PARADIGM AND PRACTICE IN CONSTRUCTION OF MODERN BRIDGES IN BHUTAN

Tandin Dorji, General Manager, CDCL.

Abstract

Bridges are an important component of socio economic development activities all over the world. It is important to integrate designer, constructor and owner to optimize the design and its construction process to complete a bridge within time, cost and quality. Bhutan's terrain has always been a formidable challenge for the construction of bridges, which demand careful selection of bridge type and methods of construction. History shows that the Bhutanese have constructed bridges long before western civilization did. Currently, modern bridges constructed across the country are bailey bridge, reinforce cement concrete bridge, steel truss bridge and pre-stressed cement concrete bridge. Construction Development Corporation Limited (CDCL) over the last six years with the construction of bridges experienced that design of any bridge should consider the serviceability, safety of the structure, durability of structure, achievability of the construction quality, ease of maintenance, environmental compatibility and economy. Bhutan requires a major paradigm shift in improving the bridge construction practices.

Many of the design that CDCL has referred while constructing a bridge has not properly captured detail geo-technical investigation which has led to change in design and location ultimately delaying the project during construction. There is a need for refining design of bridge for the good health of the structure such as avoiding location of bridge foundation away from the river bodies. Location of bridge foundation within the river bodies incur huge indirect cost to keep the area dry during construction of foundation and in providing protection wall to save the foundation from scouring. The middle pier must be avoided for a bridge span less than 100m to safeguard against scouring.

The construction methods should gear towards innovative techniques and mechanization. Every endeavor should be made to restrict dead load of the superstructure to safe guard from seismic catastrophic. Aesthetic of bridge plays a very important role in blending with the surrounding environment. Adoption of accelerated construction techniques such as pre-fabricated reinforce cement concrete or pre-stressed cement concrete or steel girder should be explored to enhance quality and strength of the structure. Thus, the intended purpose of this paper is to help the bridge designer and constructor in integrating the most suitable methods during design and construction of bridges in Bhutan from the experiences of CDCL.

Keywords: *bridge, design, foundation, substructure, superstructure, construction.*

Introduction

Bridges are an important component of socio economic development all over the world besides being one of the most prestigious crafts of engineers. The main aim of bridge construction is to reduce the road distance and improve communication. The construction of bridge involves multi discipline stakeholders such as designer, constructor and the owner at one stage or the other. The traditional approach is to perform these activities independently of one another consequently leading to fragmentation of design and construction, which still prevails in Bhutan. This has adverse effect on the project leading to unnecessary change in design, increase in liability of structure and increase in construction time and cost.

The main aim of the integration among designer, constructor and owner is to optimize the design and its construction process to complete bridge within time, cost and quality. Therefore, a modern bridge construction practice in Bhutan requires a major paradigm shift in integration among stakeholders. One such integration could be address through adopting deign build model by one stakeholder than design and construction by different stakeholders. The design-build model has become increasingly popular around the globe to help deal with the problems associated with the traditional system [1].

In Bhutan, Construction Development Corporation Limited (CDCL) adopted design build model for the first time in 2012 with the bridge projects. Over the year CDCL has experienced that design build model has improved the efficiency in delivering the projects in terms of reduce design and construction period and contract administration. Besides, there are many different factors that can affect the productivity of a bridge construction in Bhutan. The hilly terrain has always been a formidable challenge for construction of bridges. Deep gorges, rocky foundation, flash floods, landslides and difficult access to construction site are common sight and add to the degree of difficulties for bridge construction. Keeping in view of the bridge sites and constraints, the types of bridge and method of construction are to be selected carefully.

Experiences of CDCL over the last six years with the construction of bailey bridges, steel bridges, Reinforce Cement Concrete (RCC) bridges and pre-stressed concrete bridges learned that adopting design build model and innovative methods during construction are essential for hilly areas. Innovation means to change by introducing something new in anything established in order to enhance the benefits of the materials or the equipment under usage. Thus, this paper presents experiences of CDCL with the design and construction of bridges in Bhutan both from traditional approach and design build model. The intended purpose of this paper is to help the bridge designer and constructor in integrating the most suitable methods during design and construction of bridge. The paper is organized to cover; (a) history of bridges to explain how bridge came into existence in Bhutan, (b) construction problems to consider during designing of bridge and (c) current practices adopted in construction of bridges with special focus on effect due to scouring.

History of bridge in Bhutan

Stone and timber are the materials used since the start of civilization to construct bridges until mid-ninetieth century. In accordance to the book on Chakzampa Thangtong Gyalpo by Centre for Bhutan Studies [2], the highly accomplished Buddhist yogis, locally known as Chakzampa (the great bridge builder of Himalayas) Thangtong Gyalpo influenced the idea of bridge construction in Europe in the 17th century and after the 18th century, their precise technical details led immediately to the construction of suspension bridges in Europe and Asia.

