Bangladesh.

It is also being declared that the work performed in this thesis has not been submitted and will not be submitted, either in part or in full for the award of any other degree in this institute or any other institute or university.

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ACKNOWLEDGEMENT

First and foremost, we would like to thank the Almighty for blessing us with the opportunity to conduct such an important academic research to aid in the progress of mankind.

From the bottom of our hearts, we pay the utmost respect to our thesis supervisor and mentor, **Dr. Enamur Rahim Latifee**, Associate Professor, Honorable faculty member, Department of Civil Engineering, Ahsanulllah University of Science and Technology. Without his assistance and dedicated involvement in every step of the work, this paper would have never been accomplished. We would like to thank you very much for your constant support and guidance during the entirety of our thesis work.

Our gratitude also extends to our parents and family for their unconditional trust, unwavering support and endless patience throughout our lives.

Last but not least, a heartfelt thank you and utmost respect to all our teachers, friends, seniors as well as juniors- who have all taught us how to be successful academics and worthy individuals, during this beautiful journey of four years.

ABSTRACT

Strong communication is one of the key factors for development. Bridges are one of the major components of a communication network. More so for Bangladesh since there are around 700 rivers here. However, there are insufficient bridges in the country for connectivity which is hampering the economic growth. Also, the existing bridge types require long construction periods of 2 to 3 years and have service life of only 60 years. In Bangladesh, reinforced concrete (RC) girder bridges are used for spans less than 24m, pre-stressed concrete (PC) girder bridges for 24m-48m spans, and PC box girders for spans greater than 48m. RC and PC girder bridge decks are cast-in-place (CIP), which have an increased cost in terms of construction, maintenance etc. Box girders are heavy and hence require high-capacity trucks and cranes for transportation and member erection. In this paper, the concept of a new bridge deck type has been presented, named “BD-Deck 1”. This concept is unique in its design. It is a segmental bridge deck type that consists of full-depth precast, pre-stressed individual concrete panels (PCP). This bridge deck system will use the existing designs of RC and PC girders as supporting girders, but will replace the CIP bridge deck with PCP full-depth panels. The proposed bridge type will be much more cost-effective, rapid in construction and have a longer service life with minimal maintenance. The panels will be re-usable if needed for new bridges or rehabilitation of old bridges. Preliminary estimation shows cost savings of around **4.31%** in concrete material cost**, 83.59%** in reinforcement cost, **54.02%** in labor cost and **60.85%** in transportation cost in comparison to the CIP deck bridges constructed in Bangladesh. Moreover, if we consider transportation and maintenance, this proposed deck system will be much more economical. It will shorten the overall construction period since these are all precast panels; they need only be transported to the job site. The service life of this deck type will be 100 years, which is much higher than that of CIP systems of 60 years. Some types of PCP panels were first introduced in the USA in the early 1960s. In Bangladesh, pre-stressed technology was first introduced in 1977-1978 over the Boral River for PC girders. Since these panels are significantly more lightweight and smaller compared to box girders, the same carrier truck can carry a lot more panels for transportation during construction and are easier to place at the job site. Construction costs are reduced as there need not be trucks and machinery required for CIP decks. These panels will expedite deck bridge construction and create a more durable and sustainable system. The design can be implemented on a few trial bridges and if successful, the panels can be mass-produced for multiple bridge constructions, thereby reducing the production cost even more. The design conforms to all local and international standard specifications.

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List of Symbols and Abbreviations

AASHTO = American Association of State Highway and Transportation officials.

ACI = American Concrete Institute.

ASCE = American Society of Civil Engineers.

BBA = Bangladesh Bridge Authority.

CIP = Cast in Place.

DOT = Department of Transportation.

FD = Full depth.

HPC = High Performance Concrete.

PC = Pre-stressed Concrete.

PCP = Precast Concrete Panel.

PD = Partial depth

RHD = Roads and Highway Department.

RCC = Reinforced Cement Concrete.

SIP = Stay in place.

L = Length of span.

M = Moment.

As = Area of steel.

$F^{/}c$= Compressive strength of concrete.

F_y= Grade/Yield strength of steel.

d = Depth

Chapter- 01

INTRODUCTION

1.1 GENERAL

Bangladesh is a beautiful, riverine country. Across the map of Bangladesh countless rivers and tributaries, big and small, form intricate crisscrosses. The Padma, Meghna and Jamuna are the largest rivers. The Buriganga, Sitalakhya, Dhaleswari, Teesta, Madhumati, Gumati, Karnafuli etc. are the smaller rivers. Most of the rivers of our country originate from the great Himalayas and ultimately flow into the Bay of Bengal. There are hundreds of big and small rivers in our country, and perhaps that is why Bangladesh is majorly an agricultural country. The prosperity of this agriculture depends on the rivers, as they have ensured our soil is rich and fertile. So rice, jute, tea and other crops grow abundantly here. However, our rivers are also play an important role in our communication or transport. Boats, launches and steamers move on these rivers during all seasons, all year round. People as well as goods are carried from one town to another, from one port to another. Most of the cities, towns, industries, haats, bazaars, trade centers are on the banks of or at least nearby the rivers. The products of mills, factories and industries are easily carried to different places through rivers; raw materials can be carried easily to factories and industries. This is how these rivers help in commerce, trade and industry. Some of our rivers are sources of energy. Goalpara and Karnafuli hydro-electric projects are used to solve electricity crises. The rivers we have are a great influence on the people of our country. We love the rivers, the freshness of their water and the sound of their rushing music. Unfortunately, sometimes the rivers can cause great damage to our life and property. In the rainy season, the rivers overflow their banks and cause floods, wherein people have to bear untold sufferings. In spite of the numerous inconveniences and recurring damages, our rivers are useful to us in many ways that make up for the suffering. Moreover, the rivers in Bangladesh are a blessing to us, at times in disguise; they are the source of our wealth, health and happiness.

In order to establish connections and proper communication between the land masses in Bangladesh, bridges became necessary. As such, the Jamuna Bridge was constructed across the Jamuna river, the Bhairab Bridge across the Meghna river and the first such megaproject in the country by the name of “Padma Multipurpose Bridge”is currently being built across the Padma river.Another important bridge is Shambuganj Bridge situated at Mymensingh over the river Bhrammaputro. This bridge connects greater Mymensingh with other parts of the country.In the paragraph below, brief overviews of several prominent bridges around Bangladesh have been given.

1.2 Bridges in Bangladesh

Padma Multipurpose Bridge

The construction work of Padma Bridge is well underway, today. The Padma Bridge, which at 6.1 km will be Bangladesh’s longest bridge when completed, will cross the Padma River 50 km south of Dhaka, the capital. The bridge’s two-level superstructure will carry four lanes of traffic on the upper level, with a rail line and gas transmission line below. The project also includes 13.8 km of approach roads. The bridge is being designed by the New Zealand office of Maunsell AECOM, with support from the firm’s Hong Kong office. Design is expected to be completed by December 2010, with construction commencing in 2011 and lasting about three and a half years.

Bangladeshi officials predict the bridge will spur development in southwestern Bangladesh and provide better links to the port of Mongla. The bridge is expected to cost $2.4 billion, of which international aid agencies and development banks are committing $2.25 billion. Funding sources include the World Bank, Asian Development Bank, Islamic Development Bank and the Japan Bank for International Cooperation.

Jamuna Multipurpose Bridge

Bangabandhu Bridge, also called the Jamuna Multi-purpose Bridge, is a bridge opened in Bangladesh in June 1998. It was constructed over the Jamuna River. It connects Bhuapur on the Jamuna River's east bank to Sirajganj on its west bank and established a link between the eastern and western parts of Bangladesh. It is the 92nd longest bridge in the world and the 5th longest in South Asia. The Jamuna Bridge carries both broad gauge and meter gauge rail tracks, and it is a 4-rail dual gauge line. It also carries pylons for a power line. The main bridge is 4.8 km long with 47 main spans of approximately 100 meters and 2 end spans of approximately 65 meters. The total width of the bridge deck is 18.5 meters.
Jamuna multi-purpose bridge was constructed at a cost of $62 million. The cost of construction was shared by IDB, ADB, OECF of Japan, and the government of Bangladesh. Of the total, IDA, ADB, OECF supplied 22% each, and the remaining 34% was borne by Bangladesh. Already, an average of more than 3,000 vehicles is crossing the bridge daily, and toll collection has provided a welcome boost to government revenue. Spurring on the development of export processing zones and private tourism complexes on both sides, the bridge is creating jobs, promoting investment, and increasing trade. It has become a tourist spot since it's opening. There has been a resort, few hotels, and amusement park already created. Thousands of people flock to Jamuna Bridge resort every day.

Meghna Bridge

Meghna Bridge is a road bridge in Bangladesh. The official name of this bridge is Japan Bangladesh Friendship Bridge, but it is popularly known as Meghna Bridge. It was constructed over the Meghna River, which is one of the major rivers in the country. The bridge was opened on February 1, 1991. The bridge is located along the Dhaka-Chittagong highway. The total length of the bridge is 900 meters and width is 9.2 meters. The bridge has thirteen spans. Meghna Bridge was built with the financial help from the Government of Japan. It was constructed by the Nippon Koei Co. Ltd. which is an independent consulting firm in Japan. A total of $7.9 billion was spent on the construction of the bridge. Meghna Bridge is the single largest project with Japanese assistance in the world.

Khan Jahan Ali Bridge

Khan Jahan Ali bridge was constructed over the river Rupsha at Labonchara in the Khulna city. Khan Jahan Ali Bridge is also known as Rupsha Bridge. It is the third longest bridge in Bangladesh. The bridge linked Labanchara in the city and Jabusa under Rupsa thana in Khulna. It is a 4 lane bridge and the total length of the bridge is 1360 meters (1.36 km) and width of the bridge is 16.48 meters. The bridge was constructed at a cost of Tk 724.15 crore. The bridge was built by the Roads and Highways Department with technical and financial cooperation from Japan. The work on the Rupsa Bridge project started on May 17, 2001 at Labanchara area of the city and the project was originally scheduled to be completed in November 2004 but it took more 5 months to complete. The Rupsa bridge project included construction of approach roads of total length of 8.68 kilometres—2.79 km on the eastern side starting from Tilok point of the Khulna-Mongla highway and 5.89 km on the western side starting from village Krishnanagar under Batiyaghata upazila in Khulna district. This is the third longest bridge in the country.

1.3 Problem Statement

Highway construction projects have considerable impact on the public. The most readily apparent consequences are increased travel times in congested construction work zones and the resultant degradation in traffic safety. Field assembly of prefabricated bridge systems offers one mean of significantly reducing construction time. Bridge elements that can be made of precast concrete include girders, deck panels, pier columns, pier caps, abutments, and railing systems. Most bridge decks are constructed using cast-in-place concrete. The forming may be removable wood, stay-in-place metal or stay-in-place concrete panels

The great majority of bridges built in Bangladesh have a concrete deck slab. Most of these slabs are cast-in-place (CIP). Public inconvenience and loss of income during bridge construction and rehabilitation have prompted exploration of rapid construction methods. Cast-in-place(CIP) bridge deck slab represents a significant part of construction or rehabilitation of stringer-type bridge superstructures, as much of the construction time is consumed informing, placement and tying of steel reinforcement, and placement and curing of CIP concrete.

CIP deck is common because of the relatively low initial cost, without allowance for cost of traffic delay, and because of its ability to tolerate errors in girder placement positions and top-of-girder elevations.

Many bridge deck construction systems have been developed either for the construction of new bridges or for the rehabilitation of deteriorated bridge decks. Among these systems is the conventional precast pre-stressed concrete deck panel system. The precast panels are butted against each other without any continuity between them. They are set on variable thickness bearing strips to allow for elevation adjustment. This system has the advantage of high construction speed compared to the full-depth cast-in-place deck system because of elimination of field forming.

1.4 Purposes behind implementation of a new bridge deck system in Bangladesh

I. Geological History of Bangladesh:

The most ancient geographical description of the Ganges delta forming Bangladesh is found in the Claudius Ptolemy's map sketched in 150 AD. The sketched map shows the clear existence of the Himalayan highlands and the river systems those originated from it. This surely indicates the ancient importance of this geographical location in the global context. Further the recorded information about its river systems and waterways are known in the sketches found in the Aine-e-Akbari (1582 AD).

The rivers in Bangladesh form the most significant aspects of landscape of the country. Abul Fazal, the historian of 1582 A.D., of the court of Mughal Emperor Akbar, remarked that rivers in Bengal are numerous and these have great influence on the lives of the people of the country. The drainage systems in Bangladesh are very much complex; and such of those are not found anywhere in the world (Alam et al. 1990). These types of drainages were bewildering and surprising for foreign travellers in the past.

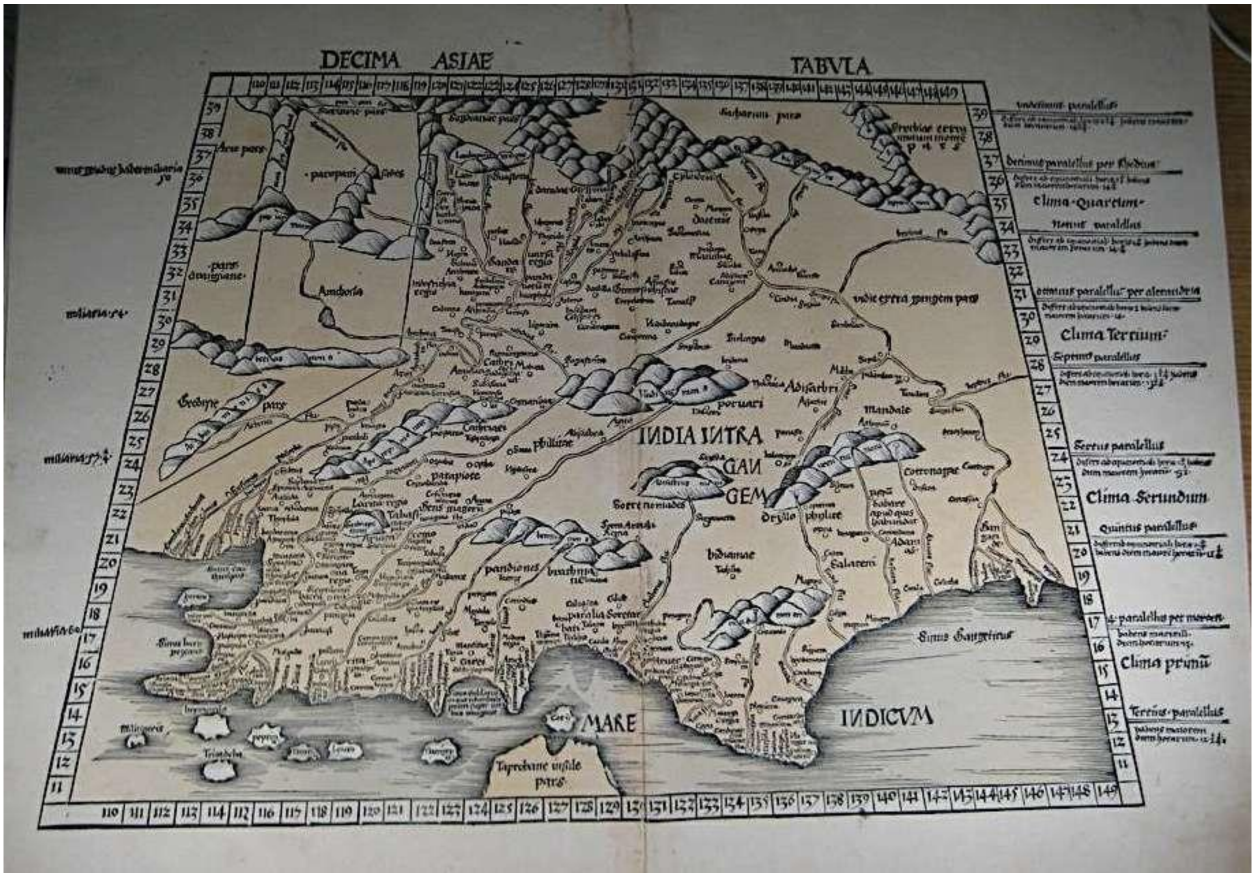


Figure 1.1: A Woodblock Ptolemaic Map, "Decima Asiae Tabula", 'Geographie Opus Novissima' (Strasbourg: J. Schott, 1513)

James Rennell's map of Bengal and Bahar (1778) was the first scientifically prepared map of the Ganges- Brahmaputra (Jamuna)-Meghna basin in a time even before the establishment of the modern prime meridian, based at the Royal Observatory, Greenwich which was established by Sir George Airy only in 1851.

The local need to travel from one part of this land to the other was, however, limited in the Mughal era (1526-1857 AD). The dependence on river systems was significant not only for transport but also for the defense of the important forts and townships. However, in the wake of imperial expansion and increasing interaction with Europe, it became increasingly important to establish fixed links over its great river systems.

The geological formation of the country, a low lying delta formed by recent deposits on the flood plains of the Ganges-Brahmapurtra-Meghna river systems, with hundreds of tributaries, distributaries and water bodies, posed a big challenge to the Civil Engineers in design, construction and maintenance of an uninterrupted country wide road-rail network. Establishment of fixed links using bridges required to have deep understanding of the river systems for achieving sustainability in the long run. The bridges constructed in the past were mostly located in the Ganges-Brahmaputra-Meghna basin but a fewin the folded flanks of Arakan-Myanmar hills. The design and construction were taking pl ace since 1870 to date after giving appropriate attention to the geomorphological features of the country using the knowledge available at the time of those constructions.

II. Geological information for the River Systems:

The Geological Survey of Bangladesh has been studying the major drainage system of 1778, 1874-77 and 1985 to publish the historical shifts of the River System in a map of Bangladesh in the scale of 1:1,000,000.Along with the study of major fault systems, the drainage systems analysis may indicate the probable causes of floods for geo-structural reasons beside hydrological and climate change considerations. It is expected, the geological aspects mainly related to the development of drainage systems, as studied will be able to identify their nature of influence on the flood flow and the landscape will be available.

Hard paucity in the historic data on local climatic conditions, particularly the earthquake, wind speed, airborne salinity limited the designers to come out with more efficient designs. The engineers were forced towards conservative designs with the projections they conceived from their professional judgments. Bangladesh Meteorological Department has 34 weather stations to monitor temperature, wind speed and humidity all over the country, only since 1993. Before that observations were limited only at a few stations.

III. Choice of Materials and Properties of Materials:

The local aggregates used for concrete production is softer and somewhat lighter (Akhteruzzaman and Hasnat 1983, Islam et al. 2015) than those used in other parts of the world. Ishtiaq Ahmad and Roy (2013) reports larger creep in brick aggregate concrete. Similar properties are also expected in stones (other than hard rock) of Bangladesh origin. This needs to be checked for deriving the basic parameters in bridge design and construction. To reduce the foundation load for achieving longer spans, smaller foundation sizes, smaller design scour depths, it is important to reduce the self weight of the structure. Consideration of efficient structural form and choice of structural steel sections can be a step forward to solve the design catch. However, to reduce the life cycle cost, it is important to reduce the cost required for corrosion protection. Thus, use of weathering steel should be considered thoroughly to reduce the life cycle cost to arrive at an efficient structural form. Measurement of air borne salinity and atmospheric exposure test data on different grades of weathering steel will infer about the applicability of new generation steel for different climatic conditions. The application of such steel in coastal zones for high air borne salinity content may not be suitable as was seen in other countries while prospect in use of this material for rest of the country needs to be immediately explored.

IV. Construction Technology and Choice of Bridge Forms:

Cost of a project depends significantly on the availability of construction technology, the time required for completing the project and thereby bringing it to service. Bangladesh is now in a transition towards modernization in pile driving techniques and development of an efficient methodology for erection of longer spans. This will obviously dictate the choice of bridge forms. An achievement is still waiting.

V. Appropriate Technology for Strengthening:

Any bridge designed today will deteriorate with time or a requirement may evolve to enhance its performance level. Strengthening for performance enhancement is a world-wide recognized terminology but it needs to be thoroughly customized for local materials and climatic conditions. Fundamental parameters governing the strengthening design needs to be re-determined or re-assured from first-hand experimental measurements.

VI. Overloading and Lack of Monitoring:

The traffic congestion, transport cost and toll prices encourage the transport owners to carry excess cargo than allowed. This excess cargo does have first impact on the bridge deck then on the bearings and expansion joints. Lack of monitoring worsens the situation. Bangladesh is yet to achieve a benchmark in bridge health monitoring through visual and instrumental observations (Amin et al. 2015).

1.5 Benefits of this System

In addition to high construction speed, full-depth, precast panel systems have many advantages, such as high quality plant production under tight tolerances, low permeability, much reduced volume changes due to shrinkage and temperature change during initial curing, and low maintenance cost.

Development of a full-depth, precast-concrete bridge deck panel system with riding quality suitable for high-speed traffic contact would be a major achievement. It would help produce a significant contribution towards developing a totally prefabricated bridge construction system in our country. Elimination of deck panel system post-tensioning, would also contribute to avoiding delays and use of specialty subcontractors. Previous research has resulted in implementation of post-tensioned and overlaid systems for connection durability and ride quality.

Precast and pre-stressed concrete composite bridge deck panels are used with cast-in-place concrete to provide a convenient and cost effective method of construction for concrete bridge decks. The panels are usually precast at a manufacturing plant. They are trucked to the bridge construction site and lifted by cranes onto concrete or steel girders. There, they span the opening between girders and serve as permanent forms for the cast-in-place concrete topping that completes the bridge deck. The precast concrete panels and concrete topping become composite and the panels contain all of the required positive moment reinforcement between girders.

Precast and pre-stressed concrete composite bridge deck panels will be referred to, in this report, as simply as "deck panels."Deck panels are similar to other pre-stressed concrete composite members with regard to applications and design considerations, there are however, situations that are unique to composite deck panels due to the way the panels are produced and used.

1.6 Design Considerations

The design of precast pre-stressed concrete composite bridge deck panels must include an analysis of the panels for stresses due to handling and during construction as well as ultimate strength of the composite section. Design drawings should show every aspect of production and installation of the composite deck panels, including storage instructions, bearing details, and all other special considerations. Drawings must include all information contained on the design drawings as well as any special information necessary for production. Composite deck panel lengths should be carefully selected with consideration given to tolerances for girder horizontal sweep in order to achieve proper bearing. These are the special cases which should be carefully studied.

1.7 Choice of Design Code and Limitations

At present, no independent national design code/standard for bridges in Bangladesh exists. The current trend is to use mainly the American Association of States Highway and Transportation Officials (AASHTO) Specifications; in which the different designers use different editions varying between 1992 and 2007. The other specialist literatures are also used. In special cases, the British Standard (BS) 5400 (1978) has been followed, for example, in preparing the Jamuna Design Specification for the Jamuna Multipurpose Bridge (Sobhan and Amin 2010). Indian Roads Congress (IRC) specifications are also often consulted. Design of second Kachpur, Meghna and Gumti bridges followed largely the Japan Road Association (JRA) provisions after consulting the Bangladesh National Building Code 1993 (BNBC 1993) for finding the wind and earthquake loading of bridges. However, BNBC (1993) is meant for buildings while AASHTO, BS and JRA codes do not consider the local conditions.