At the end of 19th century, the new material, steel caught the imagination of bridge builders. The 520m span Brooklyn Bridge was a few achievements of the 19th century to mark the beginning of the modern era of bridge engineering. Suspension bridges were introduced by the twentieth century and many elegant bridges were built like Manhattan Bridge (450m span). The early twentieth century saw the invention of new building materials, new structural systems and techniques. RCC won the heart of bridge builders because of economy. One big break in the art of reinforcing the concrete came with the introduction of pre-stressed cement concrete. Pre-stressed cement concrete came to be used in most bridge construction till present day due to quality standard and low life cycle cost [3].

In Bhutan, the idea on construction of bridge was brought by Chakzampa Thangtong Gyalpo who visited Bhutan in 1433 from Tibet. He is claimed to have constructed eight iron bridges in various locations in Bhutan [2]. The existing Tamchog Chakzam (iron suspension bridge) over Pachu River in Paro, Bhutan as shown in photograph 1 is clear evidence of an iron chain bridge built by Thangtong Gyalpo.

Photograph 1: Tamchog iron suspension bridge [2]

While the modern bridge construction in Bhutan started with technical degree of maturity like the rest of the world from 1960, the oldest methods still prevails in most part of Bhutan until today. Some of the bridges that are at the barge of extinction are ropes made from plant fibers as shown in photograph 2, single rope bridge made by bamboo cane as shown in photograph 3 and wooden cantilever bridges called Bazam as shown in photograph 4.

Photograph 2: Plant Fiber Bridge at Between Dagapela & Lhamozinkha (Author, 2014)

Photograph 3: Bamboo Cane Bridge at Taksha over Harachu, Wangdi (Author, 2015)

Photograph 4: Bazam at Punakha, photo courtesy: aglimpseofbhutan.weebly.com (2016)

History tells us that Bhutan and the Bhutanese have constructed bridges long before the western civilization. The most common bridges constructed in Bhutan today are Bailey bridge, RCC Bridge, Steel truss bridge and pre-stressed cement concrete bridge.

Approach to design of bridge

Approach to design of any bridge should consider the serviceability, safety of the structure, durability of structure, achievability of the construction quality, ease of maintenance, environmental compatibility and economy [4]. The outline described below provides key technical aspects that designer must consider while designing bridge in Bhutan.

Preliminary exploration

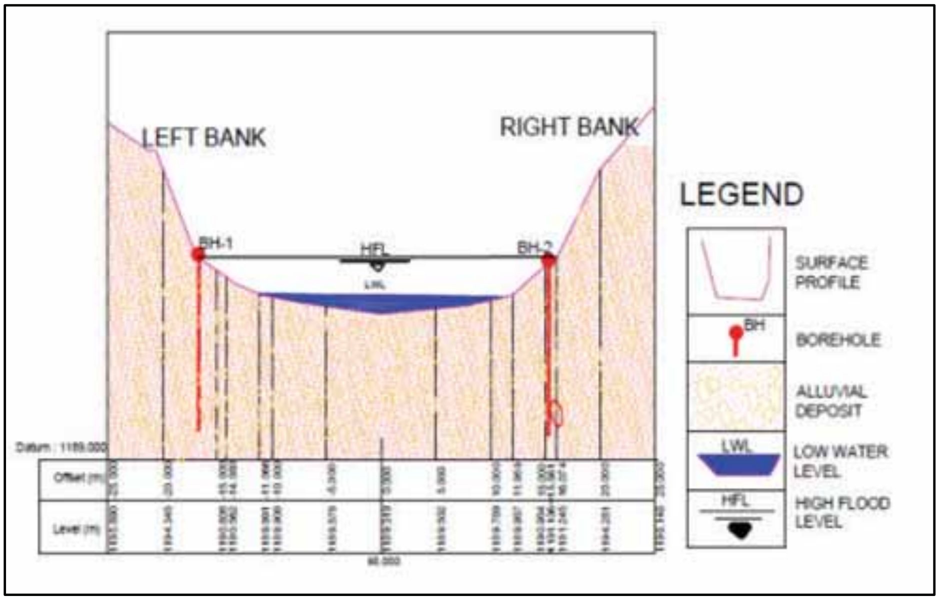
A substantial amount of data is required at the starting of the design of a bridge. Initial exploration of topographic includes the road alignment, geotechnical property, economic efficiency, workability, maintenance and harmonization with the environment. The hydraulic conditions are examined with data including the flood level, nature of the catchment, intensity and frequency of precipitation, maximum flood discharge and scour depth. Appropriate height of the decking, maximum strength of the false work and suitable seasons for construction is determined.

The determination of a reasonably accurate soil profile at each of the proposed bridge site is essential for the correct decision on the location and the type of foundation. In general, boring method can provide essential information to determine soil or rock parameters for design of bridge foundation such as internal friction angle, cohesion, deformation modulus that provides information on bearing capacity of soil for the structural analysis under dead load and traffic load.

Many of the designs that CDCL has referred while constructing bridge has not properly captured detail geo-technical investigation. This has led to delay in many of the project during construction for having to change the design and location. Such examples are Mangdezam at Ringdibi, Zhemgang where foundation on the left bank had to increase in depth due to fissure crack in the rock , Pantang bridge at Zhemgang where foundation area had to increase for not encountering bedrock, PHPA Bridge at Taksha, Wangdi for changing the location of bridge. Comparatively, the project with detail geo-technical investigation has low issues while constructing to name few such as Hejo Bridge. Photograph 5 shows the boring of soil and figure 1 shows the geotechnical investigation report of Hejo Bridge [5].

Photograph 5: Boring of soil at Hejo, Thimphu (Author, 2014)

Figure 1: Geo-technical investigation report, Hejo Bridge, Thimphu (2014) [5]



Other important inputs are the expected loads, such as wind load, seismic load, service load during construction and local conditions related with availability of building materials and equipment.

Structural systems

Bridges are designed for a specific span under particular loads such as dead load, live load, wind load, seismic load, and horizontal load due to water flow. The structural systems are designed to carry compression, tension and both of these at the same time. Arch bridges bear compression while thrusting outwards as well as downwards at the same time.

The tension bridges are the suspension and cable stayed types. The suspension bridges are long cable strung over towers and anchored on both sides. The deck is hung to this main cable by smaller cables in tension. In cable stayed bridges, the cables are connected directly from a tower to the deck. These cables in tension support the deck.

Suspended bridge is built without towers. The walkway of the bridge hangs on suspenders attached to the main cables. The bridge foundation is placed at high position at both banks of the river to achieve sufficient freeboard. The suspended bridge is simpler to construct and cheaper than the suspension type.

The tension and compression bridges can be classified into two different types as girder type and truss type Bridge. These two types are basically the same, except one is more complex than the other, which spans larger distances, economical and light in weight. Trusses are a combination of several elements especially in triangular shape where upper parts are taking compression stress and lower parts are taking tension stress.

Structurally, a bridge is a simply supported beam on two supports that tends to bend under load. Therefore, the top half of its section has compression forces while the bottom half is under tension. In larger spans, series of simply supported beams are used one after another or multi spans are joined together over piers with continuous beams.

Suitability of structure

Basically any bridge structure has the following three components; foundation, sub structure and superstructure. The design of the foundation and substructure is entirely dependent on the following parameters; Type of superstructure and its resultant load and forces, type of foundation and the soil parameters and finally topography and location of the structure. Table 1 shows the type of superstructure to be adopted for a particular bridge [6].

Table 1: Selection on superstructure base on span [6]

Sl. No.	Type of superstructure	Span recommended
1	R.C.C. solid slab	Up to 10m
2	R. C.C solid slab /Ribbed slab	10 m to 15m
3	R.C.C Multi-girder slab system	15 m to 20m
4	P.S.C. Girder/Box type superstructure	20m to 30m
5	P.S.C. Box girder	30m to 60m

Economy

Economy is the minimum life cycle cost of the bridge considering both the construction and maintenance cost. The cost of the bridge project is primarily dependent upon the type of superstructure adopted. The type of superstructure selected influences the cost of the foundation and substructure of the bridge. The increase in the total dead load of the superstructure increases the cost of foundation and substructure.

Current practice in Construction of bridge

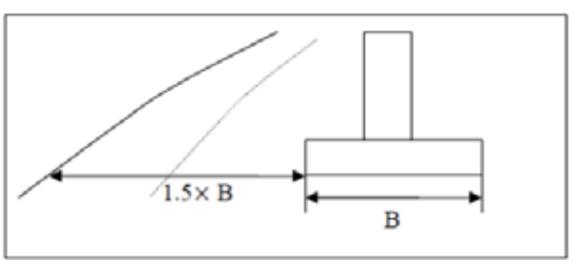
There are no definite rules for good engineering practices. With good design and adhering to specification makes a structure beautiful. The experiences from the construction of bridges in Bhutan indicate that some of the practices need refining in design for the good health of the structure. Few construction practices adopted and experienced by CDCL are here to provide ideas to the beginners while constructing the bridges.

Bridge foundation

Foundation construction for any large bridge takes time. Problems encountered during construction of foundation depend on the type of foundation, soil strata, equipment deployed and logistic problems. Foundation can be open foundation, pile foundation, well foundation or any other types of foundation. In Bhutan, shallow open foundation is mostly constructed due to geological factor. Shallow foundations are simple footings buried less than 5m depth.

It is observed that Bhutan being a mountainous terrain, stiff bedrock lies below surface soils. Thus, foundation of a bridge should have adequate set-back horizontally from the natural ground towards the mountain side with a distance not less than 1.5 times of a foundation width as shown in figure 2 [7]. The design should not be restricted to what has been designed. If required the soil parameter be reviewed and referred to material testing laboratory but within the time schedule. This helps to recommend revision in foundation level based on soil data report.