Seismic design for bridges usually considers two levels of earthquake, namely Operating Level Earthquake (OLE/ Level I) and Contingency Level Earthquakes (CLE/ Level II) earthquakes. OLE has a return period of 100 years with a 65% probability of being exceeded during that period. CLE has a return period of 475 years with a 20% probability of being exceeded during the design life of the bridge (100 years) as used in the design of the Padma Bridge (Sham 2015). However, in the second Meghna Bridge Project designs, BNBC (1993) response spectra was judged to be close to AASHTO LRFD (2007). Calculations yielded a response spectra for the Meghna site a bit different than that for the Padma Bridge. Furthermore, BNBC (1993) was found to be higher by about 50% in short-periodic region (Tatsumi et al. 2015), compared to Level-1 Type- II soil profile recorded by JRA (2012). At this moment, in absence of any design code for bridges, there exists no specific guideline to consider for earthquake loading.

Bangladesh National Building Code was prepared in 1993 based on limited wind speed measurement information. After 1993, thirty four observation stations are in service to record three hourly observations for wind. A synthesis of these data may help in updating the basic wind speed map. However, when bridges are constructed in open areas, the terrain exposure needs to be adequately judged based on local observations or model studies including dynamic effects. Some efforts are needed in these directions.

Guideline values on the consideration of the effect of daily and annual temperature differences are needed to be prescribed. So reconsideration is warranted, particularly for the design of box girder, setting out requirements and expansion-contraction measures. These measurements are also important to ensure the durability properties of rubber and ageing behavior of rubber, the essential component in all modern bridge bearings and expansion joints. In addition, in design it is to be considered that more than 60% of time of a year, in Bangladesh, near rivers, the relative humidity stays above 80%. This calls for use of dense concrete and effective measures for corrosion protection.

1.8 Objective & Scope

The objectives of this research were to develop the following:

(1) Design guidelines for fabrication and construction of full-depth, precast, concrete bridge deck panel systems with the use of post-tensioning; and

(2) Connection/ joint details for the innovative new deck panel system.

Certain steps were undertaken in order to achieve the above goals, and they are as follows:

STEP 1: Relevant literature on bridge projects with full-depth, precast concrete panel systems were collected, reviewed and summarized. Additional information on issues related to these systems such as grouting materials, shear-pocket details and precast panel-to-panel connections were collected and studied. Also, similar practices and other information related to the design, fabrication, and installation of full-depth, precast concrete bridge deck panel systems were accumulated and analyzed.

STEP 2: An international survey was prepared and sent to bridge divisions of state DOTs in United States, Canada, Japan, China, Germany, Dubai, India, Europe and Australia, as well as international consulting firms both public and private, precast concrete producers and exporters, and members of the Bangladesh Bridge Authority (BBA), and the Roads And Highways Department in Dhaka, Bangladesh.

STEP 3: Connection details for full-depth precast concrete deck systems, which can be used with high strength steel and pre-stressed/ reinforced concrete girders, were developed and evaluated theoretically. These details satisfy the following conditions: high durability, low construction time, good riding quality, easy transportation of moveable parts, low maintenance cost and high structural performance. The focus was on deck panel systems with longitudinal post-tensioning. The connection or joint details included panel-to-panel and panel-to-superstructure connections.

STEP 4: Guidelines for design, detailing, fabrication, and construction of full-depth precast concrete bridge deck panel systems were developed.

STEP 5: Specification language and commentary for the AASHTO LRFD Bridge Design Specifications necessary to implement full-depth, precast concrete bridge deck panel systems were developed.

Chapter- 02

LITERATURE REVIEW

2.1 What is a BRIDGE?

A **bridge** is a structure built to span physical obstacles without closing the way underneath such as a body of water, valley, or road, for the purpose of providing passage over the obstacle. There are many different designs that each serve a particular purpose and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the terrain where the bridge is constructed and anchored, the material used to make it, and the funds available to build it.

Figure 2.1: Cable Stayed Bridge, Shah Amanat, Chittagong

2.2 Early History of Bridges

Bridge is a structure that provides passage over obstacles such as valleys, rough terrain or bodies of water by spanning those obstacles with natural or manmade materials. They first begun be used in ancient times when first modern civilizations started rising in the Mesopotamia. From that point on, knowledge, engineering, and manufacture of new bridge building materials spread beyond their borders, enabling slow but steady adoption of bridges all across the world.

In the beginning bridges were very simple structures that were built from easily accessible natural resources- wooden logs, stone and dirt. Because of that, they had ability only to span very close distances, and their structural integrity was not high because mortar was not yet invented and rain slowly but constantly dissolved dirt fillings of the bridge. Revolution in the bridge construction came in Ancient Rome whose engineers found that grinded out volcanic rocks can serve as an excellent material for making mortar. This invention enabled them to build much more sturdier, powerful and larger structures than any civilization before them. Seeing the power of roads and connections to distant lands, Roman architects soon spread across the Europe, Africa and Asia, building bridges and roads of very high quality

Figure 2.2: An Ancient Roman Arch Bridge

One of the defining successes of Roman bridge architecture was their discovery of arches. By using this type of building, load forces of the bridge were conveyed to move along the curve of the arch, meeting with the ground where they were canceled by supports on the end of the arch. Because of that, Romans were able to create bridges that were much lighter than before and were able to hold load that was twice as heavy as the bridge itself. In construction of their numerous aqueducts, Roman architects even managed to create water carrying bridges with multiple arched tiers that reached incredible heights!

Modern bridges are usually made with the combination of concrete, irons and cables, and can be built from very small sizes to incredible lengths that span entire mountains, rough landscapes, lakes and seas.

2.3 Overview of Bridges in Bangladesh

Table 2.1: Number of Structures (By Type)
Road Transport & Highways Division
Last Update: 2017-01-05

Type of Structures	Numbers
Box Culvert	9441
Slab Culvert	3991
RCC Girder Bridge	2387
PC Girder Bridge	405
RCC Bridge	244
Arch Masonry	318
Truss with RCC Slab	30
Truss with Steel Deck	204
Truss with Timber Deck	6
Bailey with Steel Deck	973
Bailey with Timber Deck	23
Steel Beam & RCC Slab	230
PC Box	5

2.3.1 CULVERTS

A culvert is a structure that allows water to flow under a road, railroad, trail, or similar obstruction from one side to the other side. Typically embedded so as to be surrounded by soil, a culvert may be made from a pipe, reinforced concrete or other material. In the United Kingdom the word can also be used for a longer artificially buried watercourse. A structure that carries water above land is known as an aqueduct.

Culverts are commonly used both as cross-drains for ditch relief and to pass water under a road at natural drainage and stream crossings. A culvert may be a bridge-like structure designed to allow vehicle or pedestrian traffic to cross over the waterway while allowing adequate passage for the water. Culverts come in many sizes and shapes including round, elliptical, flat-bottomed, pear-shaped, and box-like constructions. The culvert type and shape selection is based on a number of factors including requirements for hydraulic performance, limitation on upstream water surface elevation, and roadway embankment height.

2.3.1 a) Box Culvert

Four-sided culverts are typically referred to as box culverts.

• Standard box sizes: 3’ x 2’ to 12’ x 12’ in 1’ span and rise increments.

• Typically come in 6’ and 8’ spans.

• Custom box sizes: Nonstandard sizing is permissible and must be designed per project design specification.

Figure 2.3: Box Culvert

2.3.1 b) Slab Culvert

This is the simplest kind of culvert design, and is mostly found in the rural regions of Bangladesh. The contraction method is very simple. This technique usually involves a piece of slab laid over a narrow water body (for example canal) flowing between two pieces of land. Slab culverts may be used for pedestrian or vehicle crossing. While this structure is significantly cheap compared to other culverts or bridges, it is also the least structurally reliable.

Figure 2.4: Slab Culvert

2.3.2 Reinforced Cement Concrete (RCC) Bridges

A girder bridge, in general, is a bridge that uses girders as the means of supporting the deck. A bridge consists of three parts: the foundation (abutments and piers), the superstructure (girder, truss, or arch), and the deck. A girder bridge is very likely the most commonly built and utilized bridge in the world.

Below is the list of 5 main types of bridges:
1. Girder Bridges
2. Arch Bridges
3. Cable-Stayed Bridges
4. Rigid Frame Bridges
5. Truss bridges

Figure 2.5: Reinforced Cement Concrete (RCC) Girder, Sangu Bridge, Bandarban

2.3.3 Girder Bridges

Girder bridges have existed for millennia in a variety of forms depending on resources available. A girder bridge, in general, is a bridge that uses girders as the means of supporting the deck. A bridge consists of three parts: the foundation (abutments and piers), the superstructure (girder, truss, or arch), and the deck. A girder bridge is very likely the most commonly built and utilized bridge in the world. Its basic design, in the most simplified form, can be compared to a log ranging from one side to the other across a river or creek. In modern girder steel bridges, the two most common shapes are plate girders and box-girders.

2.3.4 Reinforced Cement Concrete (RCC) Girder Bridges

An RCC girder bridge is one where the girders are made from reinforced cement concrete and are a widely used bridge system for short to medium span (<20m)highway bridges due to its moderate self-weight, structural efficiency, ease of fabrication, low maintenance etc. Durable and sustainable bridges play an important role for the socio-economic development of the nation.

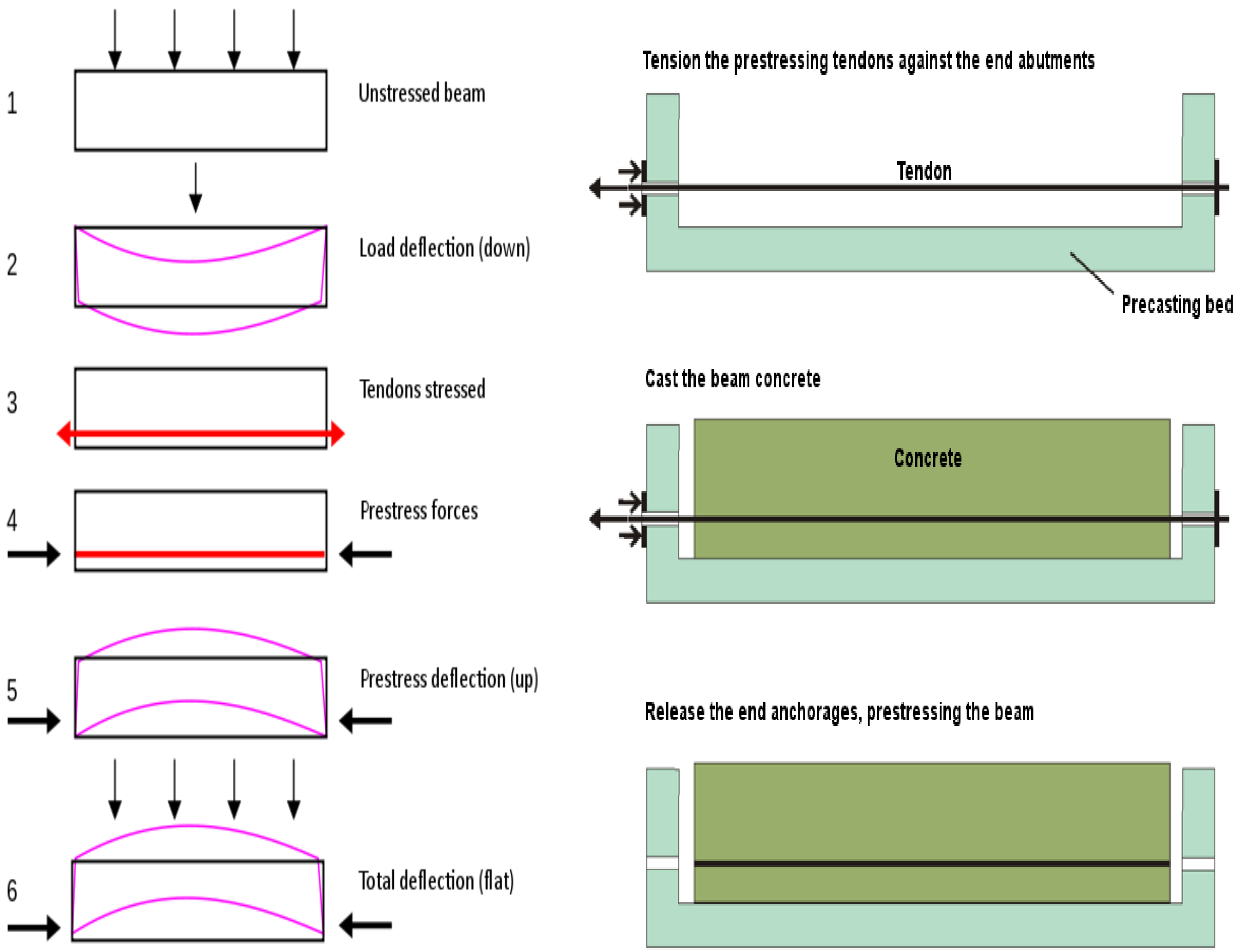
Owners and designers have long recognized the low initial cost, low maintenance needs and long life expectancy of RCC concrete bridges.

Figure 2.6: Reinforced Cement Concrete (RCC) Bridge, Dhaleswari River Bridge, Munshiganj

2.3.5 Pre-stressed Concrete (PC) Girder Bridges

Precast is utilized to construct both the superstructure and substructures of all types of bridges. Superstructures include: flat slabs, adjacent box beams, pre-tensioned beams, spliced and curved girders. Whereas substructures include: precast end bents, piles and pile bent caps, water line pile caps with a CIP columns and precast columns. Pre-stressed concrete is used in a wide range of building and civil structures where its improved concrete performance can allow longer spans, reduced structural thicknesses, and material savings to be realized compared to reinforced concrete. PC Girder design has proven good economy and sound engineering.

Proven Economy: low initial cost, minimum maintenance, fast & easy construction, minimum traffic interruption**. Sound Engineering:** simple design, minimum span/depth ratio, assured plant quality, durable, aesthetic value.



a) Post-tensioning Process of a Girder

b) Pre-tensioning Process of a Girder

Figure 2.7: Tensioning Process

Figure 2.8: Pre-stressed Concrete (PC) Girder Bridge, Mohipur-Alipur, Patuakhali

2.3.6 Arch Bridges

An arch bridge is a bridge with abutments at each end shaped as a curved arch. Arch bridges work by transferring the weight of the bridge and its loads partially into a horizontal thrust restrained by the abutments at either side. A viaduct (a long bridge) may be made from a series of arches, although other more economical structures are typically used today.

Stone, brick and other such materials are strong in compression and somewhat so in shear, but cannot resist much force in tension. As a result, masonry arch bridges are designed to be constantly under compression. Each arch is constructed over a temporary false work frame, known as a centering. In the first compression arch bridges, a keystone in the middle of the bridge bore the weight of the rest of the bridge. The more weight that was put onto the bridge, the stronger its structure became. Masonry arch bridges use a quantity of fill material (typically compacted rubble) above the arch in order to increase this dead-weight on the bridge and prevent tension from occurring in the arch ring as loads move across the bridge. Other materials that were used to build this type of bridge were brick and unreinforced concrete. When masonry (cut stone) is used the angles of the faces are cut to minimize shear forces. Where random masonry (uncut and unprepared stones) is used they are mortared together and the mortar is allowed to set before the false-work is removed.

Traditional masonry arches are generally durable, and somewhat resistant to settlement or undermining. However, relative to modern alternatives, such bridges are very heavy, requiring extensive foundations. They are also expensive to build wherever labor costs are high.

Structurally there are four basic arch types:
1. Hinge-less
2. Two-hinged
3. Three hinged
4. Tied arches

Figure 2.9: Arch Masonry

Figure 2.10: Arch Masonry, Mir Kadim Bridge, Munshiganj

2.3.7 Truss Bridges

A truss bridge is a bridge whose load-bearing superstructure is composed of a truss, a structure of connected elements usually forming triangular units. The connected elements (typically straight) may be stressed from tension, compression, or sometimes both in response to dynamic loads. This kind of bridge carries pedestrians, pipelines, automobiles, trucks, light rail, heavy rail etc. The span range is short to medium –usually not very long unless it is continuous. Truss Bridges maybe made out of timber, iron, steel, reinforced concrete and pre-stressed concrete.

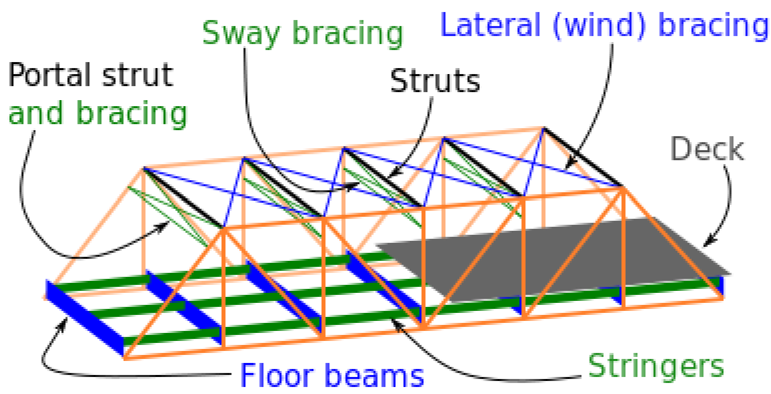


Figure 2.11: The Internal Parts of a Truss Bridge

The nature of a truss allows the analysis of the structure using a few assumptions and the application of Newton's laws of motion according to the branch of physics known as statics. For purposes of analysis, trusses are assumed to be pin jointed where the straight components meet. This assumption means that members of the truss (chords, verticals and diagonals) will act only in tension or compression.

Figure 2.12: Truss with Reinforced Concrete Cement (RCC) Slab, Sherpur

Figure 2.13: Truss with Timber Decks, Shah Amanat Bridge, Chittagong

Figure 2.14: Truss with Steel Deck, Boalia Bazar, Nalchiti, Barisal

2.3.8 Bailey Bridges

The Bailey bridge is a type of portable, pre-fabricated, truss bridge. It was developed by the British during World War II for military use and saw extensive use by British, Canadian and the American military engineering units. It was named after Sir D. Bailey (1901-85), the English engineer who designed it.

A Bailey bridge had the advantages of requiring no special tools or heavy equipment to assemble. The wood and steel bridge elements were small and light enough to be carried in trucks and lifted into place by hand, without requiring the use of a crane. The bridges were strong enough to carry tanks. Bailey bridges continue to be extensively used in civil engineering construction projects and to provide temporary crossings for foot and vehicle traffic.

The basic bridge consists of three main parts. The bridge's strength is provided by the panels on the sides. The panels are 10-foot-long (3.0 m), 5-foot-high (1.5 m), cross-braced rectangles that each weigh 570 pounds (260 kg), and can be lifted by six men. The panel was constructed of welded steel. The top and bottom chord of each panel had interlocking male and female lugs into which engineers could inset panel connecting pins

The floor of the bridge consists of a number of 19-foot-wide (5.8 m) transoms that run across the bridge, with 10-foot-long (3.0 m) stringers running between them on the bottom, forming a square. Transoms rest on the lower chord of the panels, and clamps hold them together. Stringers are placed on top of the completed structural frame, and wood planking is placed on top of the stringers to provide a roadbed. Ribands bolt the planking to the stringers. Later in the war, the wooden planking was covered by steel plates, which were more resistant to the damage caused by tank tracks.

Each unit constructed in this fashion creates a single 10-foot-long (3.0 m) section of bridge, with a 12-foot-wide (3.7 m) roadbed. After one section is complete it is typically pushed forward over rollers on the bridgehead, and another section built behind it. The two are then connected together with pins pounded into holes in the corners of the panels.

For added strength several panels (and transoms) can be bolted on either side of the bridge, up to three. Another solution is to stack the panels vertically. With three panels across and two high, the Bailey Bridge can support tanks over a 200-foot span (61 m). Footways can be installed on the outside of the side-panels; the side-panels form an effective barrier between foot and vehicle traffic and allow pedestrians to safely use the bridge.

A useful feature of the Bailey bridge is its ability to be launched from one side of a gap. In this system the front-most portion of the bridge is angled up with wedges into a "launching nose" and most of the bridge is left without the roadbed and ribands. The bridge is placed on rollers and simply pushed across the gap, using manpower or a truck or tracked vehicle, at which point the roller is removed (with the help of jacks) and the ribands and roadbed installed, along with any additional panels and transoms that might be needed.

►►Construction Process of Bailey Bridges

Bailey bridges are built on site from a pre-engineered system of ready-to-assemble components. Utilizing standardized prefabricated components, Bailey bridges can be built to match a wide range of vehicular bridging applications. Because of their excellent versatility and overall value, thousands of Bailey bridges have been installed throughout the world.

►Features

- Adaptable - pre-engineered to match each application
- Fast - modular stocked components, open to traffic in days
- Lower Cost - an alternative to custom designed bridges
- Easy - to handle, transport, assemble, install and reuse

►Materials and finishes

Domestic steel is used throughout. Most load-bearing components use low-alloy, high-tensile ASTM A242 steel with a yield point of 50,000 psi. Excellent corrosion resistance is achieved with an inorganic zinc silicate coating. Final color is lusterless light gray. Hot dipped galvanized is also available.

►Assembly and Installation

Most Bailey bridges are assembled and installed in a matter of days by a small crew. Common hand tools are utilized. All connections are pinned, bolted or clamped. No welding is necessary. Disassembly is similarly easy, and components can be stored in minimal space until reused. Bailey bridges are often installed by the cantilever launching method, in which the assembled bridge together with a "launching nose" is rolled out across the gap, without false work or heavy equipment. The cantilever method allows bridges to be quickly erected over rivers or deep gorges. Additionally, some Bailey bridges may be hoisted into place by crane.

Figure 2.15: Bailey Bridge with Steel Deck, Kalurghat Bridge, Chittagong

Figure 2.16: Bailey Bridge with Timber Deck, Koikhongjhiri, Bandarban

2.3.9 Steel/ Concrete Composite Bridges

Steel/ concrete composite deck slab bridges, or River Bridges, can be constructed with effective spans ranging from about 10 to 40 meters and skew angles of 45 degrees or more and can be adapted to changes in structural height according to their longitudinal alignment. They are now compatible with continuous girders, expanding their range of applications. River Bridges (KCSB) have a greater potential to meet social needs, labor saving and speedup of onsite construction works and the minimization of life cycle costs. This kind of design boasts the following beneficial features:

1**. Low structural height**: From among all structural types, River Bridges can achieve the lowest structural height.

2**. Rapid construction**: The construction weight of River Bridges is far lighter than that of concrete-based bridges, so heavy equipment can be downsized. In addition, formwork and scaffolding are no longer necessary as the bottom panels function as deck slab formwork, resulting in the reduction of the construction work period.

3. **Minimization of LCC**: The RC deck slabs, which are of a highly durable structure, are almost maintenance-free and also contribute to the minimization of life cycle costs.

4. **Design ability**: River Bridges can offer not only a slender appearance thanks to their low structural height but also impressive landscaping design.