Figure 2: Setback of foundation on sloping ground [7]



In rare cases pile foundation is constructed for deep foundation in Bhutan. A pile develops a soil resistance around itself. Closely spaced group of piles act as a block where the soil between adjacent piles is dragged down. CDCL has used piling technology at Golden Masheer Hatchery & Conservation at Harachu, Wangdi to protect shallow open foundation from scouring by Punatsangchu river as shown in photograph 6.

Photograph 6: Pile foundation construction, GMHCP (CDCL, 2016)

The well foundation is not constructed in Bhutan primarily due to geological strata which make it difficult for the well to sink compared to alluvial strata. For example, Pantang Bridge (Bhutan) and Chenab Bridge (India) as summarized below indicate that a well foundation is not feasible in Bhutan.

In November 2011, CDCL was asked to construct RCC double lane over Mangdechu at Panthang on Gomphu Panbang National Highway by Ministry of Work & Human Settlement. Figure 3 shows middle pier foundation design is a single circular well type foundation with an outer well diameter of 10m and well steining thickness of 1.5m with depth of the well below lowest flood level as 18m. The middle pier foundation which is design as well sinking of the bridge is practically difficult to execute. The central pier foundation lies in the center of the river flow with a river flow velocity of 6.5 m/s. A large artificial island needs to be created but it is difficult to rule out the scouring and tilting of the well in the process of construction. As a result delay in project cannot be ruled out that will result into huge time and cost overruns. The geotechnical investigation suggested shallow open foundation to carry load from the superstructure.

CDCL reviewed the same design from the construction point of view. The history of Chenab Bridge at Jammu in India was referred due to similar geological terrain. The report states that the initial contractor failed the construction of Chenab Bridge because of problems encountered in the construction of foundations having hard conglomerate soil strata. The well foundation design was difficult while sinking because of the high water current and tilting of the well has occurred ultimately abandoning the site and redesigning the bridge as open foundation [8]. The design of Pantang Bridge was changed to open foundation from well foundation as shown in figure 4 which was then successfully constructed.

Figure 3: Well foundation design of Pantang Bridge, Zhemgang (CDCL, 2012)

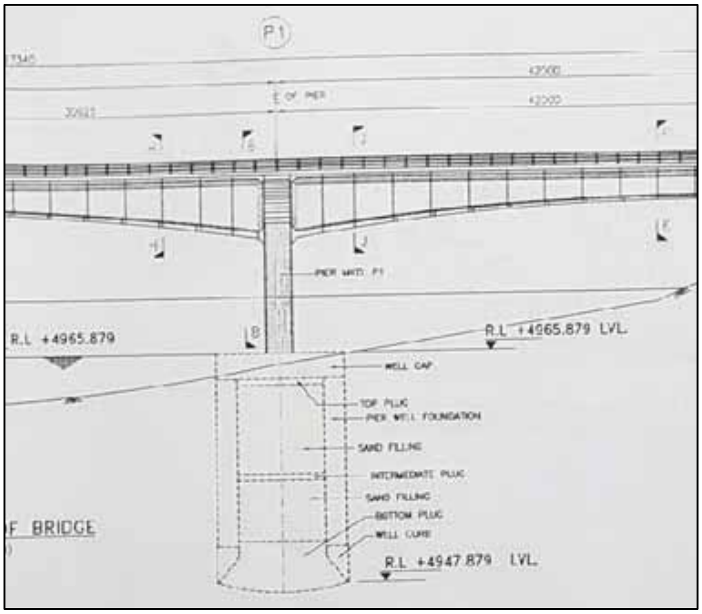
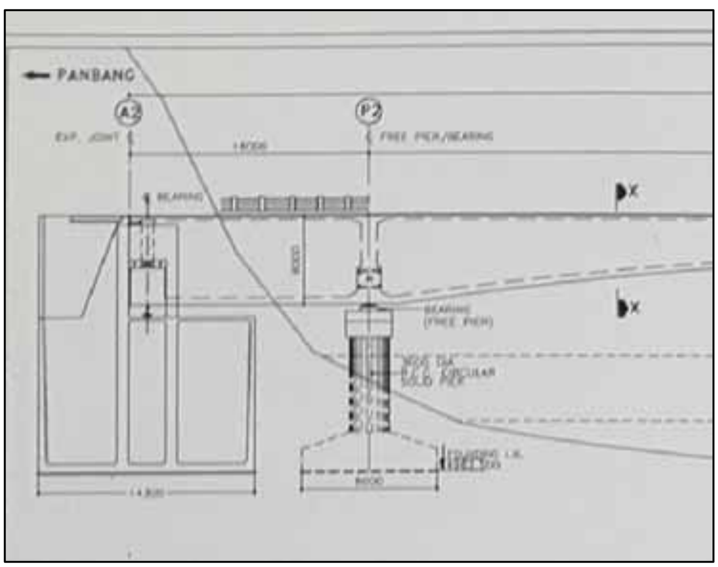


Figure 4: Open foundation design of Pantang Bridge, Zhemgang (CDCL, 2013)



Bridge substructure

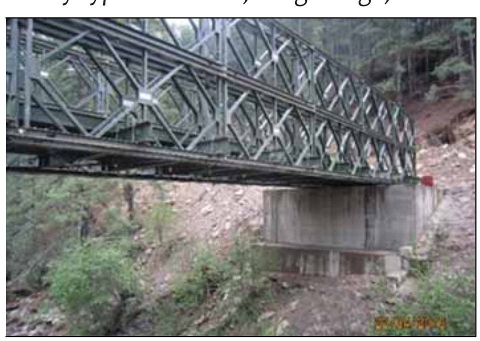
The substructure is the portion of the bridge structure below the level of bearing and above the foundation. The design generally depends on the type and dimension of the superstructure and the environment. There are mainly two parts of substructure which transmits the load to foundation. They are the abutments which function as pier and retaining wall to support the superstructure. They support the lateral loads of the soil at both ends of the bridge spans. The other part is the pier which carries the superstructure and transmits the load to the foundation as shown in photograph 7.

Photograph 7: Pier supporting the load from superstructure, Bondeyma Bridge, Mongar (CDCL, 2016)

In the case of suspension bridge type, there are anchorages where the tension in the cable is supported.

The most common type of substructure constructed in Bhutan are the gravity type, inverted T type, and inverted T counter fort type and multi cellular type box abutment. The gravity type of substructure can resist the external load by its self-weight as shown in photograph 8.

Photograph 8: Gravity type abutment, Tang Bridge, Bumthang (CDCL, 2015)



Inverted T type substructure is mainly used up to 12 m in height but could go up to 17 m in height. It is designed as a cantilever beam subjected to axial force and bending moment. In inverted T type substructure, the dead weight can be reduced and the abutment can be stabilized by the gravity of soil as shown in photograph 9.

Photograph 9: Inverted T type abutment with counterfort, Samdrupjongkhar (CDCL, 2017)

Multi cellular box substructure is suitable both for compression load as well as to anchor in the case of cantilever bridge besides counter balancing the loads as shown in photograph 10. Selection of a particular type of abutment depends upon the span, type of superstructure, height of substructure, magnitude of load and forces to be transmitted.

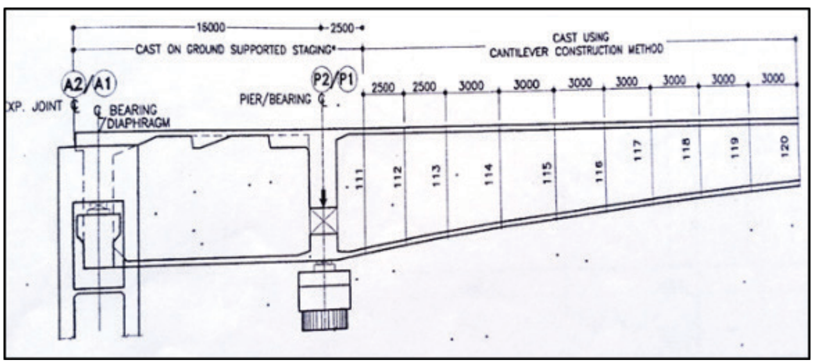
Photograph 10: Multi cellular box type abutment, Pantang Bridge, Zhemgang (CDCL, 2013)

Bridge superstructure

The final part in the construction of bridge is the superstructure. Types of superstructure are determined by the geometry of the bridge, the span, the method of construction, economical factors and environmental factors. In Bhutan, short to medium span range, Reinforced Cement Concrete cast in place, steel plate girders and Steel bailey are preferred. For longer span, reinforced concrete bowstringing and arch bridges, steel truss bridges, pre-stressed concrete bridges and suspension bridges are preferred. For larger spans, the main factor determining the superstructure is the cost of construction.

One of the recent developments in construction technique of bridge superstructure by CDCL is using free cantilevering technology for long bridge. The technique was used to build Pantang Bridge in 2014 [9]. The techniques are simple as initially, the substructure, piers, and abutments were built ready for the deck construction to begin. The 16m length of section of deck between abutment and pier was completed first by casting the concrete in-situ on staging. New sections of the deck (segment 111) as shown in figure 5 were then cast in-situ on the previously completed 16m deck.

Figure 5: Casting of deck segment [9]



The form traveler known as gantry or cantilever construction equipment were supported off the previously completed length of deck cantilevering out to support the formwork for the next section. The deck sections were casted in 2.5m to 3m length with the complete box section cast in a single concreting. Pre-stressing tendons were installed through the top slab and anchored on the end face of the new segment to support it in place. The cantilever tendons support the deck during the construction stage and provide permanent pre-stress when the structure is complete.