Figure 2.17: Steel Beam & Reinforced Cement Concrete (RCC) Slab, Isapur Bridge, Purbachal

2.3.10 Pre-Stressed Concrete Box Girder Bridges

A box girder bridge is a bridge in which the main beams comprise girders in the shape of a hollow box. The box girder normally comprises either pre-stressed concrete, structural steel, or a composite of steel and reinforced concrete. The box is typically rectangular or trapezoidal in cross-section. Box girder bridges are commonly used for highway flyovers and for modern elevated structures of light rail transport. Although normally the box girder bridge is a form of Beam Bridge, box girders may also be used on cable-stayed bridges and other forms.

If made of concrete, box girder bridges may be cast in place using false work supports, removed after completion, or in sections if a segmental bridge. Box girders may also be prefabricated in a fabrication yard, then transported and emplaced using cranes. For steel box girders, the girders are normally fabricated off site and lifted into place by crane, with sections connected by bolting or welding. If a composite concrete bridge deck is used, it is often cast in-place using temporary false-work supported by the steel girder.

Advantages: reduces the slab thickness and self-weight of bridge, cost effective, greater strength per unit area of concrete, quality assurance, as precast girders are made off-site etc.

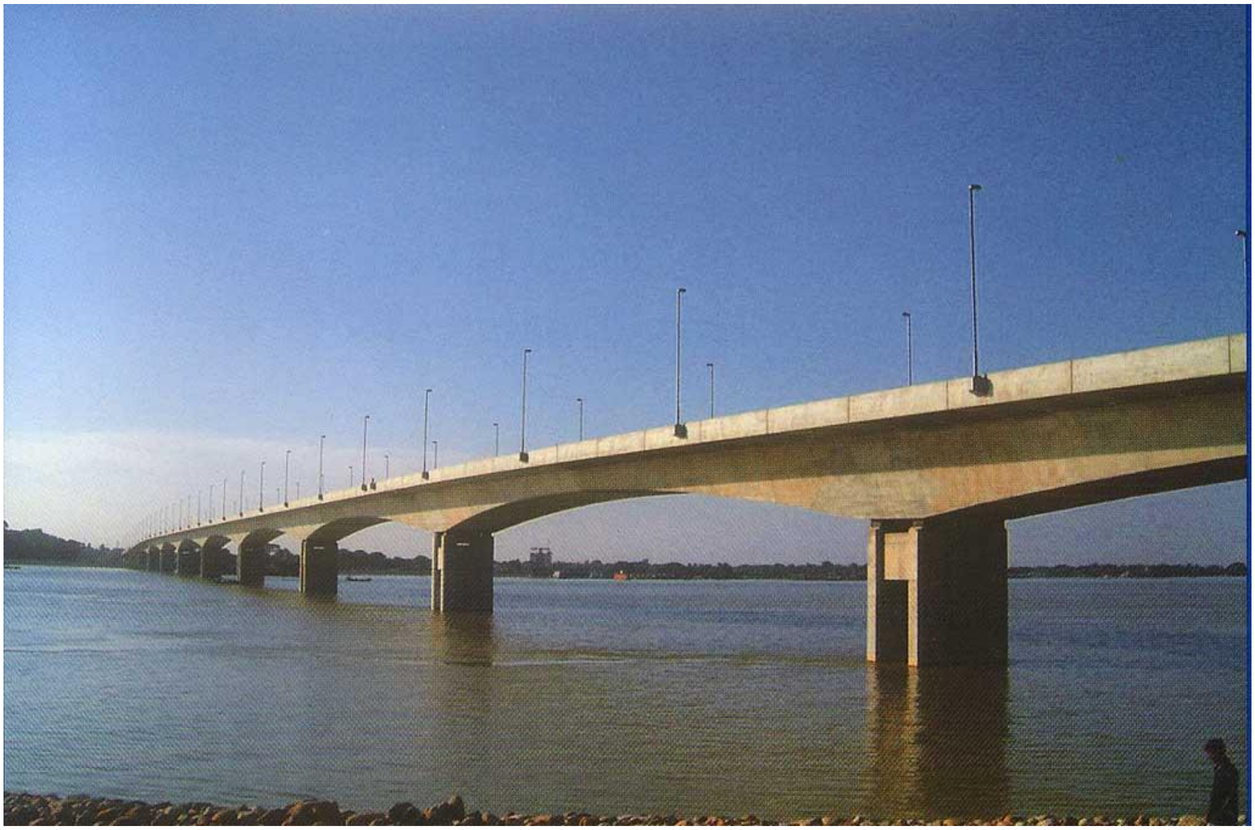


Figure 2.18: Pre-stressed Concrete (PC) Box Girder, Bhairab Bridge

2.4 Early History of PCP Bridge Deck Panel

The use of precast pre-stressed concrete panels (PCP), then known as "planks", to act as integrated or stay-in-place (SIP) deck forms for highway bridges was first proposed in the early 1950s for a series of underpasses for the Illinois Toll Highway Authority on the Northwest Tollway near Chicago4, 5, 6. This system was pursued in an effort to explore alternate bridge types with emphasis on economy. Pre-stressed concrete appeared as the best option and efforts were made to develop a design that would use pre-stressed piles, girders and pre-stressed SIP panels.

The first such full-scale prototype bridge was load tested in Illinois in 1956 an was the Beverly Road Bridge located at the intersection of Northern Illinois Toll Highway and Beverly Road in Cook County. Proposals for that bridge were received on April 26, 1956 and the contract was awarded to the W. E. O'Neill Construction Company.

Six tests were performed on the bridge that included piles, girders and slabs. Additional tests were conducted at Lehigh University on portions of composite deck slab. In conclusion, the test structure was subjected to severe loads at different stages of construction. The resulting girder and slab moments were, in most instances, far in excess of design moments based on AASHO H-20 truckloads plus impact. The maximum positive transverse moment in the slab was the equivalent to that resulting from nearly seven times live plus impact loads. The maximum negative transverse moment in the slab was over five times that of one live plus impact loading. There can be no doubt that complete and positive composite action between the precast girders; precast slabs and CIP slab prevailed throughout the tests.

Precast, pre-stressed deck panels have also been used as full depth deck replacements. An early example of the use of PCP-FD is in the "Pintala Creek Bridge" in Alabama in the 1960s. Later, in 1968, Gutswiller, M.J., Lee, R. H. and Scholer C. F., of Purdue University10, reviewed the concept of using full depth precast and pre tensioned slabs which are placed on top of the girders, then post–tensioned and tied mechanically to the underlying girders. Later this method was extended in 1990's for Maryland's rural highways11. A system of 3 or 4 ft. wide precast/pre-stressed concrete slabs placed adjacent to each other and post-tensioned laterally in place with a CIP concrete topping. The Texas Highway Department constructed three PCP-PD bridges in Grayson County, Texas, using a pre-stressed concrete SIP element in the deck similar to that used in Illinois. These bridges were opened to traffic in August 196312. In 1970, a research project was taken to determine the behavior of these three bridges. The researchers observed that: The bridges were found to be in sound condition. The transverse cracks found over the panel joints extended only halfway through the CIP concrete. The bridges were sounded for delamination, and no delamination had occurred in the area of transverse cracks. The cores taken through deck slab hold the bond between CIP and PCP secure, and direct shear test determined the failure bond stress as 285 psi. In 1975, The Texas Transportation Institute produced four research reports in connection with the use of the in the three 1963 Texas bridges12. The first research (Report No. 145-1) reiterates what was described in the Transportation Research Circular No. 181. No evidence of non composite action was found. Some transverse cracking was found in the CIP deck that coincided with transverse butt joints between pre-stressed panels. Core samples showed these cracks to extend approximately halfway through the CIP deck. The second research (Report No. 145-2) investigated the development length of strands in similar pre-stressed panels and observed the effect of cyclic loading. An average development length of 22 inches was required for the 3/8 inches diameter strands tensioned with a force of 13.75 kips, and 34 inches was needed for the strands with 1⁄2 inch diameter tensioned with a force of 27.5 kips. Cyclic loading was found to have negligible effect on strand development length or panel stiffness. Since the length of the shortest test panel was 68 inches, the full pre-stress force could be developed in each case. When the 1⁄2 inch diameter strands were used in the 68 inches panels, it was concluded that only a few inches near mid span received the full pre-stress force. The third research (Report No. 145-3) experimentally and theoretically investigated the ability of the pre-stressed panel bridge to distribute wheel loads in a satisfactory manner and to behave as a composite unit. The following conclusions were drawn:

1. The bond at the interface between the pre-stressed, precast panels and the CIP concrete performed without distress under cyclic design loads and static failure loads.

2. Wheel loads were transferred and distributed across transverse panel joints satisfactorily.

3. It is feasible to design for composite action in a pre-stressed panel bridge of the type studied.

The fourth research (Report No. 145-4F) focused on failure of composite panels, subjected to static and cyclic loads: Curves of load versus number of load cycles at failure, S-N curves, were developed from fatigue tests. The panel with shear lugs consistently took more load cycles to failure for loads ranging from 210 to 260 percent of design load. If the S-N curve for the panels with no Z-bars is projected out along the abscissa, it will level out at about 10 million cycles at 200 percent of design load. No load lower than about 200 percent of design load, on that basis, will damage the specimen. Kluge, R.W. and Sawyer H.A., at University of Florida13, conducted extensive studies to determine the extent of interaction between CIP concrete topping and PCP panels without mechanical connectors and to develop design criteria for this type of bridge deck system. The investigation was divided into four series spanning from 1969 to 1973. They concluded:

1. Design calculations for shear are unnecessary, since PCP/CIP acts as monolithic concrete deck, as long as no foreign material is allowed in the panel.

2. Transverse reinforcement in the PCP panels should not be less than No. 3 bars at 12inches centers.

3. Minimum embedment lengths, including the embedment of free strand-ends of PCP panels should be: 3/8 inches strand, 62 inches; 7/16 inches strand, 80 inches; 1⁄2 inches strand, 100 inches.

The first comprehensive full-scale test of a bridge using stay-in-place precast pre-stressed concrete panels was performed under service and overload conditions at Pennsylvania State University by Barnhoff and Rainey14, 15. There were two 60 spans, one span with conventional deck and the other span with PCP/CIP, both subjected to identical loading. The following conclusions were drawn.

1. The deck utilizing PCP panels was slightly more flexible than the conventional deck, thereby allowing larger beam deflections, but resulting in smaller live load moments in the slab.

2. The slight difference in behavior of the decks does not justify a separate procedure to determine design moments in decks with PCP panels.

3. Full composite action was developed between the CIP concrete and the PCP panels. Mechanical shear connectors are not required if the plank surface is given a scored finish.

One of the objectives of the laboratory tests conducted by Barnoff and Rainey was to compare different types of joints between the panels. Three different joint types were studied: a butt joint, a beveled joint, and a U-joint. There were no significant differences in the structural performance of panels made with these different joints. It should also be noted that simulated wheel loads of 80 kips applied directly over the joint were required to fail the panels. Several auxiliary studies were also conducted. One of these was to determine the effect of deicing agents on the deterioration of the bridge deck. Calcium chloride and sodium chloride were applied to the bridge deck during the two winters that the bridge was in service. Half-cell readings were made to determine the amount of salt penetration, and cores were taken to find the depth, which showed that the depth of penetration was not sufficient to cause corrosion of reinforcing steel in the two-year life of the bridge deck.

The PCI Bridge Committee, came up with “Tentative Design and Construction Specifications for Bridge Deck Panels,” in 1978.

SIP panels have also been used to span longitudinally from supporting abutment to supporting abutment instead of the more common use of spanning laterally from bridge girder to bridge girder. In 1980, Hays, C.O. Jr., R.L. Cox and Obranic G.O. conducted a research on “Full Span Form Panels for Short Span Highway Bridges” at the University of Florida17. The researchers concluded that a minimum panel width of 122 cm (48 inches) be used and that an improved detail with more positive transfer of shear from panels to supports was needed to reduce deformation and cracking.

In 1981, Fagundo, Tabatabai, and Soongswang conducted research at the University of Florida to determine the adequacy of the SIP panels with CIP topping composite deck system18. They concluded:

Test results indicate that slabs that were repaired and provided with positive bearing, regained of all their original stiffness. It is believed that, in bridge decks with positive bearing provided under the panel, the concentration of the shear stresses on the CIP portion near the ends of the panel is reduced and these decks have less maintenance problems than similar decks without positive bearing. In 1982, a survey of the State Highway Departments by the PCI Bridge Committee showed that 21 states used the panels regularly and another seven states were trying the method through bidding options or were developing details prior to trial projects.

Also in 1982, research performed at the University of Texas at Austin by Bieschke and Klingner on full-scale bridge specimens indicated that there was no local or global difference in the performance of decks constructed using SIP panels with or without strand extensions19.

The use of strand extensions would later be addressed in the PCI Bridge Design Manual of 1997.

There is a significant implication to strand extensions, which require the fabrication to install forms in the bed between each panel thereby increasing fabrication cost. If there is no strand extension, the panels may be cast in a single, long slab and subsequently cut to length when the concrete reaches transfer length. Strand extensions are generally not recommended. In 1987, the PCI committee on bridges presented guidelines for the design, manufacture and erection of PCP-PD panels, where suggestions were given for the dimensioning and detailing of panels, techniques for casting panels and helpful ideas in the handling, shipping and erection of panels

A 1986 survey conducted by PCI contacted all State Highway Departments in the United States, a number of Tollway and Transportation Authorities, and PCI member plants to determine the contemporary specifications and method of production for PCP. This survey and also the research mentioned earlier were compiled, studied and investigated by Ross Bryan Associates, a PCI commissioned consultant, producing a guideline, “Recommended Practice for Precast Pre-stressed Concrete Composite Bridge Deck Panels,” in 1988.

In 1993, Ahmad Idriss Talal of University of Illinois at Chicago surveyed full depth precast panels for deck replacement22, 23. Out of 51 Department of Transportation-DOT’s that responded to the survey, 10 were using the system, 41 were not using the system and 43 DOTs were interested in using the system while 8 were not interested.

In 1994, Ramirez and Kumar at the Purdue University, West Lafayette, Indiana, investigated the interface horizontal shear strength in composite decks with partial-depth precast concrete panels24. They concluded that pre-stressed deck panels with a broom-finished surface do not require horizontal shear connectors if the normal horizontal shear stress is less than 116 psi (0.8 MPa).

In 1995, Klingner et al. conducted an experimental investigation at the University of Texas at Austin, into the punching shear fatigue behavior of bridge decks25. The bridge decks incorporated PCP panels designed as “Ontario Type” bridge decks26. The researchers concluded that the punching shear capacity is significantly increased by the presence of arching action. For a HS 20-44 truck, the increase in punching shear capacities about 170% due to the arching action present in the pertinent PCP deck.

In the 1990s a team of researchers at the University of Nebraska-Lincoln developed a new system for PCP-PD panels named NUDECK27. The Precast/Pre-stressed Concrete Institute (PCI) incorporated this option later in the “PCI Bridge Design Manual”, 1st edition, 199720. With the NUDECK system, the precast panel covers the entire width of a bridge, resulting in elimination of the need for forming of the overhangs.

In 1996, one of the largest instances of bridge deck rehabilitation work involving PCP partial depth panels took place for the Historic Hillhurst (Louise) Bridge in Calgary, Alberta, Canada after 75 years of service2. The total deck width was 64.3 ft and bridge length was 565 ft. The PCP panels were 7.87 ft. wide and 13.1 ft long (spacing between steel stringers) and 5 inches deep. One half inches pre-stressing strands with an ultimate strength of 270 ksi were placed at 5.3 inches on center.

In 1997, Precast/Pre-stressed Concrete Institute (PCI) published 1st edition of “PCI Bridge Design Manual”. This manual details PCP-PD and PCP-FD options including design, fabrication and construction.

In 1999, Ronald A. Cook et al. at the University of Florida tested a full-scale model of a bridge with a superstructure at a 3% super elevation incorporating plain reinforced precast panels28. Welded wire fabric was used exclusively for the reinforcement of the precast panels (Types I, II, and III based on panel features and end condition) and based on the testing performed; the Type III panel appeared to be a viable option.

2.5 Different PCP bridge deck systems

PCP bridge deck system can be of the following types:

I. A precast pre-stressed concrete panels-partial depth (PCP-PD), which act as SIP deck forms,
II. A precast pre-stressed concrete panels-full depth (PCP-FD), which act as the entire deck thickness,
III. PCP-PD-full span- used to span from abutment to abutment, and
IV. PCP-PD-post tensioned-where panels are post tensioned in both directions.

1. PCP-PD panels are:

•Precast and concentrically pre-stressed
•Topped over by cast-in-place (CIP) concrete
•Roughened at the top surface to achieve composite action

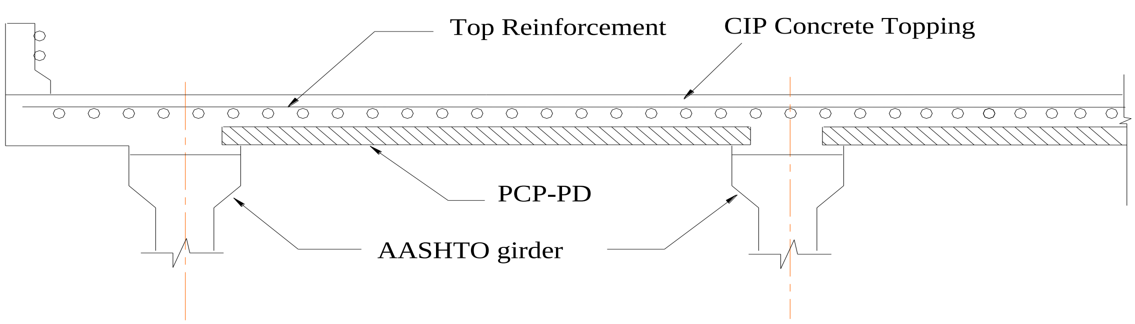


Figure 2.19: Typical Transverse Section of a PCP-PD Bridge Deck System

2. PCP-FD panels:

•Provide the full depth of the bridge deck,
•Have pre-stressing strands or mild steel commonly used in two layers, and
•Employ non-shrink grout at panel-to-panel connections.

Some other variations found in the New England Region in Connecticut where it was successfully tested in two major deck replacements in 1989 and 1994. In this system, post-tensioning is applied uniformly throughout the entire bridge width and panels have pockets over the girders for placement of shear connectors. There is another one called NCHRP System which has panels with a non-prismatic stemmed section to optimize the system in terms of weight and reinforcement, and post-tensioning is applied over the girders. Prof. Tadros of the University of Nebraska developed NUDECK system which was originally a continuous stay-in-place panel system that evolved later to a full-depth precast, pre-stressed system.

In 1982, a survey of the State Highway Departments by the PCI Bridge Committee showed that 21 states used the panels regularly and another seven states were trying the method through bidding options or were developing details prior to trial projects(PCI 1987).

According to 1987 survey of PCI, 24 states were using the system (PCI 1987). According to 2003 University of New Hampshire survey, 25 states were using the system (Cook and Latifee, 2003).

2.6 IMPORTANT TERMS

2.6.1 High Performance Concrete

High-performance concrete (HPC) is a relatively new term for concrete that conforms to a set of standards above those of the most common applications, but not limited to strength. While all high-strength concrete is also high-performance, not all high-performance concrete is high-strength. Some examples of such standards currently used in relation to HPC are:

- Ease of placement
- Compaction without segregation
- Early age strength
- Long-term mechanical properties
- Permeability
- Density
- Heat of hydration
- Toughness
- Volume stability
- Long life in severe environments
- Depending on its implementation, environmental.

2.6.2 High Strength Steel

The development of pre-stressed concrete was influenced by the invention of high strength steel. It is an alloy of iron, carbon, manganese and optional materials. The following elements are made of high strength steel: wires, strands, cables, tendons, bars etc. The types of high strength steel are follows:

- **Cold working (cold drawing)**

The cold working is done by rolling the bars through a series of dyes. It re-aligns the Crystals and increases the strength.

- **Stress relieving**

The stress relieving is done by heating the strand to about 350º C and cooling slowly. This reduces the plastic deformation of the steel after the onset of yielding.

- **Strain tempering for low relaxation**

This process is done by heating the strand to about 350º C while it is under tension. This also improves the stress-strain behavior of the steel by reducing the plastic deformation after the onset of yielding. In addition, the relaxation is reduced.

2.6.3 Pre-tensioning

Pre-tensioning is accomplished by stressing wires or strands, called tendons, to predetermined amount by stretching them between two anchorages prior to placing concrete. The concrete is then placed and tendons become bounded to concrete throughout their length. After concrete has hardened, the tendons are released by cutting them at the anchorages. The tendons tend to regain their original length by shortening and in this process transfer through bond a compressive stress to the concrete. The tendons are usually stressed by the use of hydraulic jacks. The stress in tendons is maintained during the placing and curing of concrete by anchoring the ends of the tendons to abutments that may be as much as 200m apart. The abutments and other formwork used in this procedure are called pre-stressing bench or bed.

2.6.4 Post-tensioning

In a post-tensioned beam, the tendons are stressed and each end is anchored to the concrete section after the concrete has been cast and has attained sufficient strength to safely withstand the pre-stressing force in post-tensioning method, tendons are coated with grease or a bituminous material to prevent them from becoming bonded to concrete. Another method used in preventing the tendons from bonding to the concrete during placing and curing of concrete is to encase the tendon in a flexible metal hose before placing it in the forms. The metal hose is referred to as sheath or duct and remains in the structure. After the tendon has been stressed, the void between the tendon and the sheath is filled with grout. Thus the tendons become bonded to concrete and corrosion of steel is prevented. Post-tension pre- stressing can be done at site. This procedure may become necessary or desirable in certain cases. For heavy loads and large spans in buildings or bridges, it may be very difficult to transport a member from pre-casting plant to a job site. On the other hand, pre-tensioning can be used in pre-cast as well as in cast-in-place construction. In post-tensioning it is necessary to use some types of device to attach or anchor the ends of the tendons to the concrete section.

2.7 What is Concrete?

Concrete is a mixture of sand, gravel and/or other aggregates (the matrix), bound together by a water-based binder, cement. Admixtures (modifying agents) and additives (fine mineral powders) are sometimes introduced to improve the characteristics of the fresh concrete, of the mixing process and/or of the final hardened material.

- **Types of concrete**

a) Precast
b) Cast in place

2.7.1 What is Precast Concrete?

Precast concrete decks consist of either precast reinforced concrete panels or pre-stressed concrete panels. These panels can either serve as the final deck surface or as a temporary deck to allow placement of a final cast-in-place concrete deck. The advantage of a precast concrete deck is in the acceleration of the construction schedule. Precast panels allow for quicker placement, which, in principle, speeds up overall bridge construction.
A precast concrete product is a factory-made piece manufactured with concrete and which, later, together with other pieces, will become part of a larger structure. Precast concrete elements are prepared, cast and hardened at specially equipped plants with a permanent location.
Once a precast concrete product is produced and all the undertaken quality controls satisfactory, the unit is stored until delivery. It is then transported for use at another site.

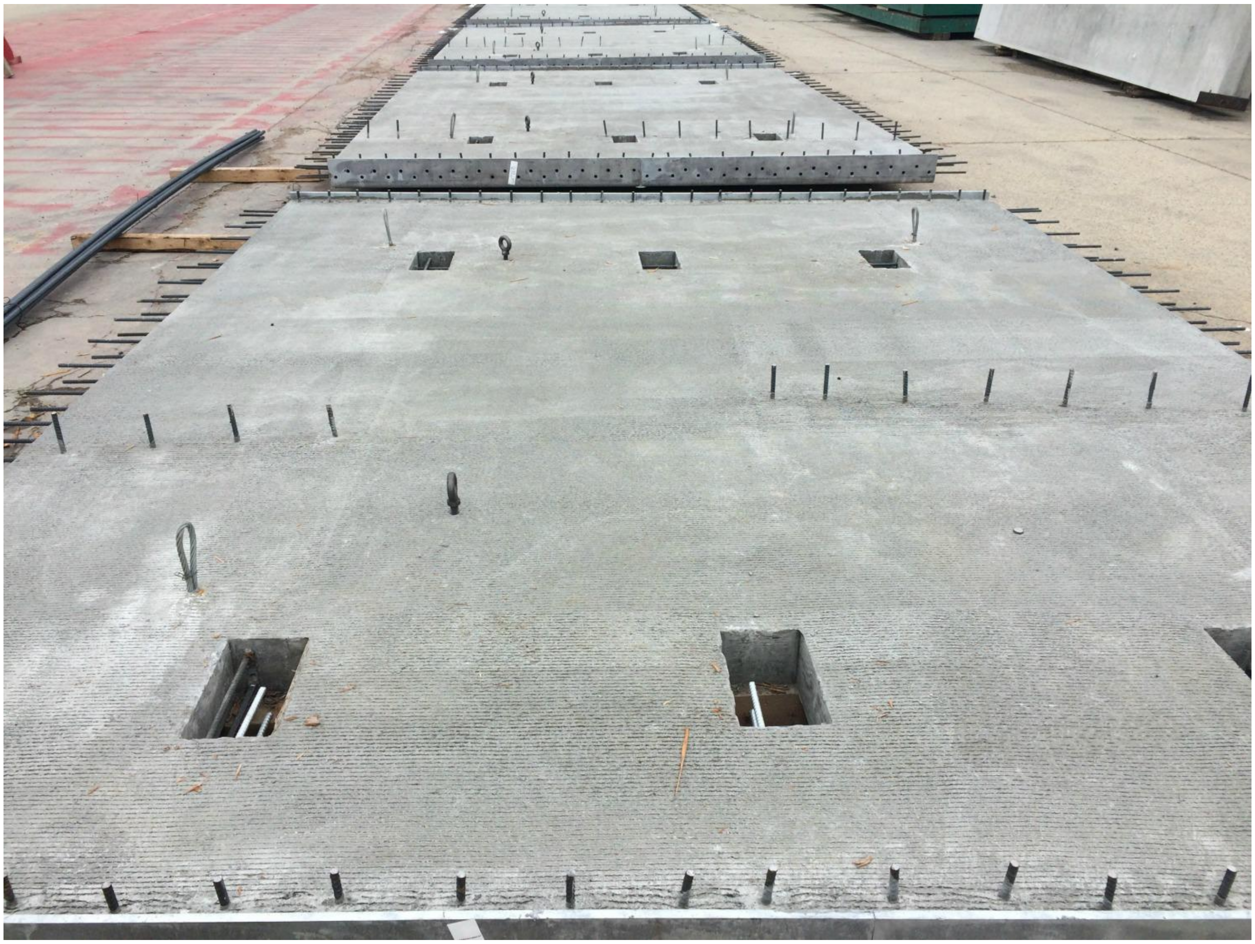


Figure 2.20: Precast Concrete

The main **advantages** of such a process are:

•The intrinsic quality of an **industrial product**, manufactured in a **controlled environment** and with **accurate methods;**

•**Advanced quality control**, which goes far beyond the checking of the fresh concrete, can be introduced. Dimensional accuracy, properties of the hardened concrete and position of reinforcement can all be checked before inclusion of an element in the final work;

•Factory-made products are **independent of weather conditions** and can be proceeded separately from construction work on site.

2.7.2 What is Cast-in-Place Concrete?

A cast-in-place concrete deck is a thin concrete slab, either using normal reinforcement or pre-stressing steel, usually between 7 and 12 inches, with reinforcing steel interspersed transversely and longitudinally throughout the slab. There are several advantages to using a reinforced concrete deck. One of the major advantages is its relatively low cost. Other advantages are ease of construction and extensive industry use. Even though cast-in-place concrete decks have advantages, there are disadvantages using this particular type of deck, such as cracking, rebar corrosion, and tire noise. A large cost of bridge maintenance is in maintaining the riding surface (Fu, et al., 2000). Lack of deck crack control can lead to rebar corrosion and increased life cycle cost, not to mention a poor riding surface for the public.

Cast-in-place concrete is transported in an unhardened state, primarily as ready-mix, and placed in forms. Ready mixed concrete is proportioned and mixed off the project site. The concrete is delivered to the site in a truck agitator (often incorrectly called a “cement truck”) but can also be delivered in a non-agitating truck. Specialized paving equipment may be used to mix and spread concrete for pavement.

Figure 2.21: Cast-in-place Concrete

►Uses:

•Most foundations and slabs-on-ground.

•Walls, beams, columns, floors, roofs.

• Large portions of bridges, pavements, and other infrastructure.

►Why:

Cast-in-place concrete is the material of choice for slab-on-ground and foundations because of its long-term durability and structural support. It is also used in all types of buildings for either structural support as beams and columns, as well as for floors, walls, and roofs

►Sustainability:

Ready mixed concrete has many environmental benefits during construction and for the life of the structure. See associated sustainability solutions and technical briefs (right) for more detail.

►During construction:

i. **Waste Minimization:**

Concrete is ordered and placed as needed and does not need to be trimmed or cut after installation. Wash water is frequently recycled using trucks equipped with devices that collect wash water and return it to the drum where it can be returned to the ready mixed concrete plant for recycling.

Extra concrete is often returned to the ready-mix plant where it is recycled or used to make jersey barriers or retaining wall blocks; or it can be washed to recycle the coarse aggregate. Special set retarding admixtures can be added to return concrete to allow for storage and future use.

ii. Local:

Materials are usually extracted and manufactured locally.

iii. Recycled content:

Fly ash, slag cement, or silica fume can substitute partially for cement, and recycled aggregates can replace newly mined gravel.

►During the life of the structure:

i. **Energy Performance and Thermal Mass:** Thermal mass improves energy performance when appropriately insulated. When 3 inch or more in thickness, concrete forms an air barrier.

ii. **Durable:** Concrete stands up to natural disasters, wind-driven rain, moisture damage, and vermin. Less replacement means reduced resource requirements.

iii. **Cool:** Using light- or natural-colored material helps reduce the heat island affect.

iv. **Low emitting:** Concrete has low VOC emission and does not degrade indoor air quality.

v. **Recyclable**: Concrete is commonly recycled in urban areas into fill and road base material at the end of service life.

Table 2.2: Difference between Precast & Cast-in-situ Concrete

Precast	**Cast-in-situ**
Elements are manufactured in a controlled casting environment and have it is easier to control mix, placement and curing.	Elements are manufactured on site and hence it is difficult to control mix, placement and curing.
Quality can be controlled and maintained easily.	Quality control and maintenance is difficult.
Less labours are required.	More labours are required.
Less skilled labours are required.	More skilled labours are required.
Precast construction is quick as it can be installed immediately and there is no waiting for it to gain strength.	Construction is slow as gaining of strength requires time.
Increase in strength can be achieved by accelerated curing.	Increase in strength at situ by accelerated curing is a difficult task.
Elements can be cast in controlled condition.	Elements are cast in open environment.
On site strength test is not required.	On site strength test is required.

2.8 Pre-stressed Concrete

Pre-stressed concrete invented by Eugene Frevssinet in 1928 is a method for overcoming concrete's natural weakness in tension. Although pre-stressed concrete was patented by a San Francisco engineer in 1886, it did not emerge as an accepted building material until a half-century later. The shortage of steel in Europe after World War II coupled with technological advancements in high-strength concrete and steel made pre-stressed concrete the building material of choice during European post-war reconstruction. North America's first pre-stressed concrete structure, the Walnut Lane Memorial Bridge in Philadelphia, Pennsylvania, however, was not completed until 1951.

In conventional reinforced concrete, the high tensile strength of steel is combined with concrete's great compressive strength to form a structural material that is strong in both compression and tension. The principle behind pre-stressed concrete is that compressive stresses induced by high-strength steel tendons in a concrete member before loads are applied will balance the tensile stresses imposed in the member during service.

Pre-stressing removes a number of design limitations conventional concrete places on span and load and permits the building of roofs, floors, bridges, and walls with longer unsupported spans. This allows architects and engineers to design and build lighter and shallower concrete structures without sacrificing strength.

Figure 2.22: Pre-stressed Concrete

The principle behind pre-stressing is applied when a row of books is moved from place to place. Instead of stacking the books vertically and carrying them, the books may be moved in a horizontal position by applying pressure to the books at the end of the row. When sufficient pressure is applied, compressive stresses are induced throughout the entire row, and the whole row can be lifted and carried horizontally at once.

Pre-stressed concrete has experienced greatest growth in the field of commercial buildings. For buildings such as shopping centers, pre-stressed concrete is an ideal choice because it provides the span length necessary for flexibility and alteration of the internal structure. Pre-stressed concrete is also used in school auditoriums, gymnasiums, and cafeterias because of its acoustical properties and its ability to provide long, open spaces. One of the most widespread uses of pre-stressed concrete is parking garages.

2.8.1 Advantages of Pre-stressed Concrete

1. The size or dimensions of structural members are reduced, which may increase the clearances or reduce storey heights.
2. It permits the use of large spans (greater than 30 m) with shallow members, even when heavy load are encountered.
3. In addition to general advantages, such as excellent fire resistance, low maintenance costs, elegance, high corrosion-resistance, adaptability etc, the pre-stressed concrete is found to sustain the effects of impact or shock and vibrations.
4. Because of smaller loads due to smaller dimensions being used, there is considerable saving cost of supporting members and foundations.
5. The pre-stressing technique has eliminated the weakness of concrete in tension and hence crack free members of structure are obtained.
6. Because of better material (i.e. controlled concrete and high tension steel) being used and nullifying the effect of dead loads, smaller deflections are caused.

2.8.2 Disadvantages of Pre-stressed Concrete

The following are among the advantages of using pre-stressed concrete.

1. The unit cost of high strength materials being used is higher.
2. Extra initial cost is incurred due to use of pre-stressing equipment and its installation.
3. Extra labour cost for pre-stressing is also there.
4. Pre-stressing is uneconomical for short spans and light loads.

2.9 Pre-tensioning

In pre-tensioning, the steel is stretched before the concrete is placed. High-strength steel tendons are placed between two abutments and stretched to 70 to 80 percent of their ultimate strength. Concrete is poured into molds around the tendons and allowed to cure. Once the concrete reaches the required strength, the stretching forces are released. As the steel reacts to regain its original length, the tensile stresses are translated into a compressive stress in the concrete. Typical products for pre-tensioned concrete are roof slabs, piles, poles, bridge girders, wall panels, and railroad ties.

Figure 2.23: Pre-tensioning Process

2.9.1 Advantages of Pre-tensioning

• Pre-tensioning is suitable for precast members produced in bulk.

• In pre-tensioning large anchorage device is not present.

2.9.2 Disadvantages of Pre-tensioning

• A pre-stressing bed is required for the pre-tensioning operation.

• There is a waiting period in the pre-stressing bed, before the concrete attains sufficient strength.

• There should be good bond between concrete and steel over the transmission length.

2.10 Post-tensioning

In post-tensioning, the steel is stretched after the concrete hardens. Concrete is cast around, but not in contact with un-stretched steel. In many cases, ducts are formed in concrete unit using thin walled steel forms. Once the concrete has hardened to the required strength, the steel tendons are inserted and stretched against the ends of the unit and anchored off externally, placing the concrete into compression. Post-tensioned concrete is used for cast-in-place concrete and for bridges, large girders, floor slabs, shells, roofs, and pavements.

Figure 2.24: Post-tensioning Process

2.10.1 Advantages of Post-tensioning

1. Reduced cost: Post tension slabs are excellent ways to construct stronger structures at an affordable price. There are many structures like parking garages as well as stadiums, since they are required to hold much more weight than average buildings; this slab becomes a viable option.

2. Flexibility in design: The designs made with this slab are sleek, require lesser space and give way to **dynamic contours**. All this makes them ideal for the expression of creativity in the building design.

3. Lesser usage of materials: Since the post tension slab is thin, the materials used with it are also lesser. Be it the thin beams, walls or supporting pillar of buildings, this **compact concrete slab** does not need bulky materials.

4. Durability: Being a very strong substitute of the normal concrete, it lasts longer.

2.10.2 Disadvantages of Post-tensioning

1. **Corrosive**: Since there are a number of tendons and wires spread inside the post tension slab, it can result in corrosion. But largely, this tendency to corrode depends on the quality of the material used.

2. Complexity of work: The post tension slab can be made only by skillful professionals. The local workers may not have the necessary skills required to prepare this complex slab.

3. Poor workmanship can lead to accidents: The main problem with using **post tension slab** is that if care is not taken while making it, it can lead to future mishaps. Many a times, ignorant workers do not fill the gaps of the tendons and wiring completely. These gaps cause corrosion of the wires which may break untimely, leading to some untoward events

2.11 Full Depth Bridge Deck Panel

Precast deck panels are capable of improving durability and quality of the deck thorough casting in a controlled environment. Full-depth precast deck panels are usually developed for accelerating bridge construction. Use of these panels to bridge construction has gained wide acceptance because they can offer several advantages such as rapid construction, minimal onsite formwork and scaffolding, reduced labor and structural costs, and improved quality and durability. In addition, these bridge decks may require lower maintenance and life-cycle costs.

Currently, full-depth precast deck panels are connected to supporting girders through shear pockets. Void spaces are placed within the precast panels when they are fabricated at the pre-stressing yard. When full-depth precast deck panels are transported and installed at the construction site, shear pockets are aligned with the mechanical shear connectors of the supporting beam and set in place. The shear pockets are generally through the panel thickness. However, the opening for shear studs could also be on the bottom side only, allowing smoother riding surface. After placement, the pockets are filled with grout to connect deck panels to the supporting girders._Leveling bolts are also incorporated into precast deck panel, allowing the achievement of desired deck profile. Various transverse joint types have been utilized in practices, such as match cast joints with shear keys, and joints with mild or post-tensioned reinforcement.

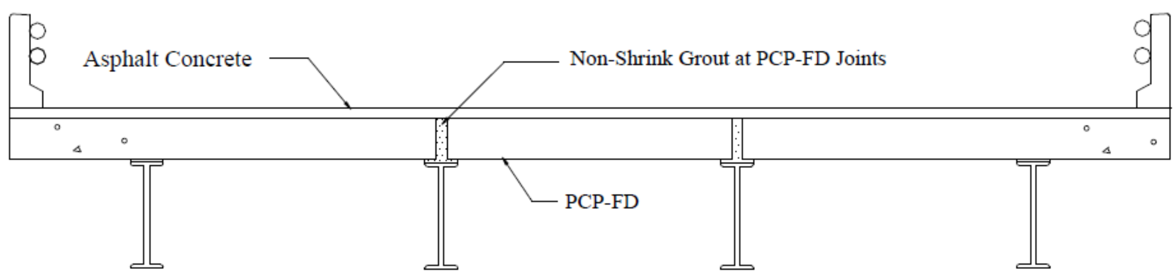


Figure 2.25: Full Depth Bridge Deck Panel

2.12 Partial Depth Bridge Deck Panels

Many different states have used partial depth deck panels; for example, 85% of all bridges built in Texas use this forming method. Unlike full-depth deck panels, partial depth panels act as a stay-in-place form when used for bridge construction and a topping slab or overlay is applied once the panels are in place. These panels are generally 3.5 in. to 4 in. thick and are placed on top of the beams on interior spans. Using partial depth precast deck panels accelerates construction by eliminating the need to construct formwork, although overhangs are usually constructed with conventional forming methods because of future widening concerns. One disadvantage is the possibility of cracks in the topping slab located at the joints of the precast panels. Washington DOT only allows the use of partial-depth panels in the positive moment region of the deck because, in this area, the top of the slab is in compression. Texas DOT has sponsored a great deal of research on precast partial depth deck panels, including laboratory studies, field verification, strength tests, and cyclic live load tests. It is preferred to use pre--stressing as the main reinforcement in partial depth panels. Due to their shallow depth, it is important to use a minimum amount of pre-stressing force and a small strand diameter 13 to decrease the probability of edge cracking during the development of the strands. The panels are made composite with steel or concrete beams by using welded stud shear connectors or standard shear reinforcement, respectively, in the gap between adjacent panels. When the topping concrete is placed, this gap is filled. For this system, it is important to provide a concrete bedding between the panels and beams, so that the panels are continuously supported to resist live loads; otherwise, the riding surface can be poor, and joints may spall. With regard to ensuring that the panels and topping concrete act as a single unit to resist loads, research has shown that composite action between the panels and topping is possible without using horizontal shear reinforcement (Whittemore et al., 2006) (Buth et al., 1972); intentionally roughening the top surface of the panel, after removing laitance or other contaminates, can provide the needed bond between the CIP concrete and precast panel.

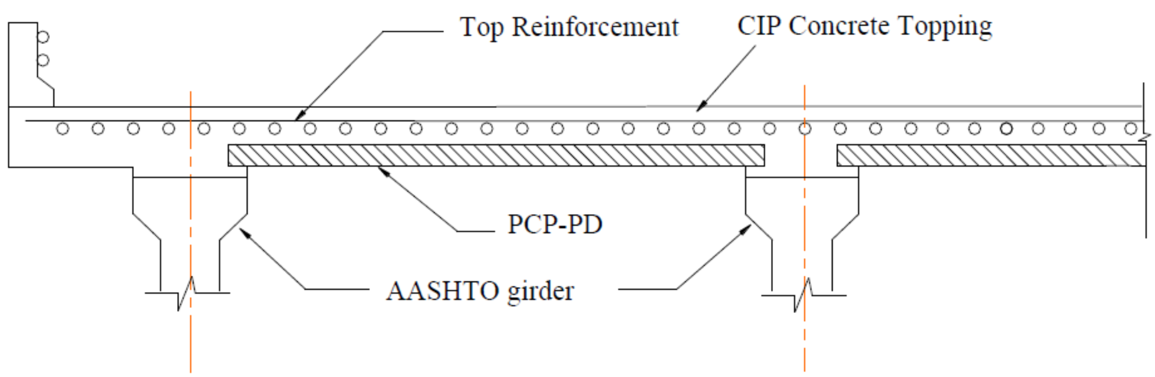


Figure 2.26: Partial Depth Bridge Deck Panel

2.13 Ribbed Slab

2.13.1 Background of Ribbed Slab

During recent years the demand on using three-dimensional FE (Finite Element) analyses for bridge design has increased substantially. This has led to many questions, among them the interpretation of FE results for reinforced concrete. A common way to design rein-forced concrete is by linear elastic FE analysis. This can give a good representation of concrete behavior as long as the structure remains un-cracked. Cracked reinforced concrete has a highly non-linear behavior and peaks of stresses that initiated the cracks will redistribute to other regions with higher stiffness. This stress redistribution is not simulated by a linear elastic FE analysis. Instead, stresses can become much larger than for the real structure, like stress concentrations at geometric- or static discontinuities. Hence, at some critical points the deviation of the FE results be-come too large compared to the real structural response and therefore one cannot directly use them for design purposes.

A way of taking into account the stress redistributions in design can be by smearing out the stress concentrations within larger parts of the structure and in this way get rid of the unrealistic peaks. By doing so, one could get better representation of the actual behavior and would not need to carry out demanding non-linear analyses for each design case. Therefore, recommendations are needed about how to perform this distribution.

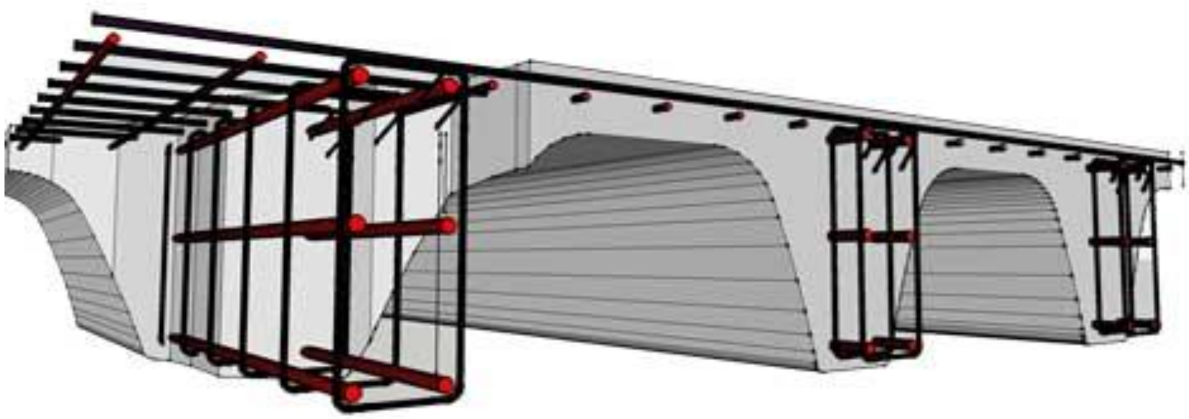


Figure 2.27: Cross Section of the Ribbed Slab

2.13.2 Purpose and Scope of Ribbed Slab

The primary purpose of this project is to give recommendations on how to distribute shear force in a bridge deck with two-way action. The recommendations are of interest because they may help the design to become more accurate, avoiding over-conservatism. The purpose is also to gain better understanding about how concrete slabs behave with respect to shear and failures caused by shear. In this master's the-sis, focus is put on specific cases with concentrations of shear force, for instance concentrated loads on bridge decks. The recommendations should however be general and applicable to all cases with concrete slabs.

2.14 Necessity of Shrinkage Reinforcement

Hardening of concrete always associate with change in volume resulting shrinkage stresses. It is advisable to minimize such shrinkage by using concrete with the smallest possible amounts of water and cement compatible with other requirements, like strength and workability, and by thorough moist-curing of sufficient during. But a certain degree of shrinkage is usually unavoidable irrespective of what precautions are taken.

In case of slab having moderate dimensions freely rested on its supports can contract to compensate the shortening of its length produced by shrinkage. But in normal case, slabs and other members are joined rigidly to other parts of the structure and restricted to contract, producing shrinkage stress. In outdoor structures like bridges, a decrease in temperature relative to that at which the slab was poured subjected to similar effect of shrinkage.

2.15 CODE Requirements

Minimum Shrinkage and temperature reinforcement normal to primary flexural reinforcement is required for structural floor and roof slabs (not slabs on ground) where the flexural reinforcement extends in one direction only.

2.15.1 Placement of Reinforcement

In slabs, provided with reinforcement provided for bending moments has the desirable effect of reducing shrinkage and distribution cracks. However, as contraction take place equally in all directions, it is necessary to provide special reinforcement for shrinkage and temperature contraction in the direction perpendicular to the main reinforcement. This added steel is known as temperature or shrinkage reinforcement.