The stressing was done when the concrete achieves 35 MPa strength. A cycle of 7-10 days were considered for casting various segments. The cantilevers were extended up to mid-span. Cantilevers from adjacent piers were then joined together with an in-situ concrete stitch and pre-stressing tendons installed to make the deck continuous. Finally, the remaining permanent pre-stressing tendons were installed to complete the bridge as shown in photograph 11.

Photograph 11: completed Pantang bridge, Zhemgang (CDCL, 2014)

Scaffolding

The other important factor in determining the superstructure is the availability of conditions for construction of scaffolding. Scaffolding is a temporary structure, usually of timber as shown in photograph 12 and steel as shown in photograph 13 erected to support the construction of permanent bridge.

Photograph 12: Scaffolding by timber, Bondeyma Bridge, Mongar (CDCL, 2016)

Photograph 13: Scaffolding by steel, Dechencholing Bridge, Thimphu (CDCL, 2016)

If the flow of the water is in reasonable limits, the scaffolding may be designed in beam or arch types as shown in photograph 14 with footings on water. Moreover, some kind of structure such as steel trusses and prefabricated reinforced concrete girder do not require scaffolding. Likewise, in case of fast flowing rivers or deep gorges where it is not possible to build scaffolding, form traveler is also preferred. As shown in photograph 15.

Photograph 14: Scaffolding by steel arch, Haydrong Bridge, Thimphu (CDCL, 2017)

Photograph 15: Form traveler without Scaffolding, Pantang Bridge, Zhemgang (CDCL, 2014)

Observations and recommendations

Dewatering

For Bhutan, it is best to avoid location of bridge foundation from the river bodies unless restricted due to limited space. The construction of foundation below the subsoil water level poses problems of water logging as shown in photograph 16. It is therefore very often necessary to dewater the area of excavation. Several operations have to be carried out within the excavation to control the seepage using heavy pumps, protecting slope through sand bagging, lowering river flow at downstream and diverting river flow to keep the area dry for construction of substructure. The water table should be maintained at least 0.5 m below the bottom of the excavation to keep the area dry. Huge indirect cost is involved to keep the area dry till the completion of bridge foundation. Besides additional protection wall have to be provided to save the bridge foundation from scouring. Therefore, work can be carried out more efficiently and economically if the excavation area is kept dry.

Photograph 16: Waterlogging at foundation, Pachu Bridge, Paro (CDCL, 2017)

Scouring effect

Scour is the major problem in bridge causing failure. Scour is termed as the excavation and removal of material from the bed and banks of rivers as a result of the erosive action of flowing water. According to L J Prendergast and K Gavin [10], scours are of three types, namely, general scour, contraction scour and local scour. General scour occurs naturally in river channels and includes the aggradation and degradation of the river bed that may occur as a result of changes in the hydraulic parameters such as changes in the flow rate or changes in the quantity of sediment in the channel.

Contraction scour is a result of the reduction in the river channel's cross-sectional area that arises due to the construction of structures such as bridge piers and abutments. It manifests itself as an increase in flow velocity and resulting bed shear stresses.

Local scour occurs around individual bridge piers and abutments. Entersar AS and EL Ghorab [11] shared that downward flow acts as a vertical jet in eroding the bed which is the initial cause of the scour. The horseshoe vortex is a consequence of separation of the flow at the edge of the scour hole upstream of the pier and result in pushing the down-flow inside the scour hole closer to the pier as shown in figure 6. This removes the materials under the foundation resulting into increased in stress and reduce stiffness in the remaining soil as in figure 7 [10].

Figure 6: Schematic of the scour process, source [10]

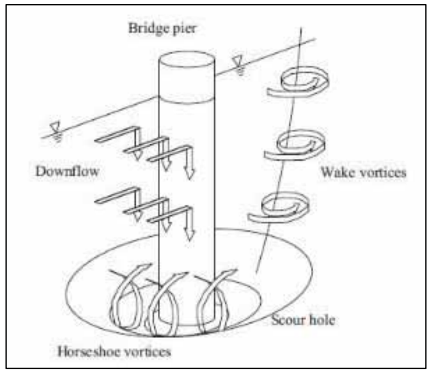
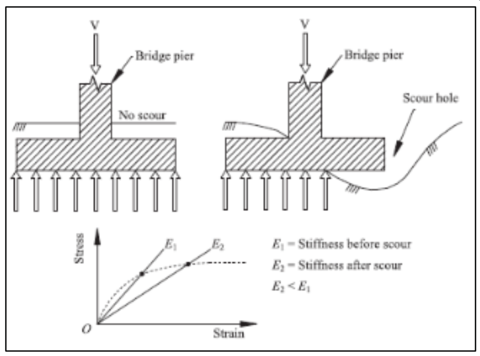
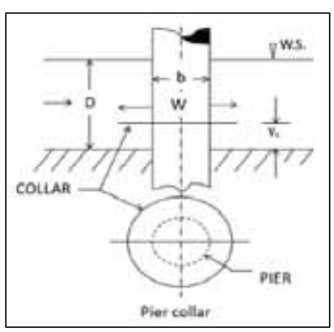


Figure 7: Reduction in stiffness caused by scour [10]



Entesar AS and EL Ghorab [11] shared different methods in reduction of scour around bridge piers. They are (a) streamlining the piers reduces the scour depth up to about 10–20%, (b) providing a circular collar with 3b to 6b in diameter around the circular pier with 0.2D height above the river bed as shown in figure 8 which reduces the scour depth up to 20–55% and (c) Constructing barriers upstream of the bridge piers that consist of a number of piles.