Reinforcement for shrinkage and temperature stresses normal to the principal reinforcement should be provided in a structural slab which the principal reinforcement extends in one direction only. ACI code 7. 12. 2 specifies the minimum ratios of reinforcement area to gross concrete area (i.e. based on the total depth of the slab) shown in Table below, but in no case may such reinforcing bars be placed farther apart than 5 times the slab thickness or more than 18 in. In no case is the reinforcement ratio to be less than 0.0014.

Table 2.3: Minimum Ratio of Temperature and Shrinkage Reinforcement

Minimum ratios of temperature and shrinkage reinforcement in slabs based on gross concrete area

Slabs where Grade 40 or 50 deformed bars are used	0.0020
Slabs where Grade 60 deformed bars or welded wire fabric (smooth or deformed) are used	0.0018
Slabs where reinforcement with yield strength exceeding 60,000 psi measured at yield strain of 0.35 percent is used	$\frac{0.0018 \times 60{,}000}{f_y}$

The steel required by the ACI code for shrinkage and temperature crack control also represent the minimum permissible reinforcement in the span direction of one-way slabs; the usual minimum for flexural steel do not apply.

Finally, temperature and shrinkage reinforcement plays an important role for temperature and moisture change. It should be done according to the code.

Chapter- 03

DESIGN OF BD DECK-1

3.1 Specifications of Deck Girder Bridges in Bangladesh

In Bangladesh, for bridge designs with spans less than 24m reinforced concrete (RC) girder bridges are used, for 24m-48m spans pre-stressed concrete (PC) girder bridges are used, and for spans greater than 48m PC box girders are used(RHD 2016). All of the above deck systems use the cast-in-place decks. The Roads and Highways Department follows the general guidelines (applicable for both Pre-stressed Concrete and Reinforced Concrete bridges) given below-

- Specification followed: AASHTO Standard Specifications for Highway Bridges, 1996/ LRFD-2004.
- Live Loading Standard H.S. Trucks H 20–S16-44 Loading including Lane Load (HL-93), unless otherwise specified.
- Design Wind Velocity: 100 mph (160 kmph).
- Unit Weight of Concrete: 24.00 kN/m^3.
- Modulus of Elasticity of Steel: Es= 20,000.00 MPa.
- Concrete shall have to develop a strength of f'c= 20.00 MPa (if not mentioned otherwise) at 28 days (cylinder crushing strength). This should be ensured by preparing trial mix design before actual concreting work.
- Deck Slab
  Clear cover: a) top= 38mm, b) bottom= 25mm.

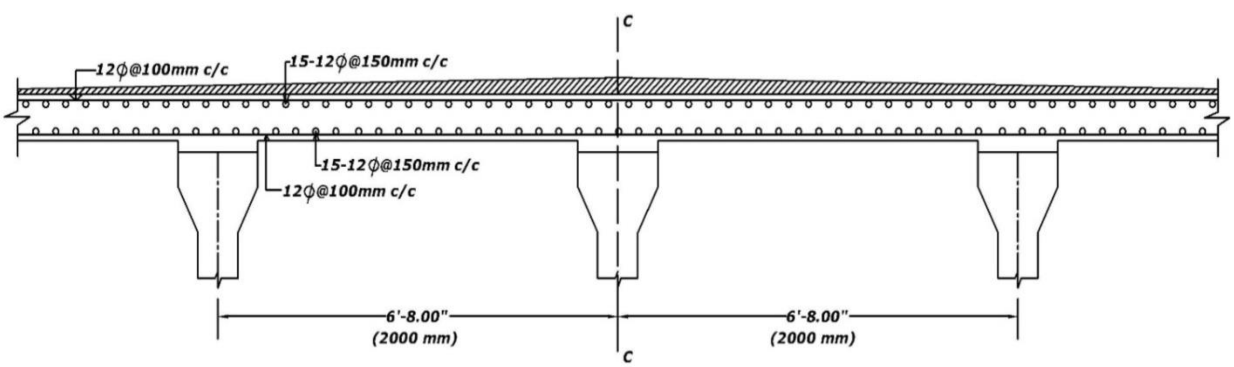


Figure 3.1: Reinforcement Details of a Typical Bridge Deck of a Span of 27m (Roads & Highways Department, Bangladesh, 2016)

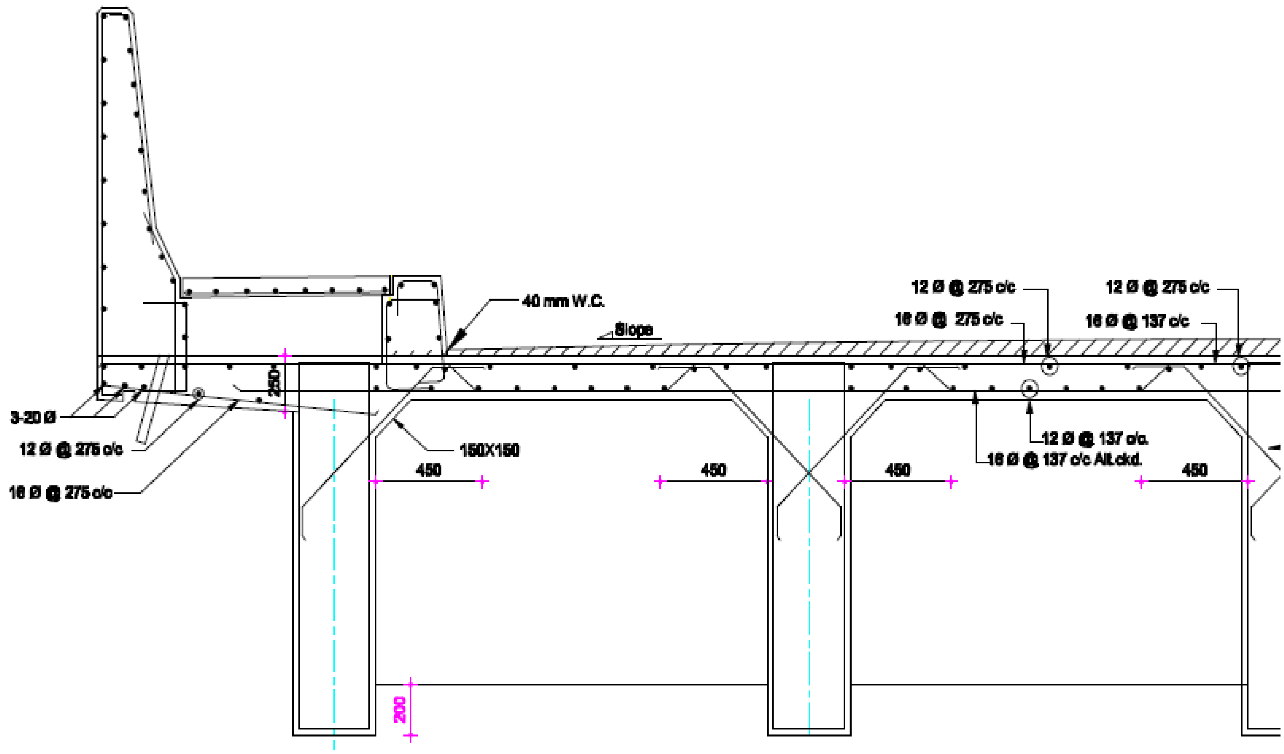


Figure 3.2: Reinforcement Details of a Typical Bridge Deck of a Span of 21m (Roads & Highways Department, Bangladesh, 2016)

3.2 DESIGN CONCEPTION

In the design of bridges, the crucial loads required to be calculated are Lane Loads, Impact Loads, Live Loads and Dead Loads. These parameters are subsequently used to determine Moment Capacity and eventually design the deck slab. For the design of BD Deck 1, the existing Moment Capacity for the 21m span RCC Deck Slab Bridge as designed by Roads & Highways Department of Bangladesh was used in the determination of important parameters required in the design of the new deck panel system, using data from their website as well as documents procured personally from their offices.

Moment Capacity values from Roads & Highways Department were used in back-calculations to determine other vital parameters for the new deck panel design, as mentioned previously. These parameters are specifications for shrinkage reinforcement, pre-stressing strand diameter and length, anchorage and duct specifications, panel thickness, length and width (overall dimensions), shear pockets, dowel bars and panel joints in both longitudinal as well as transverse directions.

Due to a constraint in time, the calculation of the major loads – Lane Loads, Impact Loads, Live Loads and Dead Loads- were not specifically calculated for the design of BD Deck 1. It would have been more accurate had that been done, but an alternative method, also correct, was used. The loading and other relevant data that could not be specifically measured or calculated were used, for a typical 21m span of RCC Deck Slab Bridge as designed by Roads & Highways Department of Bangladesh.

3.3 Design Calculation (For Exterior and Interior Deck Panel)

Moment Capacity from the Drawings of Roads & Highways Department (typical 21m span)

Main Reinforcement used= 16mm dia. @ 137mm C/C
Area of steel= (0.31*12")/5" = 0.744 in^2 /ft [controls]
As_{min}= .0018*12*8= 0.1728 in^2/ft
a= Asfy/.85bf'c = (.744*60)/(.85*12*3) = 1.46 in
As= 12M/[.9*60*(7-.73)]= 0.744
So, M= 21 k-ft

Reinforcement for BD-Deck-1 Proposed Design Matching RHD bridge deck Moment Capacity

Moment= 21 k-ft
As= (21*12")/.9*270*(7-.33) = 0.155 in^2/ft
a= .155*270/.85*6*12 = 0.684 in
Provide two 3/8 in dia. pre-stressing strands,
Area of pre-stressing steel= 0.085*2 = 0.17 in^2
Distribution reinforcement,
As_{min}= 0.002bh = .002*12*8 = 0.192 in^2
Having used 10mm bars, the spacing was found to be= 0.121*12/0.192 = 7 in C/C.

(Data for this calculation was taken from The Roads & Highways Department of Bangladesh, 2016.)

3.3.1 Design of Curb

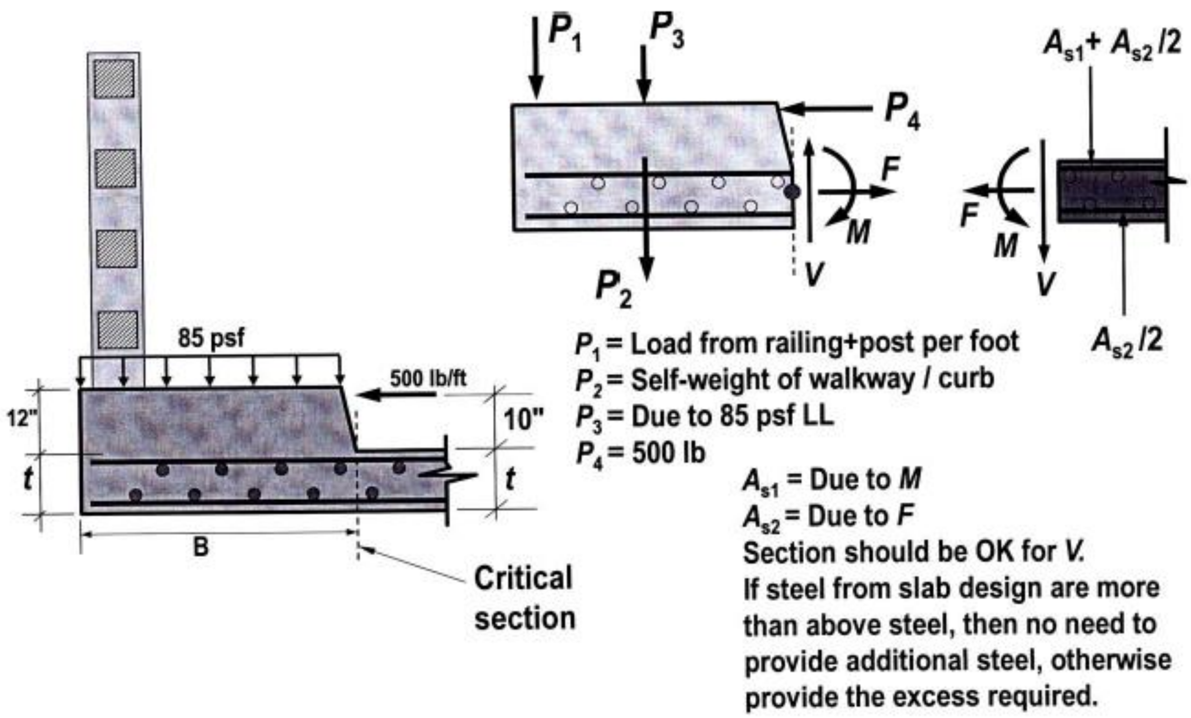


Figure 3.3: Curb

CURB:

P1= load from railing + post per foot = (76.04 + 50)*3.5 = 441.47lb

P2= self-weight of walkway = 3.5 *1 *150 * 1.5ft = 787.5lb

P3= due to 85psf LL = 85*3.5*1 = 297.5lb

P4= 500lb

Bending Moment, M= (441.47*3.5)+(787.5*3.5/2)+(297.5*3.5/2)= 3443.895lb-ft

F=P4=500lb

Curb thickness, t+12= 18in

$d_{required}=\sqrt{\frac{3443.895*12}{.9*.016*12*60000*(1-.59*.016*\frac{60000}{3500})}}$

= 4.8in <$d_{provided}$

Steel Area due to M, A_{s1}= M/Øf$_y$(d-a/2)

= 3443.895/{.9*60000*(18-.077/2)} = .00355 in^2

[a=1in, A_s=.046 in^2/ft

a=.077in, A_s= .045in^2/ft]

Therefore, a=$A_s f_y$/.85f_c'b

a=.077in and As=.045in^2

Spacing= .11*12/.045=29.3 in

<u>Use #3 bars @ 29in c/c.</u>

For accidental impact loads in the horizontal direction,

Assuming impact load, P4 or F=500lb

$A_{S\ F}$= F/(Øf$_y$) = 500/(.4*60000) = .009 in^2/ft

Spacing= .11*12/.009 = 146.7 in > 2t (= 2*5in = 10in)

Use #3 bar @ 10in c/c.

3.3.2 Design of Railing

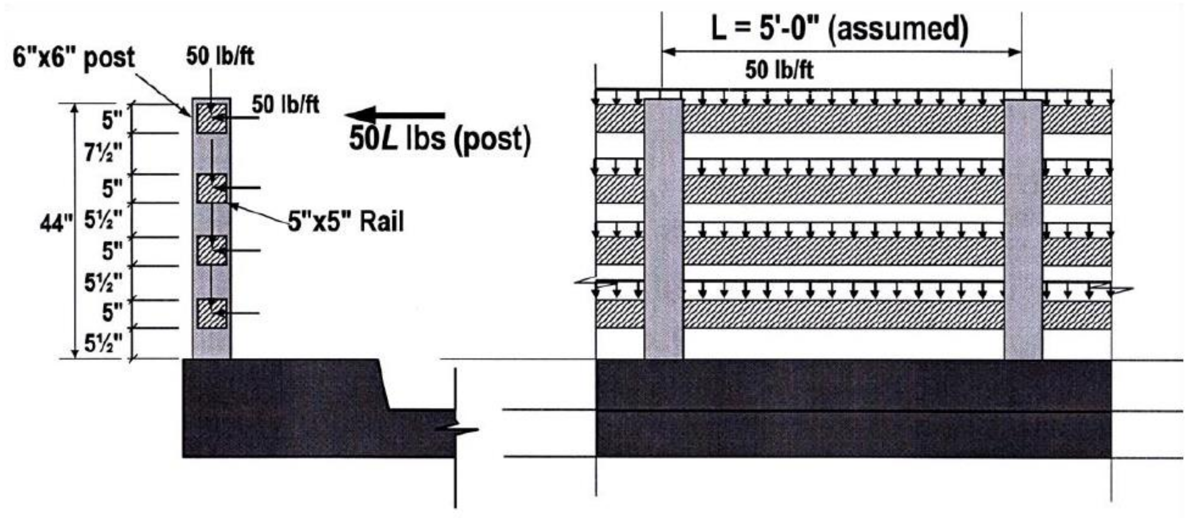


Figure 3.4: Railing

RAILING:

Assuming 5”x5” railing

Considering live load on each railing, W_L = 50lb/ft

Self-wt calculation,

W_D= 5”x5”/144 * 150 = 26.04 lb/ft

Total weight, W= $W_L + W_D$ = 50 + 26.04 = 76.04 lb/ft

Moment calculation,

Moment, M= $(WL^2/10) = 1/10 * 76.04 * 5^2 = 190.1$ lb-ft

Depth Check,

We know $\mu = ØÞbd^2f_y(1-.59Þf_y/f_c')$

$d^2 = 190.1 * 12 * 10^{-3}/.9*.016*5*60*(1-.59*.016*60/3.5)$

Therefore, $d= 0.794in<d_{assumed}$ (=2.5in)

Area of Steel, $A_s= M/Øf_y(d-a/2)$

$= 190.1/\{.9*60000*(2.5-.07/2)\} = .001428\ in^2$

[$a=1in$, $A_s=.0211\ in^2/ft$

$a=.09in$, $A_s= .017in^2/ft$

$a=.07in$, $A_s=.017in^2/ft$]

Therefore, $a=A_sf_y/.85f_c'b$

$a=.07in$ and $As=.02in^2$

$As_{min}=(200/f_y)*b_wd = (200/60000) *5* 2.5 = .04\ in^2$ (controls)

Use #3 bars.

3.3.3 Design of Rail Post

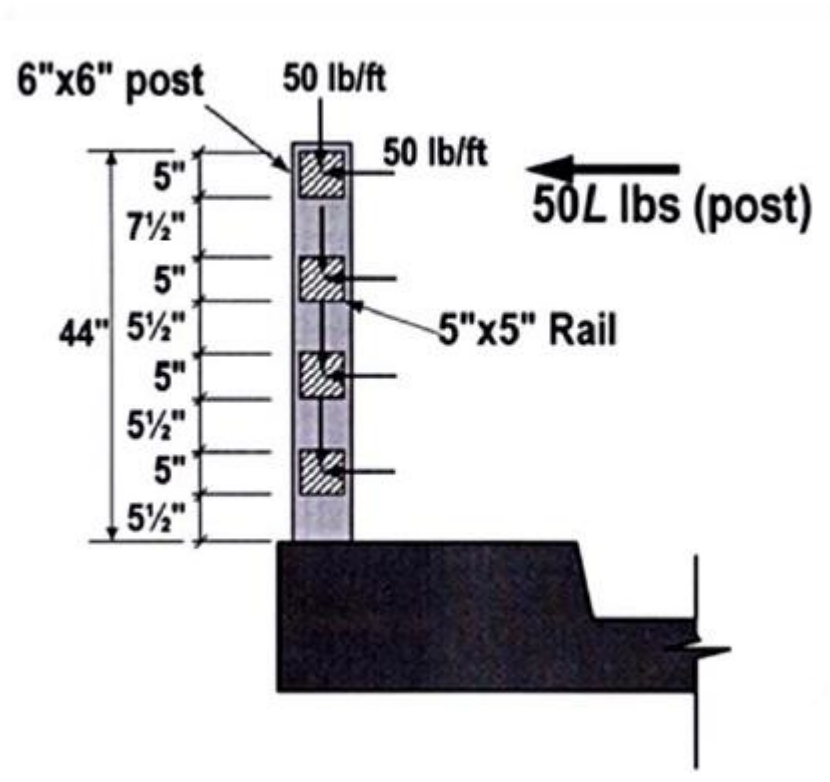


Figure 3.5: Rail Post

RAIL POST:

Height assumed, t = 48in

Rail post shall be designed for lateral loads only,

P=50L = 50*5 = 250lb

Moment, M=P*t = 250*4' = 1000 lb-ft = 1 kip-ft

We know $\mu = Ø Þ b d^2 f_y (1-.59 Þ f_y / f_c')$

d=(1*12)/(.9*.016*6*60 (1-.59*.016*60/3.5))

Therefore, $d=1.7in < d_{provided}(=3.5in)$

Area of Steel, $A_s= M/Øf_y(d-a/2)$

$= 1000/\{.9*60000*(3.5-.22/2)\} = .00546\ in^2$

[$a=1in$, $A_s=.074\ in^2/ft$

$a=.25in$, $A_s= .066in^2/ft$

$a=.22in$, $A_s=.066in^2/ft$]

Therefore, $a=A_sf_y/.85f_c'b$

$a=.22in$ and $As=.066in^2$

$As_{min}=(200/f_y)*b_wd = (200/60000) *6* 3.5 = .07\ in^2$ (controls)

<u>Use #3 bars.</u>

3.4 BD DECK 1 DETAILS

The proposed design consists of full-depth precast, pre-stressed concrete panels. The panel depth is 8 inches with ribs- where the upper depth of 4.5 inches is the continuous solid and the lower depth of 3.5 inches is the rib depth. The ribs are 2 feet C/C and they span from girder to girder.

In the proposed design, the panel width is 7 feet. Higher strength concrete of 6000 psi (42 MPa) and higher strength steel of 270,000 psi (1862 MPa) are considered for pre-tensioning. The pre-stressing strands are of 3/8 inches diameter. The transverse dimension of the panels will depend on the girders' C/C distance.

The shrinkage reinforcements are 10mm bars provided at the top. The strength of the distribution reinforcement is taken as 60,000 psi (414 Mpa). The crown can be achieved by the base support under the panels.

The deck panels will be joined by using dowel bars, as shown in the figure 3.7. These dowel bars will be placed within the shear pockets and then filled by non-shrink grout. At the top, a 0.5 inch gap is provided between two panels, which are filled with bitumen filler. This will allow for concrete expansion and contraction. If needed, bitumen overlay for a smoother surface, with approximately 3 inches at the crown and 1 inch near the curbs can be provided.

The minute details of BD Deck 1 are still being developed. The following figures show sections of the proposed design. This deck design has taken into consideration the existing capacity of the cast-in-place (CIP) bridge decks as employed by Roads and Highways Department of Bangladesh.

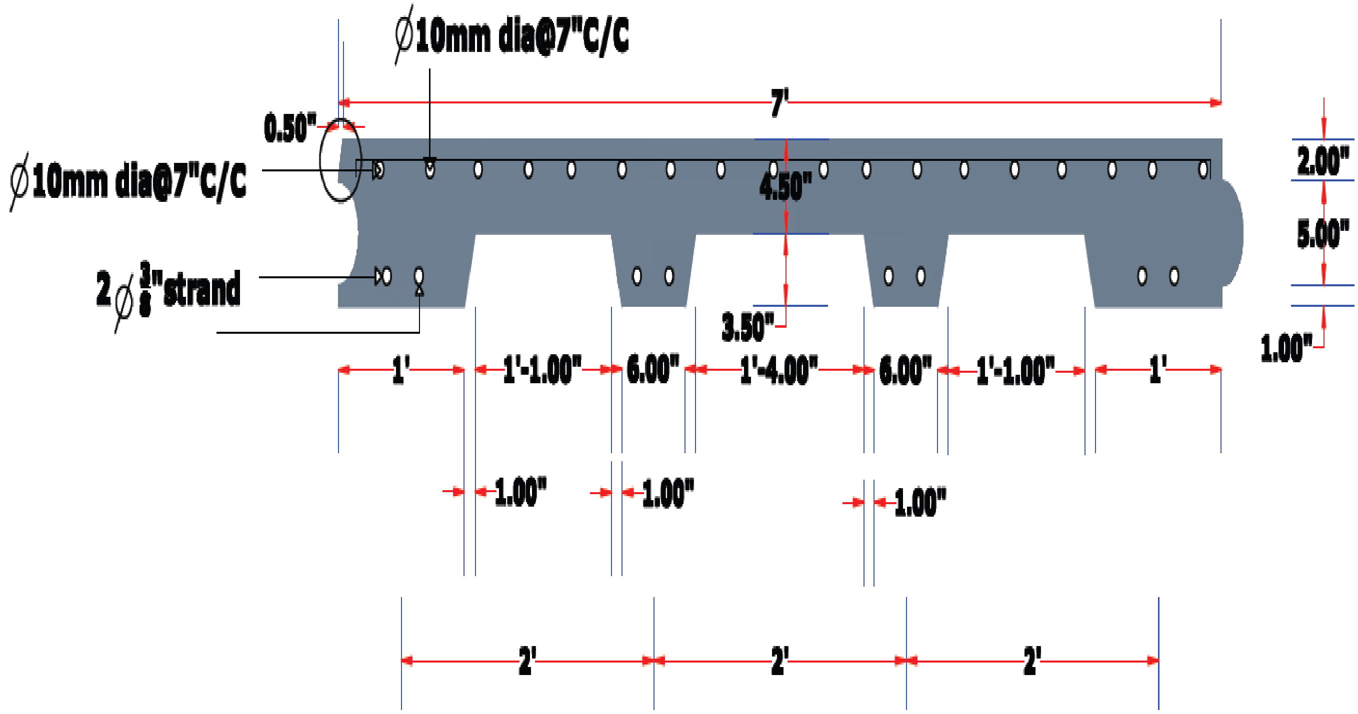


Figure 3.6: Typical Cross Section of BD Deck 1

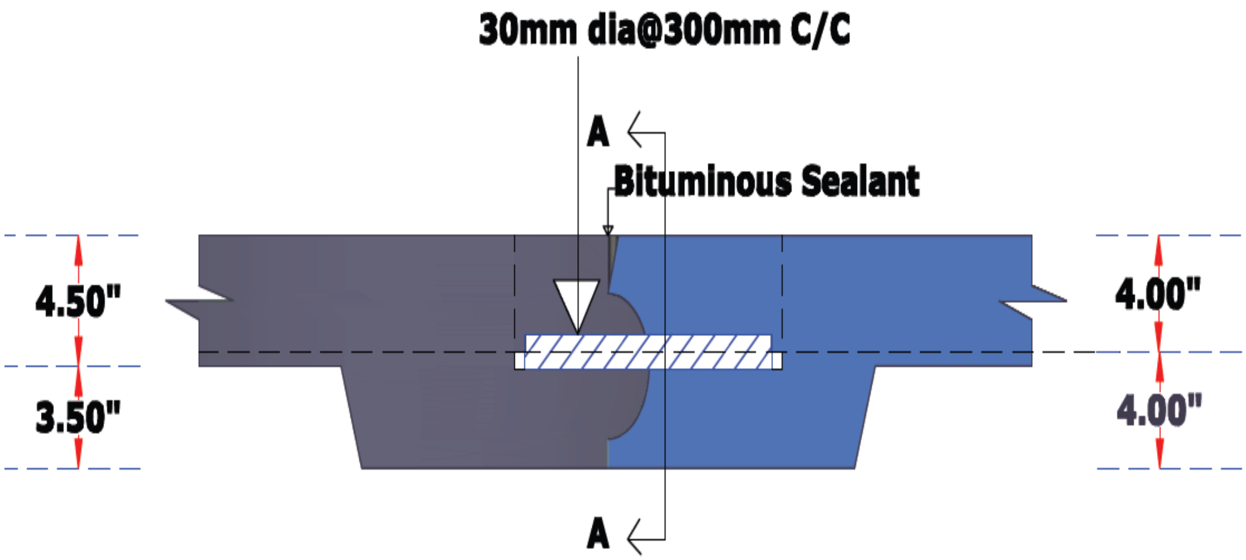


Figure 3.7: Contraction Joints with Dowel Bar

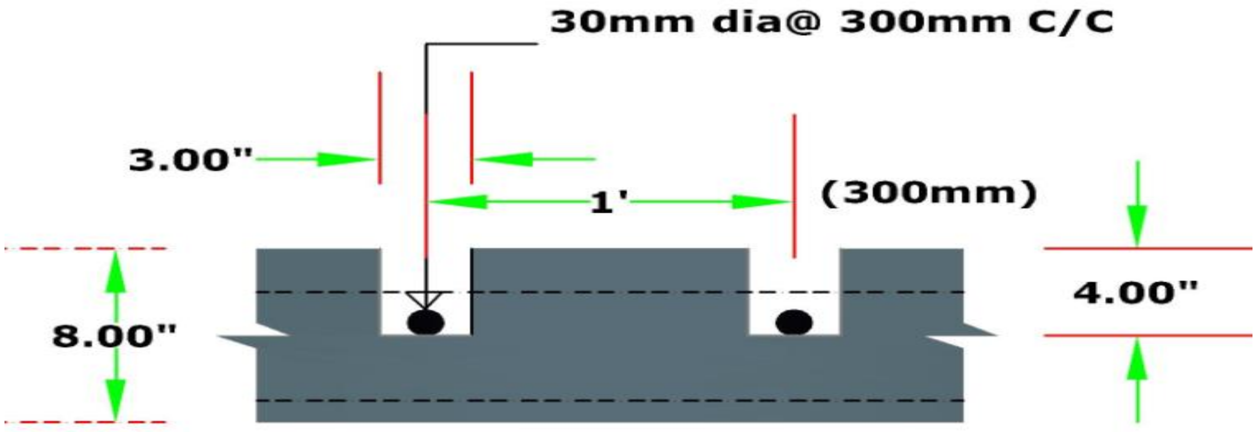


Figure 28: Section A-A of Figure 3.7

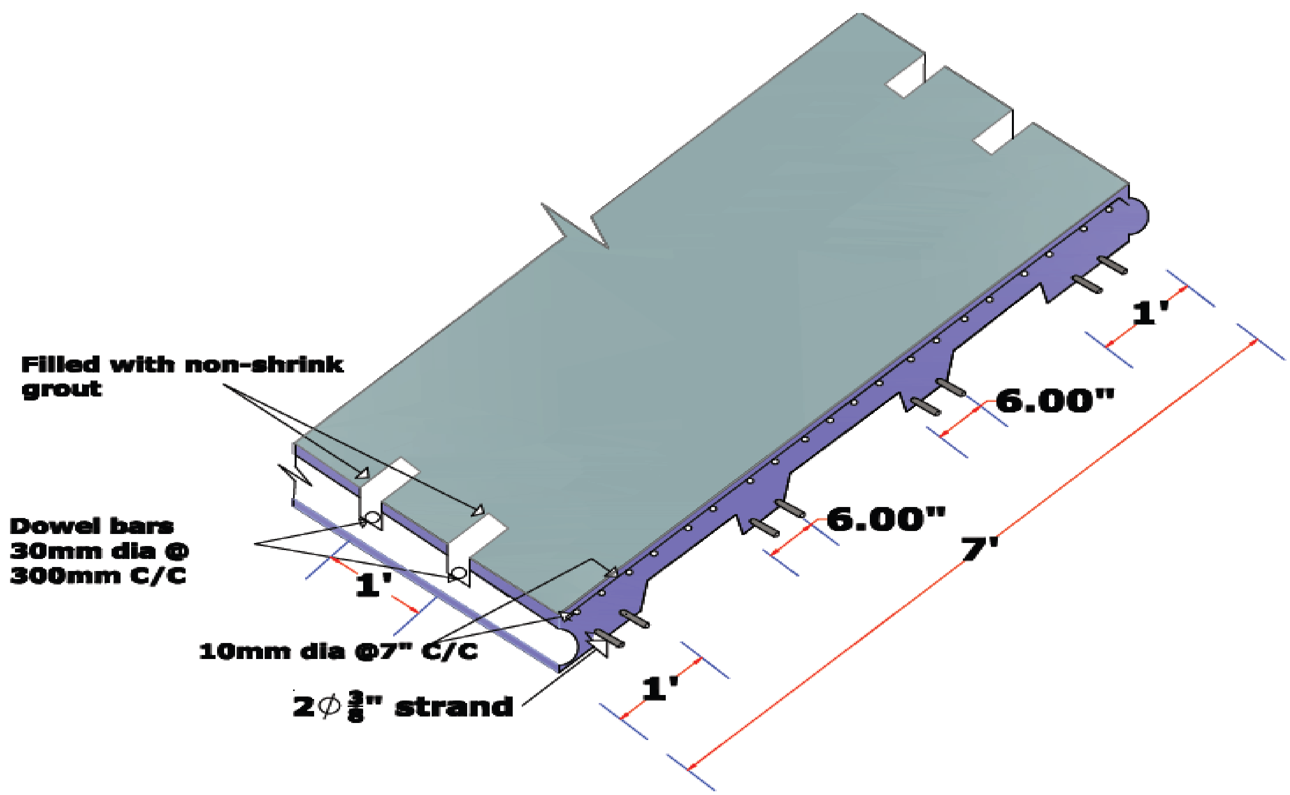


Figure 3.9: BD Deck 1

3.5 Construction process of Deck Panels

3.5.1 Fabrication, Transportation, Handling and placement

The loads and forces on the precast and pre-stressed slabs during fabrication, transportation, and erection require separate analyses because the support points and orientation are usually different than when the panel is in its final position. Several factors must be considered to select the most feasible manner of furnishing the concrete panels for a project (Babaei et al., 2001).
These factors can be summarized as follows:

1. Stability and stresses on the concrete element during handling.

2. Transportation size, weight regulations, and equipment restrictions.

3. Available crane capacity and rigging at both the plant and the project site.

3.5.2 Pre-fabrication of Precast pre-stressed Deck panels

The concept of precast (also known as "prefabricated") pre-stressed construction includes those deck panels, where the majority of structural components are standardized and produced in plants in a location away from the bridge construction site, and then transported to the site for assembly. These components are manufactured by industrial methods based on mass production in order to build bridges in a short time at low cost.

Figure 3.10: Pre-fabrication of Deck Panels in Plants (Bostwana, South Africa)

The main features of this construction process are as follows:

•The division and specialization of the human workforce.
•The use of tools, machinery, and other equipment, usually automated, in the production of standard, interchangeable parts and products.
•Compared to site-cast concrete, precast concrete erection is faster and less affected by adverse weather conditions.
•Plant casting allows increased efficiency, high quality control and greater control on finishes.
•This type of construction requires a restructuring of entire conventional construction process to enable interaction between design phase and production planning in order to improve and speed up construction.

The deck panels are manufactured from 2.5 or 3mm plate. The edges are coined to ensure that the panels butt up to each other resulting in a perfect concrete finish on the underneath of the slab.

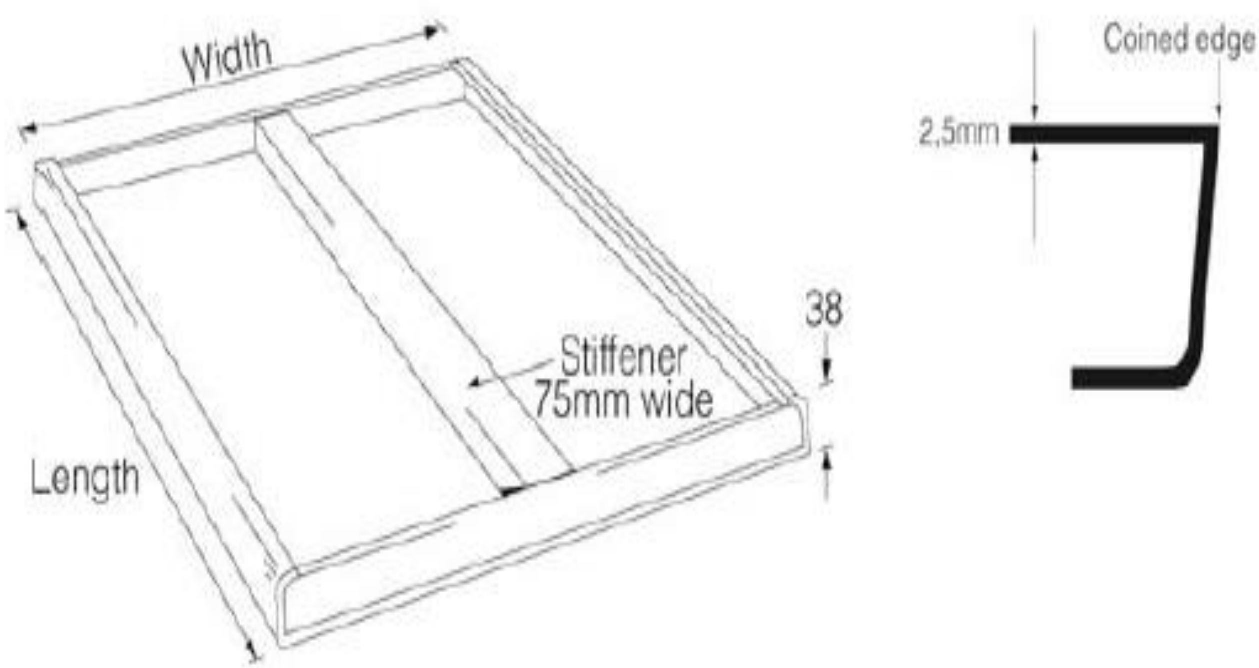


Figure 3.11: Typical Formwork for Mass Production of Deck Panels

Table 3.1: Different Sizes and Masses Coined Deck Panels

Size (mm)	Mass(kg)
1219 x 457	18.3
1219 x 305	10.3
1219 x 229	8.2
1219 x 152	6.2
914 x 610	17.3
914 x 457	14.1
914 x 305	7.8
914 x 229	6.3
914 x 152	4.7
825 x 450	12.3
825 x 300	7.2
825 x 200	4.4
825 x 100	3.4
1425 x 450 (Double Stiffener)	21.7
1425 x 300	14.5

3.5.3 Transportation

Transportation of Precast concrete deck panels include:

- Lifting from the casting bed and moving to storage.
- Moving from temporary storage to be loaded for transportation.
- Loading onto means of transportation.
- Transporting on road, rail or sea.
- Moving from temporary site storage to final location.

Precast concrete deck panels are usually lighter than the equivalent area of on-site cast-in-place concrete. This can represent a significant reduction in the number of truck movements and reduced consumption of fossil fuels. The amount of energy consumed during the transport of precast elements is about 0.00114 MJ/kg/km. This represents 5% to 10% of the total energy consumption during manufacturing of precast concrete elements.

Figure 3.12: Transportation of Deck Panels

3.5.4 Handling

Position of the crane must be considered, since capacity is a function of reach. Improper jobsite handling and storage, of the relatively thin pre-stressed sections required for modular bridge deck construction or replacement, can lead to dimensional instability, cracking, or warping that will adversely impact the panels' suitability for placement in the new superstructure. The contractor should be directed by representatives from the pre-stress supplier in regard to proper lifting techniques as well as blocking configurations necessary if jobsite storage will be required prior to slab installation. If jobsite storage is required, the site should be carefully chosen and set up so that varying weather conditions do not lead to settlement problems. Once the initial dunnage bedways are set up, periodic elevation checks should be performed for verification that no settlement problems have occurred. Special attention must be given to irregularly shaped pieces or any section that might have a post-casting induced crown.

3.5.5 Precast Panel Placement

Construction using precast slabs requires the availability of cranes in order to lift and place the precast slabs on the deck grade. The crane can be located on the bridge if the bridge strength and width can appropriately accommodate it. Cranes and other heavy equipment should not be allowed on the bridge if they impose structural overloads and cause damage to the bridge. The boundary and constraint conditions could also significantly control the placement of the cranes or other related equipment such as power lines, roads, rivers, etc.

Figure 3.13: Placement of Deck Panel

3.6 Steps of Deck Placement

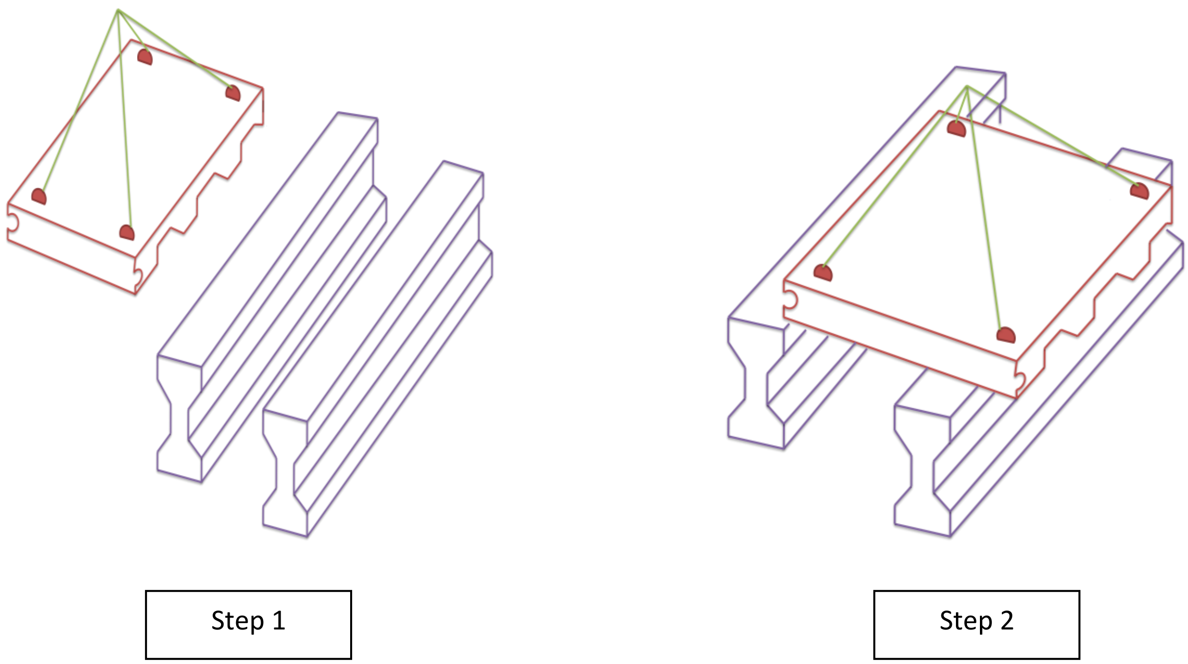
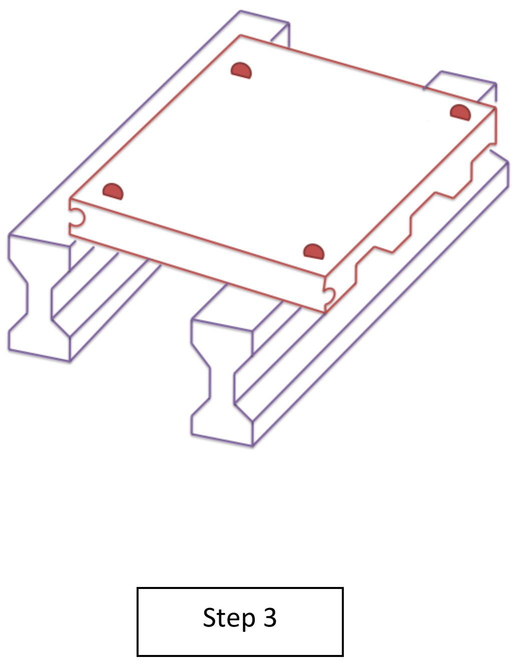


Figure 3.14: Lifting & Placement of a Panel on Supporting Girders

► **Step 1**: A singular panel is lifted using crane and chords attached to the panel.

► **Step 2**: The panel is placed on top of the supporting girders, to in this case.



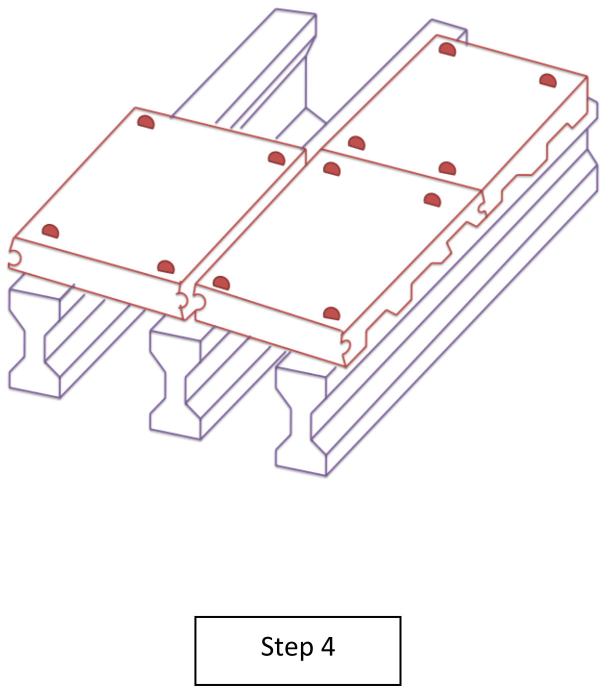


Figure 3.15: Placement of Subsequent Panels

► **Step 3**: The chords are detached from the panel.

► **Step 4**: The other panels are placed in a similar fashion.