Figure 8: Circular collar dimension [11]



Understanding of water flow impact on pier is important for economical design. Table 2 shows an example of the intensity of pressure calculated from the following equation on piers parallel to the direction of the water current [12].

P = KA [(γV2)/2g] =A [(γ/2g)] KV2

Where,

P = intensity of pressure due to water current, in kg/m2

γ=density of water

A=water proof of bridge pier

g=gravity acceleration

V = the velocity of the current at the point where the pressure intensity is in m/s

K = a constant having the values for different shapes of piers (1.5 for square shape, 0.66 for circular, 0.5 to 0.7 for triangular cut for angle 3ỏ to 6ỏ.

Assume value of A [(γ/2g)] = 52

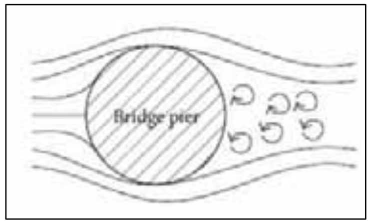
P= 52KV2

Table 2: Intensity of pressure on pier

Pressure	K=1.5 (square)	K=0.66 (circular)	K=0.5 (3ỏ) to 0.7 (6ỏ) (triangular)
Assume, v=6m/s	2808 kg/m2	1235.52 kg/m2	936kg/m2 to 1310.4kg/m2

The above result indicates that providing triangular shape of middle pier has less impact due to water flow. Generally, water force on the pier is calculated using the methods specified in the design codes. However, in the field of bridge engineering, few research efforts are made to examine the potential destructive effect of the water flow pressure on the pier. According to Yin –hui Wang et al. [12], when the flood impacts the bridge pier, the flow can be disintegrated into two parts: the moment impact that flood impacts the bridge pier and the motion that water flows around the pier after the moment impact. The flowing velocity of the flood will be rapidly influenced when flow impacts pier. Due to lack of constraint, most of water will flow forward along the walls of two sides of pier, but part of water will stop flowing or even flow backward because of being obstructed by pier, as shown in figure 9 and photograph 17.

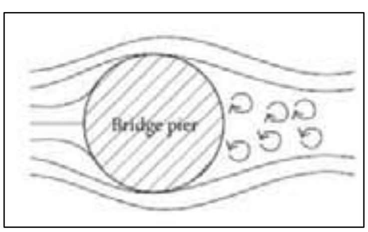
Figure 9 Flow obstructed by pier



Photograph 17: Flow obstructed by middle pier at upstream Bondeyma Bridge, Mongar (CDCL, 2016)

Therefore, at the moment of which flow impacts pier, the moment impact effect, as "water hammer effect," which is far larger than the effect of static fluid pressure, will be generated on the pier. After the flood impacts the bridge pier, water always flows around the pier, as shown in figure 10 and photograph 18. The positive side of pier bears higher pressure, and the back side of pier bears lower pressure. The dynamic water pressure is induced by these pressure differences around the pier. The structure generates vibration and deformations because of this dynamic water pressure. The pier will be constantly under motion. The distribution and magnitude of dynamic water pressure also changes according to flood level [12].

Figure 10: Flow around the pier



Photograph 18: Flow causing eddies at downstream, Bondeyma Bridge, Mongar (CDCL, 2016)

Afflux

Moreover, when a bridge is constructed, the abutment and pier structures cause the reduction of natural waterway area. The waterway of bridge is the area through which the water flows between river bed and bridge superstructure. This constriction of linear waterway leads to increase in flood discharge and velocity of the flood which gives rise to sudden heading up of water on the upstream side of stream. This heading up phenomenon is known as afflux. Greater the afflux, greater will be the velocity under downstream side of the bridge and greater will be depth of scour and consequently greater will be the depth of foundation required. Thus, designer should avoid providing middle pier as in the case of Bondeyma Bridge.

Appropriate technology

In Bhutan the adaptation of new construction techniques in bridge is still at its initial phase. The conventional way to manage construction projects has been challenged by the actual socio economic needs to deliver a project with higher quality, lower cost and in a short period of time. Many Bhutanese construction methods and techniques have not changed and mechanization is still at its incubation stage. It is high time that Bhutan adopts accelerated construction by using various techniques and technologies in bridge construction to help reduce construction time and in maintaining safety and quality.