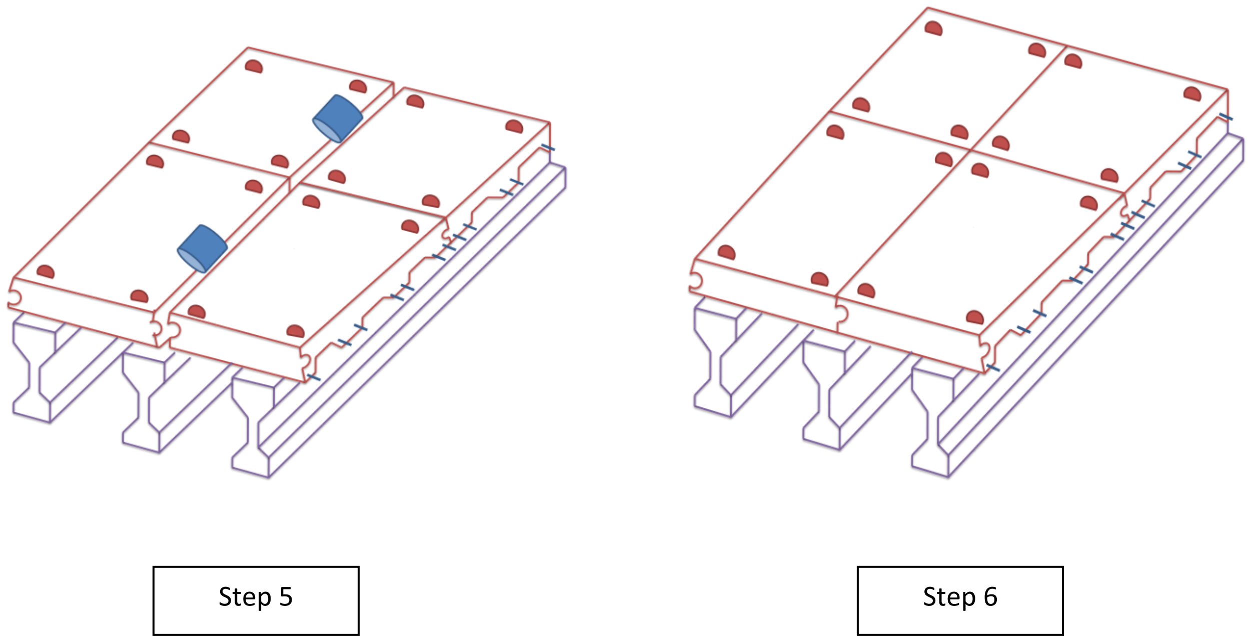
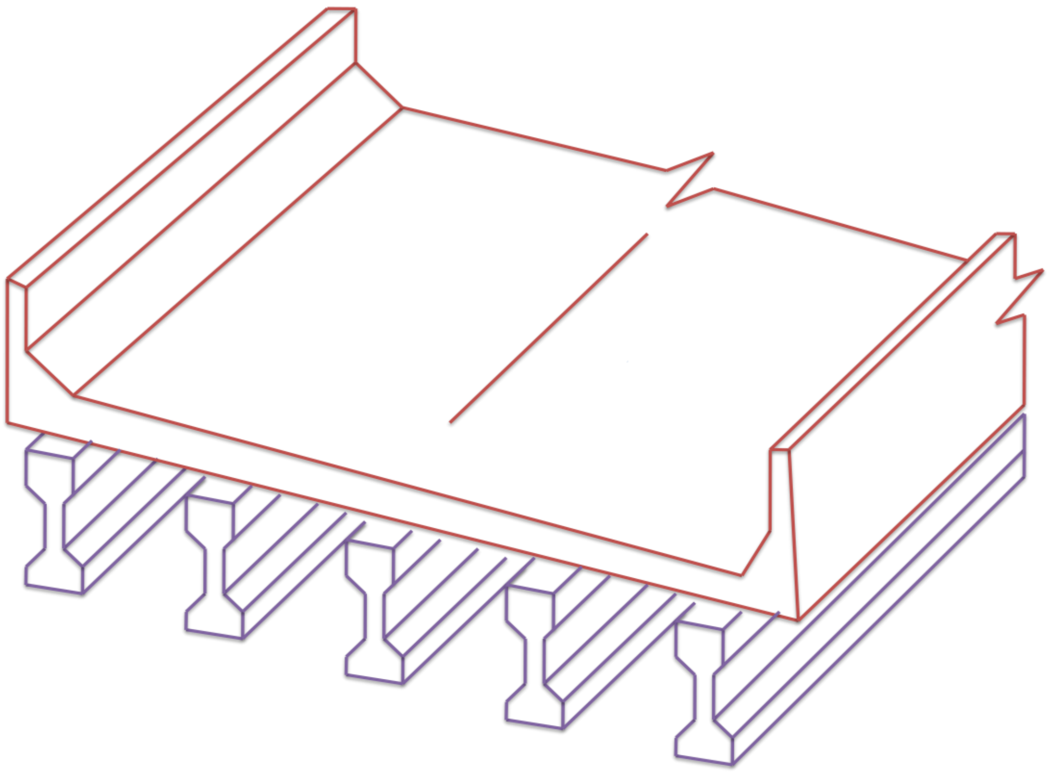


Figure 3.16: Shear Pockets between Panels Filled with Grout

► **Step 5**: The panel joints in the longitudinal directions (as shown in the figure) are filled with grout.

► **Step 6**: The same grouting is done throughout the deck at all such joints.



Step 7

Figure 3.17: Construction of Deck Completed

► **Step 7**: The final step is the bitumen layer a top the panels now jointed. The deck is hence completed.

3.7 Joint Construction

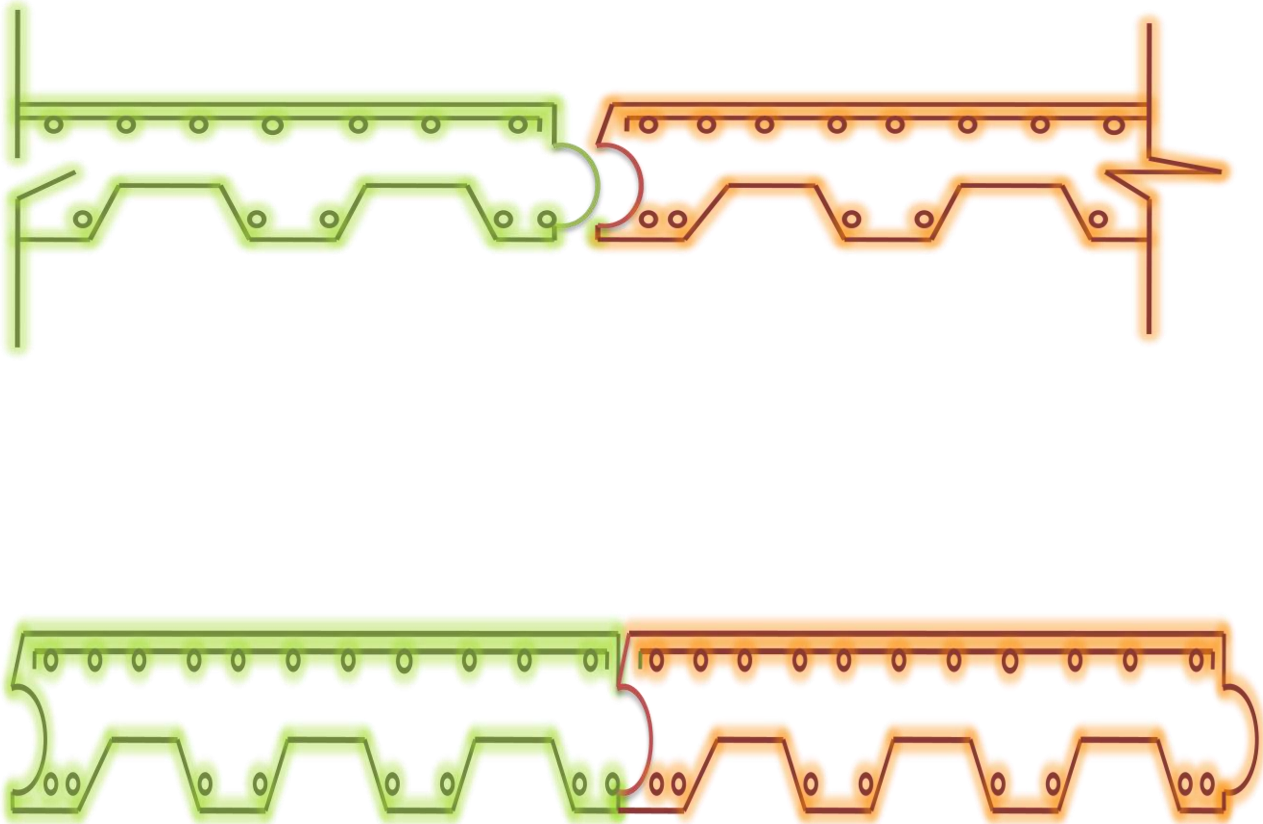


Figure 3.18: Cross Section View of Male-Female Panel Joint

Chapter- 04

ECONOMIC ANALYSIS

4.1 Area Reduction

Area = 8/12 * 7 = 4.6 ft^2

Hollow portion,

Area = ((13/12 * 2 + 16/12) * 3.5/12) + (.5 * (1/12) * (3.5/12)) * 6

= 1.02 + 0.07 ft^2

=1.09 ft^2

Reduced Area = (1.09/4.6) * 100%

= 23.76%

4.2 Volume Reduction

Volume = (2* 2.13* 0.203) m = 0.864 m^3

Area of hollow portion = 1.09 ft^2 = 0.1012643m^2

Reduced volume = (0.10126 * 2) m^3, where 2m = girder to girder distance

= 0.20252 m^3

Volume of shear pocket = (.0762* 0.1016* 0.3) m^3 = .00232 m^3

Total volume = (0.864 - 0.20252 - .00232) m^3 = 0.66 m^3

4.3 Cost Details

4.3.1 RCC Deck Slab (For 21m span)

Rates of schedule for Road and Bridge works (August 2015) of RHD, Bangladesh

Table 4.1: Material Rates of RCC Deck Slab

Serial No.	Item code	Item Description	Unit of measurement	Total unit price 2015 taka (with Tax and Vat)
01	n/a	Polythene sheet	sq. meter	15
02	n/a	Wooden formwork using 4 times	Cu. meter	6,250.00
03	n/a	Watering	Cu. meter	10.00
04	n/a	Brick chips(25-40mm)	Cu. meter	3000.00
05	05/01/03(k)	Concrete class- 30 (deck slab, side walk, wheel guard, curb etc)(batching plant)	Cu. meter	17,151.00
06	n/a	Reinforcement (60 grade)	Ton	65,640.00
07	05/02/03	Wire mesh reinforcement	Ton	85,456.00
08	05/08/02	Bridge Deck joint	Lin. meter	10,500.00

►Cost Calculation for Concrete:

Total cost for concrete = (15+6,250.00+10.00+3000.00+17,151.00) = 26426.00 tk/m^3

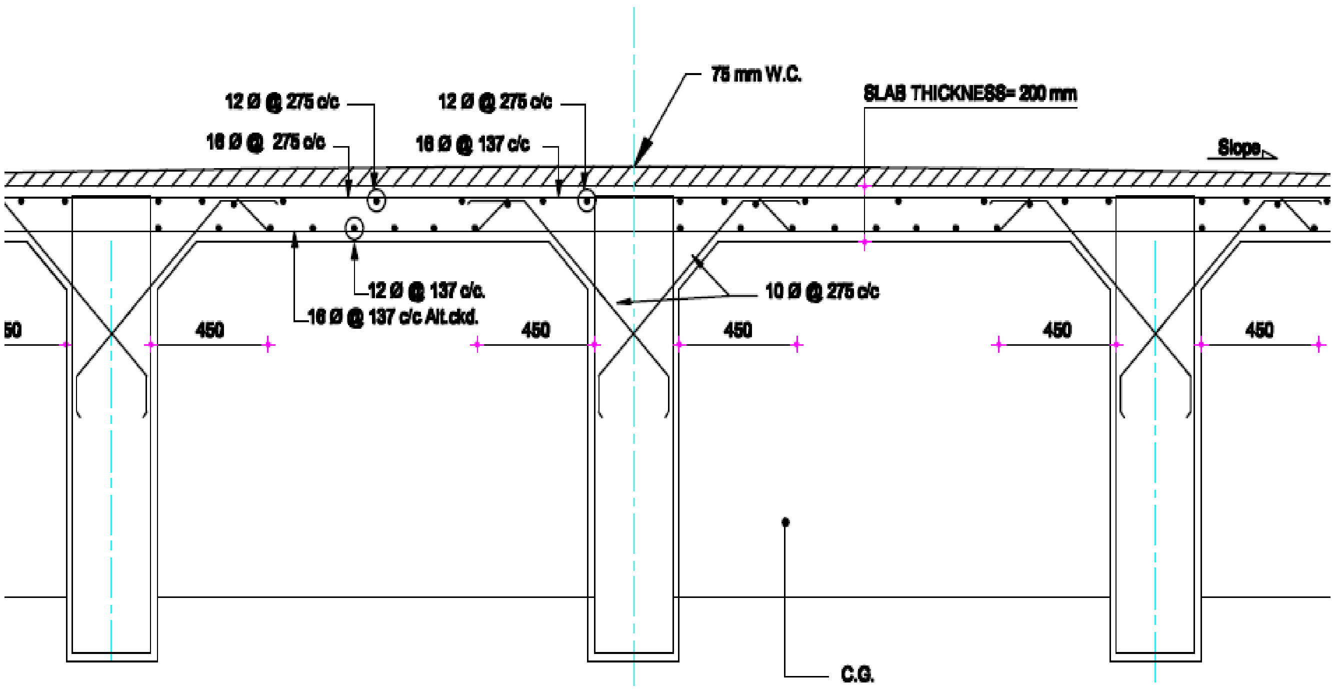


Figure 4.1: Typical deck Slab Detailing of 21m Span (Drawing from Roads & Highway Department)

►Cost Calculation for Reinforcement:

•Along Transverse Direction:

1. Main Reinforcement = 16Ø @ 275mm c/c
2. Cranked Bar (with girder) = 10Ø @ 275mm c/c
3. Extra Bar = 16Ø @ 137mm c/c
4. Alt. Cranked = 16Ø @ 137mm c/c

•Along Longitudinal Direction:

1. Distribution Reinforcement = 12Ø @ 275mm c/c

So, for **Distribution Reinforcement** 12Ø @ 275mm c/c at longitudinal direction,

Cross-sectional width = 10250mm

No of Bars required = (10250/275) = 37.27 ≈ 38nos

10250m (cross-sectional width) is provided with = 38 bars

Therefore, 1000mm or 1 meter is provided with = ((38*1000)/10250) = 3.70 ≉ 4nos bars of 21m.

Therefore, total length of 4 bars = (4*21) = 84 meter

For Main Reinforcement 16Ø @ 275mm c/c at transverse direction,

Length = 21000mm

No of Bars required = (21000/275) = 76.36 ≉ 77nos

21000 is provided with = 77nos bars

Therefore, 1000mm or 1 meter is provided with = ((77*1000)/21000) = 3.63 ≉ 4nos bars of 10.25m.

Therefore, total length of 4 bars = (4*10.25) = 41 meter

Similarly,

For **Cranked Bars**: <u>4 bars of 1.25m length</u> are required.

For **Alt. Cranked &Extra Tops**: <u>16 bars of 1.25m length</u> are required.

Therefore, total length of cranked bar = (4*1.25) = 5 meter

Total length of cranked bar = (8*1.25) = 10 meter

Total length of cranked bar = (8*1.25) = 10 meter

From roads and Highway Schedule of rates 2015,

Table 4.2: Specifications of Reinforcement Bars Depending on Bar Size and Bar Number

Nominal Size (dia in mm)	Bar No.	Cross-sectional area in mm²	Perimeter in mm	Mass per running meter in kg	Length per 100kg in meter
4		12.6	12.7	0.099	1010.10
5		19.6	15.71	0.154	644.35
6	2	28.3	18.85	0.222	450.45
7		38.5	21.99	0.302	331.12
8		50.3	25.13	0.395	253.16
10	3	78.5	31.42	0.616	162.34
12	4	113.0	37.7	0.888	112.61
16	5	201.0	50.27	1.579	63.33

10 mm diameter: weight 0.616 kg/m

12 mm diameter: weight 0.888 kg/m

16 mm diameter: weight 1.579 kg/m

So, total weight of reinforcements for 10Ø, 12Ø and 16Ø = ((5*0.616)+(84*0.888)+((41+10+10)*1.579))

= 173.991 kg

Now, 1 ton or 1000 kg = 65640 taka

Therefore, 173.991 kg = ((65640*173.991)/1000) = 11420 taka per meter

For wire mesh-reinforcement, lump sum 100 kg/m is required.

Cost for wire-mesh reinforcement = ((100*85,456.00)/1000)

= 8545 taka

TOTAL REINFORCEMENT COST= (11420 + 8545) **= 19965 taka/meter.**

Table 4.3: Labor Cost of RCC Deck Slab

Serial no.	Category	Unit	Taka (Recommended rate)
1	Ganger	Per day/Person	800
2	Fore man	Per day/Person	800
3	Carpenter	Per day/Person	600
4	Asphalt mystery	Per day/Person	600
5	Mason	Per day/Person	600
6	Skilled	Per day/Person	550
7	unskilled	Per day/Person	400
Total			4350

TOTAL LABOR COST = 4350 taka/ person/ day

Table 4.4: Transportation Cost of the Materials of RCC Deck Slab

Serial No.	Item code	Item Description	Unit of measurement	Total unit price 2015 taka (with Tax and Vat)
01	01/04/01	Saloon car 1200 cc capacity	month	55,000.00
02	01/04/02	Pick-up double cap	month	66,000.00
03	01/04/03	Four wheel drive vehicle minimum 6 seats	month	77,800.00

Total price per month = (55000+66000+77800) tk.

= 198800 tk.

TOTAL TRANSPORTATION COST = (198800/30) = 6630 taka/ day

Table 4.5: List of Different Types of Costs RCC Deck Slab (21m Span)

Material	Price
Concrete	26,424 taka/m^3
Reinforcement	19965 tk. /meter
Labor	4350 taka per person per day.
Transportation	6630 taka per day

4.3.2 BD deck 1

Roads and Highway Department of Bangladesh

Rates of schedule for Road and Bridge works (August 2015)

Table 4.6: Material Rates of BD Deck 1

Serial No.	**Item code**	**Item Description**	**Unit of measurement**	**Total unit price 2015 taka (with Tax and Vat)**
01	05/01/03(m)	Concrete class-40 (Batching plant)	Cu. meter	25,285.00
02	05/03/01	Pre-stressing wire or strand	Ton	2,73,590.00
03	n/a	Distribution Reinforcement	Ton	65,640.00
04	05/02/03	Wire mesh reinforcement	Ton	85,456.00
05	n/a	Dowel bar	Each	40

►Cost of High Strength Concrete:

Total concrete cost = 25,285.00 tk.

Calculation of Cost of Distribution reinforcement and Pre-stressing Strand:

For Distribution Reinforcement

From the Drawing of BD deck 1, used 10mmØ @ 7” c/c

= 10mmØ @ 177.8mm c/c in both directions.

For individual Deck panel,

In Longitudinal direction = 7’ =2134.15mm

No. of Bars required = (2134.15/177.8) = 12nos

Therefore, Bars per 1000mm or 1meter = ((12*1000)/2134.15) = 5.62 = 6 bars of 2m length

= 12 meter

In Transverse direction = 2m(c/c distance of girders) = 2000mm

No. of Bars required = (2000/177.8) = 11.248nos = 12nos

Therefore, Bars per 1000mm or 1meter = ((12*1000)/2000) = 6 bars of 2.13m

= 12.78 meter

So, total weight of reinforcements for 10Ø = ((12+12.78)*0.616) = 15.26 kg/meter

Now, 1ton or 1000 kg. = 65640 tk.

Therefore, 7.392 kg. = ((65640*15.26)/1000) = 1001.96 taka per meter

For wire mesh-reinforcement, lump sum 5 kg/meter is required.

Cost for wire-mesh reinforcement = ((10*85,456.00)/1000)

= 854.56 tk.

Total cost for reinforcement = (1001.96+854.56) = 1856.52 tk. /meter

►For Pre-stressing Strands,

From the drawing of BD deck 1, for individual deck slab, 8 pre-stressing strands are required each of which are 3/8” or 9.525mm diameter and length of which is 3meter.

7’ or 2.14 meter requires 8 strands

Therefore, 1 meter require = (8/2.14) = 3.73 = 4 nos. of 3 meter.

Therefore, total length of the pre-stressing strands = (4*3) = 12 meter.

Product Specifications
Bright (Ungalvanized LRPC Strands)

INDIAN SPECIFICATIONS : IS-14268/1995

Class	Nominal Diameter of Strand	Tolerance	Nominal area of Strand	Minimum Breaking Strength of Strand		0.2 Proof load (90% of Breaking Strength)		Minimum % Elongation GL=600mm	Nominal Weight of Strand (Approx)	Relaxation Loss	Chemical Composition
	(mm)	(±mm)	(mm^2)	(kN)	(kg)	(kN)	(kg)		(kg/km)	(%)	(%)
11	9.5	+0.66 -0.15	54.8	102.3	10434	92.1	9394	3.5	432	2.5 max. at 70% of specified min. breaking load after 1000 hours OR 1.8 max. at 70% of specified min. breaking load after 100 hours	S = .04 max. P = .04 max.
	11.1	+0.6 6 -0.15	74.2	137.9	14065	124.1	12658		582		
	12.7	+0.66 -0.15	98.7	183.7	18737	165.3	16860		775		
	15.2	+0.66 -0.15	140.0	260.7	26592	234.6	23929		1102		

From the above table,

The weight of 9.5 nominal diameter of strand is 432 kg/km or 0.432 kg/meter.

Therefore, weight of 12 meter strands = (0.432*12) = 5.184 kg.

Price of pre-stressing strand of 1 ton or 1000 kg = 2,73,590 tk.

Price of pre-stressing strand of 5.184 kg = ((5.184*2,73,590)/1000)

= 1418.29 = 1419 taka.

Total cost of Distribution reinforcement and Pre-stressing Strand = (1857+1419) tk.

= 3276 tk.

Table 4.7: Labor Cost of BD Deck 1

Serial no.	**Category**	**Unit**	**Taka (Recommended rate)**
1	Rebar Fabrication	Per day/Person	500
2	Shuttering	Per day/Person	500
3	De-shuttering	Per day/Person	500
4	Segment lifting	Per day/Person	500
Total			2000

Total labor cost = 2000 taka.

Table 4.8: Transportation Cost of BD Deck 1

Serial No.	Item code	Item Description	Unit of measurement	Total unit price 2015 taka (with Tax and Vat)
01	01/04/03	Four wheel drive vehicle minimum 6 seats	month	77,800.00

Total price per month = 77800 tk.

Total price per day = (77800/30) = 2594 tk.

Table 4.9: Summary of Costs for BD Deck 1

MATERIAL	PRICE
Concrete	25,285 taka/m^3
Reinforcement	3276 taka/meter
Labor	2000 taka/ person/ day
Transportation	2594 taka/ day

4.4 Cost Comparison

1. Concrete (per m^3):

RCC deck slab = 26,424 tk.

BD Deck 1 slab = 25,285 tk.

Therefore**, COST SAVED** = **1139 tk.** (4.31% saved)

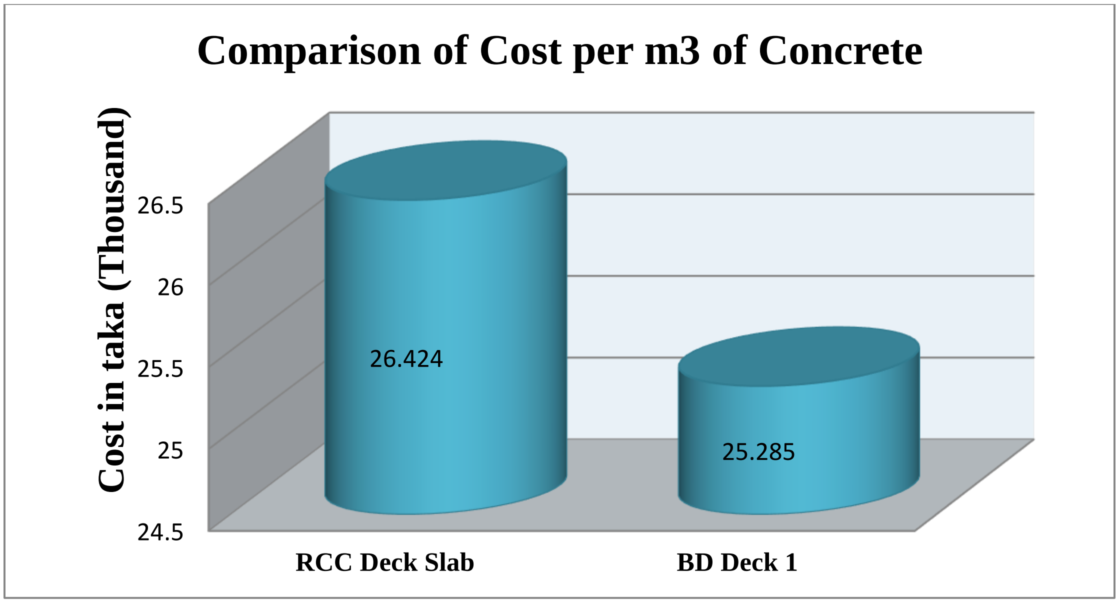


Figure 4.2: Comparison of Concrete material Cost

2. Reinforcement (per meter):

RCC deck slab = 19,965 tk.

BD Deck 1 slab = 3276 tk.

Therefore, **COST SAVED** = **16,689 tk.** (83.59% saved)

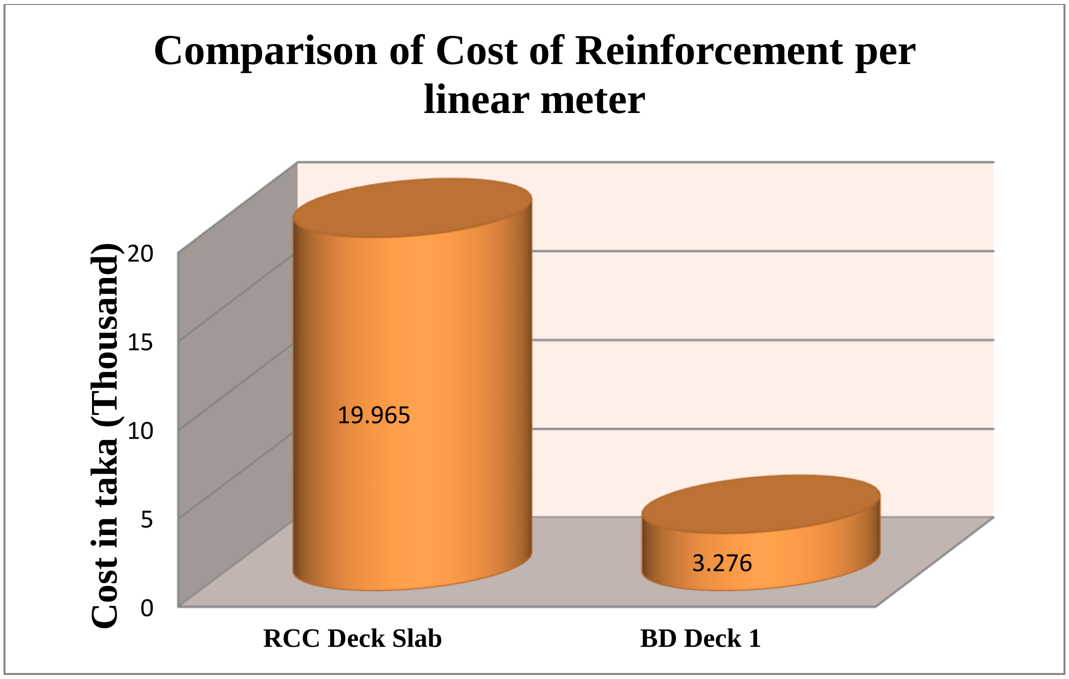


Figure 4.3: Comparison of Reinforcement Cost

3. Labor (per person/day):

RCC deck slab = 4,350 tk.

BD Deck 1 slab = 2,000 tk.

Therefore, **COST SAVED** = **2,350 tk.** (54.02% saved)

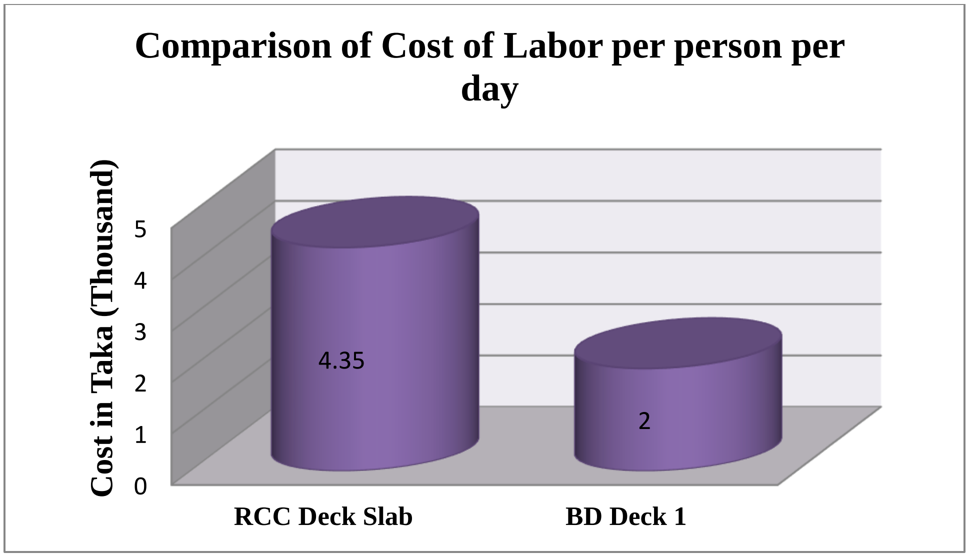


Figure 4.4: Comparison of Labor Cost

4. Transportation (per day):

RCC deck slab = 6,627 tk.

BD Deck 1 slab = 2,594 tk.

Therefore, **COST SAVED** = **4,033 tk.** (60.85% saved)

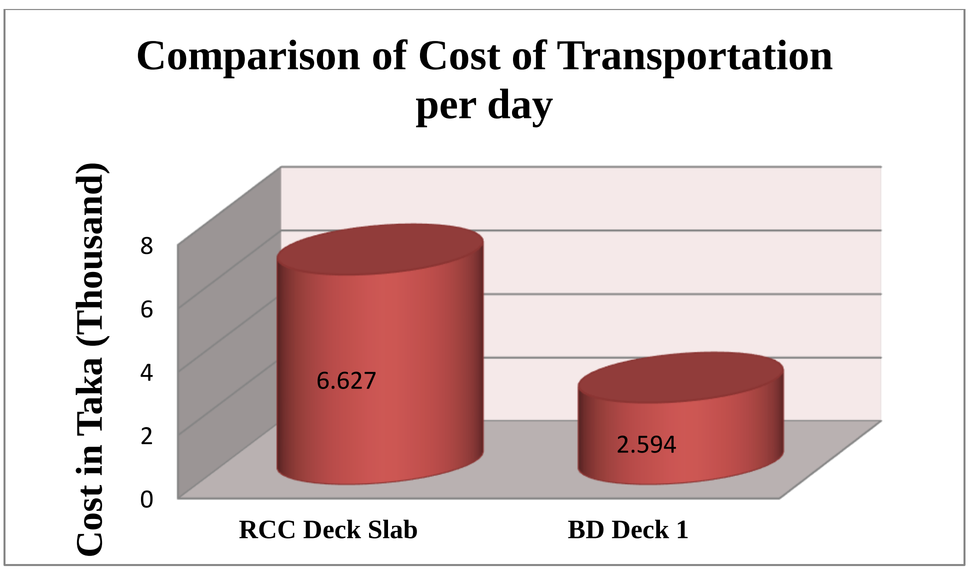


Figure 4.5: Comparison of Transportation Cost

Table 4.10: Comparison of Costs between RCC Deck Slab & BD Deck-1

	RCC Deck Slab (cost in taka)	BD Deck-1(cost in taka)
Concrete	26424	25285
Reinforcement	19965	3276
Labor	4350	2000
Transportation	6627	2594

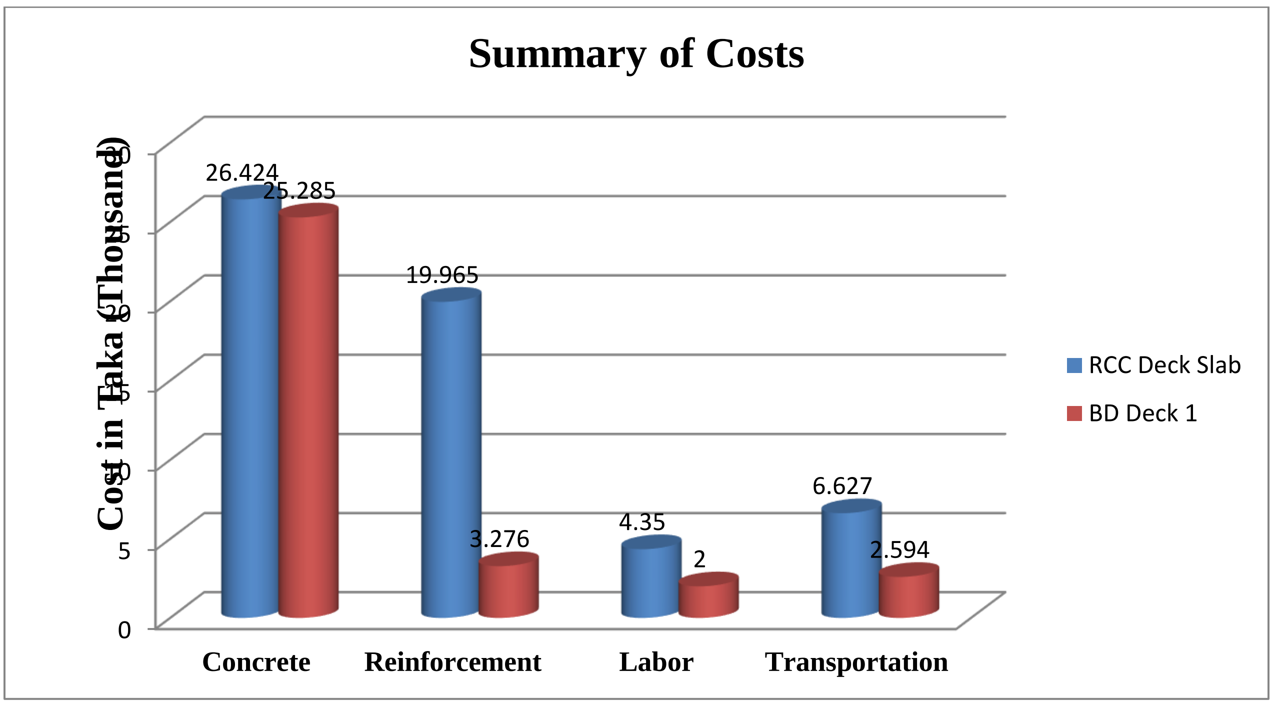


Figure 4.6: Summary & Comparison of Costs between RCC Deck Slab & BD Deck 1

4.5 Comparison of Costs between RCC Deck Slab & BD Deck 1 (per km)

4.5.1 BD Deck 1

(Background Calculation)

[Data obtained from "Unity Engineering & Construction"
Address: 28 Tipu Sultan Road, Wari, Dhaka-1100]

According to the data obtained, span of pre-stressed girder is 24m. Cost of 24m span is 80 to 90 lac taka (that are already used in Mogbazar-Mouchak Flyover Project). Here for calculation we have taken the average value of 85 lac taka for 24m span.

1. **MATERIAL COST OF 1 BOX GIRDER**

   We know that the Span = 24m, with 8 boxes per span.

   Length of 1 box = 24m/8 = 3m
   Width of 1 box= 7.5m
   Depth of 1 box = 2m
   So, Volume of 1 box= 3*7.5*2 = 45m^3
   The solid portion of the total volume is 40%. Therefore volume of 1 box is = 45*0.4=18m^3
   Therefore, **Material Cost**= 85 lac/8 = **10.6 lac taka**

2. **LABOR COST OF 1 BOX GIRDER**

   Labor required per box:
   Rebar Fabrication – 24 persons
   Shuttering – 24 persons
   De-shuttering – 8persons
   Segment Lifting – 4 persons
   Total labors needed = 60
   Rate = 500tk/ head/ day
   No. of days needed to make 1 box girder = 80 days

   Labor Cost = 60*500*80 = **24 lac taka**

3. TRANSPORTATION COST OF 1 BOX GIRDER

Project duration = 24 months
Trailer rate = 10 lac per month
High-Capacity Crane rate = 14 lac per month

Considering, only 1 day is required to transport 1 box girder from plant to site, and 8 boxes are carried at the same time each trip-

Transportation Cost = 24lacs/ (30*8) = **0.1 lac taka**

4. FORM WORK COST OF 1 BOX GIRDER

Rate = 300 ton mold at 1 lac per ton
Where, 1 mold can make 329 boxes

So, total cost of 1 mold = 300*1 = 300 lac taka

Formwork Cost = 300/329 = **0.91 lac taka**

Therefore, the Total Cost of 3m Span or 1 Box Girder is = 10.6 + 24 + 0.1 + 0.91

= 35.6 lac taka

For a volume of 18m^3 (box girder) cost is = 35.6 lac

For a volume of 0.66m^3 (BD Deck 1 panel) cost is = (35.6*0.66)/ 18 = 1.30 lac taka

Therefore, for 3m span of BD Deck 1, the cost is = 1.30 lac

for 1m span of BD Deck 1, the cost is = 1.30/3 = 0.435 lac

for 1000m span of BD Deck 1, the cost is = 435 lac taka = 43.5 million taka per km

Cost of BD Deck 1 = 43.5 million taka per km

4.5.2 RCC DECK SLAB

(According to data collected from the *Schedule of Rates, 2015* by the Roads & Highways Department of Bangladesh)

1. **CONCRETE COST (per meter)**
   Rate = 14,177 tk/m^3
   (Item Code – 05/01/02(e))
   For 1m of the bridge, the Concrete Cost is
   = 14,177 tk/m^3 * (slab thickness * slab width)
   = 14,177 tk/m^3 * (0.2m * 10.25m) [From the drawing of the Bridge Deck Slab of 21m span from RHD Department]
   = **29,062 tk/m** in the longitudinal direction

2. **SHRINKAGE REINFORCEMENT COST (per meter):**

   Table 4.11: Cross Sectional Area & Mass of Round Bar

Nominal Size (dia in mm)	Bar Number	Cross Sectional Area in mm^2	Perimeter in mm	Mass per Running meter in kg	Length per 100 kg in meter
10	3	78.5	31.42	0.616	162.34
12	4	113	37.7	0.888	112.61
16	5	201	50.27	1.579	63.33
20	6	314	62.83	2.466	40.55

Rate (grade 60 steel) = 65,640 tk/ton

[From unit Rate of Materials (Annexure-II)]
No. of rods-

- Top : 46 rods of 12mm dia.
- Bottom : 6 rods of 20mm dia.
  36 rods of 12mm dia.

For 1m bridge, the weights of rods are-

- 12mm: 0.888kg * [((46+36)/10.2)*21] = 0.149 tons
- 20mm: 2.466kg * (6/10.2) *21 = 0.0304 tons

For 1m of the bridge, the Cost of Shrinkage Reinforcement is

= (0.149 +0.0304) * 65,640 = **11,776 taka/m**

3. **MAIN REINFORCEMENT COST (per meter)**

Rate (grade 60 steel) = 65,640 tk/ton

<u>For 16mm bars</u>

- At top, every 275 mm there is = 1 rod

Therefore total number of bars = 21000/275 = 77 rods
Number of rods per meter = 77/21 = 4 rods
Length of total rods = 4* 10.25 = 41 m
Considering alternate cranked bars at bottom, there are 77 more rods at top.
Number of cranked bars per meter = 77/21 = 4 rods
Length of cranked bars = 4*(450+350+450)/1000 = 5 m
Therefore total length of bars = 41+5 = 46 m

- At bottom, every 137 mm there is = 1 rod

Therefore total number of bars = 21000/137 = 154 rods
Number of rods per meter = 154/21 = 8 rods
Length of total rods = 8* 10.25 = 82 m
Considering alternate cranked bars at bottom, there are 8 more rods at top.
Length of cranked bars = 8*(450+350+450)/1000 = 10 m
Therefore total length of bars = 82+10 = 92 m

Therefore total length of 16mm bar = (46+92) = 138 m

Weight of 16mm bar = 138*1.579 = 0.22 tons

For 10mm bars

Every 275mm = 8 rods
Every 1mm = 8/275 rods
Number of total rods along 21000mm = 611 rods
Number of rods per meter = 611/21 = 29 rods
Length of 10mm bars = 29*(450+350+450)/1000 = 36.25 m
Weight of 10mm bar = 36.25*0.666 = 24.15kg = 0.024 tons

For 1m of the bridge, the Cost of Main Reinforcement is
= (0.22 + 0.024) * 65,640 tk/ton
= 16,017 taka/m

4. **WOODEN FORMWORK COST (per meter)**
Rate = 6250 tk/m^3

For 1m of the bridge, the Cost of Wooden Framework is
= 6250 tk/m^3 * (10.25m * 0.2m)
= 12,812.5 taka/m

Labor and Transportation costs are taken to be 10% of the sum of the other four, each.

Therefore, 1m span of RCC Deck Slab costs

= Concrete + Shrinkage Rein. + Main Rein. + Framework + Labor+ Transportation

= 75,000 taka/m

If 1m of bridge costs = 75,000 taka per m

Then 1000m or 1km of bridge costs = 750 lac taka per km = 75 million taka per km

Cost of RCC Slab Deck = 75 million taka per km

Table 4.12: Comparison of Costs between RCC Deck Slab & BD Deck 1 (per km)

RCC Deck Slab	**BD Deck 1**
75 million taka per km	43.5 million taka per km

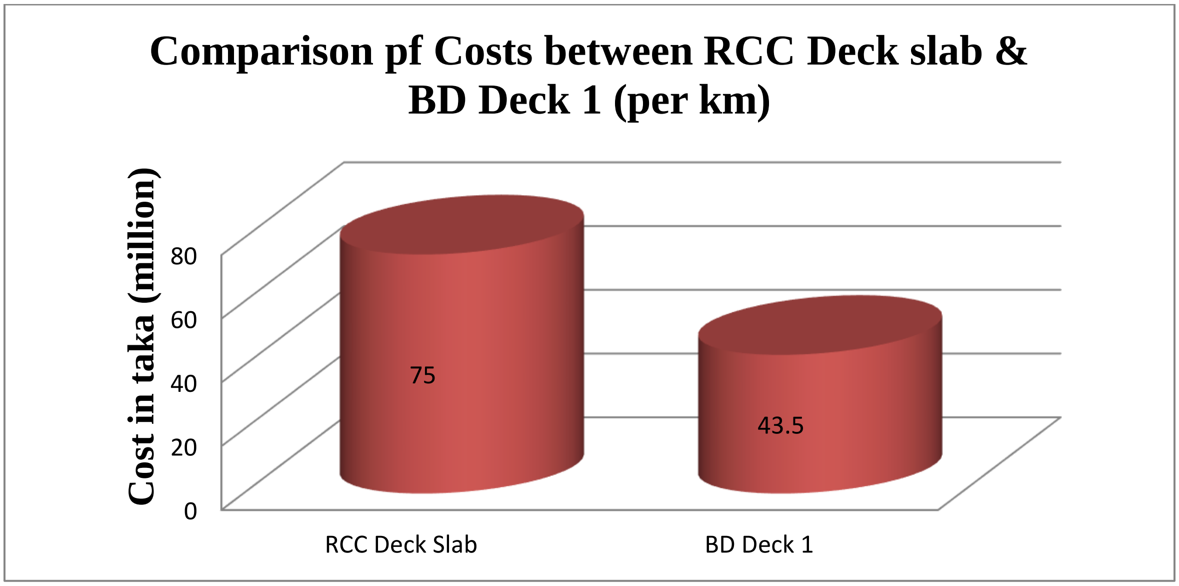


Figure 4.7: Comparison of Costs between RCC Deck Slab & BD Deck 1 (per km)

From the above calculation the difference of cost between RCC Deck Slab & BD Deck 1 per km is (75-43.5) = 31.5 million taka. Therefore 31.5 million taka is saved per km.

So, BD Deck 1 is more cost effective than the traditional RCC Deck Slab.

Chapter- 05

CONCLUSION & RECOMMENDATION

5.1 CONCLUSION

This paper was written to uphold the design of a precast, pre-stressed deck panel system called the BD Deck 1, its merits and scope in Bangladesh. The designed deck is connected with a basic component of most bridges built, especially those built in the U.S., regardless of whether the supporting elements are steel or concrete beams, arches or trusses. On the other hand, decks are the major source of bridge deterioration and deficiency. Due to ribbed panels to be employed, the self-weight will be reduced by **24%** which will lower the cost of construction materials required.

This shape allows for greater flexure capacity, with less bending undergone for a given amount of loading as compared to the usual, rectangular panel. The panels being used to make up the deck are lightweight and easily transportable. The panels will be re-usable if needed for new bridges or rehabilitation of old bridges. Preliminary estimation shows cost savings of around **4.31%** in concrete material cost**, 83.59%** in reinforcement cost, **54.02%** in labor cost and **60.85%** in transportation cost in comparison to the CIP deck bridges constructed in Bangladesh. According to overall, detailed calculations of cost the BD Deck 1 saves a total of **31.5 million taka per kilometer** as compared to the traditional RCC Deck Slab. Construction is made simple and convenient owing to the precast concrete panels being relatively easy to place onto the rest of the already erect frame. Detail guidelines should follow in future with field testing of the proposed system.

The deck obtained is compressed in two directions resulting in significant reduction in operation and maintenance and in greater durability of the overall structure. The space between beam flanges is fully covered with deck panels, thus protecting workers against accidental falling. Rapid construction and reduced maintenance diminish the probability of workers' injury, which is a welcome bonus of this system. Proper design and detailing are of utmost importance, and, if properly executed, will result in high quality decks with good durability. In a continuing effort to improve the design, young engineers are working to compile research data, study current design and detailing practices and investigate production procedures (including tolerances). The end result will be a complete design that is feasible and implementable in the Bangladeshi perspective.

5.2 RECOMMENDATION

- Due to a lack of resources as well as a constraint in time, a prototype of this design was not able to be tested for loading and failure patterns. The authority may extend resources or fund thesis groups in order to enable students to conduct a more detailed thesis work in the future.

- Most of the calculations in the design section of this system were done with data collected from the Roads and Highways Department in Dhaka, Bangladesh, due to a lack of pre-existing data on this exact design as this is the first of its kind in Bangladesh. A more thorough and accurate design could have been achieved had more data been available.

- Due to time constraints, responses to the international survey conducted were not mentioned or used in any part of the research work published in this paper.

- Cost estimations for fabrication, placement as well as transportation would have been more detailed/ accurate had the university authority helped in making headway in communication efforts with the national and international entities contacted for cost estimates.

- In the design calculations, some parameters were assumed to be constant (for example, the strength of reinforcement, ultimate strength of concrete etc. were considered to be constant depending on availability of the material) in order to shorten the design procedure and to make the design conveniently time efficient, but practically, accurate values of the said parameters are used for the most economical design possible.

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