Fast track construction is possible only with good planning, good team work and making proper resources available on time. Various factors which govern the successful fast track construction are project feasibility study with geotechnical investigations, government's approvals, clearances and fund availability. Outsourcing of activities during construction such as ready mix concrete, precast hand railing, adoption of composite bridge design such as RCC substructure and Steel Superstructure where construction could go simultaneously, adoption of design build concept, form traveler as shown in photograph 19 and automatic concrete batching plant as shown in photograph 20, could enhance fast track construction.

Construction of urban structures like flyover and underpass are associated with its own peculiar constraints such as restricted working space and hindrance from traffic where construction at site is not feasible. Many a times either of the facilities are not available and therefore conventional method of construction at site are not feasible. Thus, modern method of precast in the casting yards which then transported and erected by means of cranes on substructure needs to be explored and decided during design.

Photograph 19: Form traveller, Pantang Bridge, Zhemgang (CDCL, 2014)

Photograph 20: Automatic concrete batching plant, Samdrupjongkhar Bridge (CDCL, 2017)

Durability

Durability of a bridge is to perform the intended service life of structure even during the ageing of the bridge without significant degradation in the serviceability and safety of the structure and its components. In the case of reinforce cement concrete or pre-stressed concrete bridge, good quality concrete is a prerequisite. To achieve durable concrete, good quality construction materials completely free from deleterious substances have to be used along with strict quality control measures during execution.

Particular attention should be given while constructing bridge in the remote place as concrete batching plant cannot be installed and proportioning and mixing has to be done in a semi mechanized manner resulting in inconsistent quality of concrete. The photograph 21 shows one of the example of Tang Bridge at Bumthang which was constructed in remote place by some contractor. The bridge had a serious issue of not meeting the quality which CDCL had to redo design and retrofit to maintain the quality of the structure as shown in photograph 22.

One of the measures to maintain the durability of structure through quality control in remote location is using steel girders. Steel being produced in the factory has inherent quality assurance as the fabrication is done in ideal condition with stringent quality control thereby enhancing the design strength of the structure. Precast reinforce cement concrete girder and deck slab for small bridge could also be produced under quality control and constructed in remote location.

Photograph 21: Inferior quality concrete abutment, Tang Bridge, Bumthang (CDCL, 2015)

Photograph 22: Retrofitted Bridge, Tang, Bumthang (CDCL, 2016)

Safety

The safety here means structural safety of bridge against all types of loads that it may be subjected to during its intended service life. Since Bhutan falls in Zone V of the seismic map of India, it is important to reduce the seismic loads. Therefore, every endeavor should be made to restrict and reduce the Dead Load (DL) of the structure by adopting and adapting the existing available methods to suit the objectives.

The horizontal seismic force (Frequency) as per IS 1893-2002 on the structure is worked out by multiplying dead load (W) of the structure with factor α (alpha is the importance factor), β (beta is the response reduction factor) and γ (gamma is the average response acceleration coefficient for soil type & appropriate natural periods and damping of the structure) which are 0.08, 1.2 and 1.5 respectively for this region.

$$\begin{aligned}\text{Horizontal Force} &= (\alpha \times \beta \times \gamma) \times W \\ &= (0.08 \times 1.2 \times 1.5) \times W \\ &= 0.144W\end{aligned}$$

To this, frictional force at the bearing is to be added which is 0.03 times the DL of the superstructure. Therefore, the total horizontal force at the bearing level is (1.44+0.03) W i.e. 0.174W. Thus, a horizontal force of 17.40% of weight of superstructure is generated at the bearing level. When Pre-stressed concrete superstructure with higher DL is adopted this horizontal force apart from increasing the cost of the foundation and substructure may seriously jeopardize the safety of the structure in the event of the severe earthquake [13]. As our knowledge on earthquake engineering is limited the designer must chose lighter materials like steel truss which can span very large spans with less dead load for bridge construction.

Aesthetics

1)

Aesthetic of bridge in hilly region plays a very important role in blending with the surrounding environment. The bridge structure should represent a fusion of art and technology. Providing suitable surface treatment for texturing on surface of piers, abutments and retaining walls can give aesthetic quality. Integration of bridge structure with movement of terrain and river can enhance the expression of bridge. The horizontal and vertical alignment of bridge with proper geometry can add to the architecture of bridge. Particularly in Bhutan there is very limited area on bridge structure to incorporate Bhutanese architecture and therefore it is not possible to codify the rules to incorporate in the Designs of bridges. However, hand railing of bridge could be design as traditional railing such as Jadhang Tazi as shown in Photograph 23.

Photograph 23: Jadhang Tazi at bridge hand railing, Hejo Bridge, Thimphu (CDCL, 2016)

Challenges

Construction of permanent bridges in Bhutan poses natural and logistic problems due to inaccessibility of the site and very short duration of working period. Winter snow, monsoon rains and intermittent rains restrict the total working time to seventy percent in a year.

As the entire Bhutan lies in seismic zone V of the seismic map of India, consideration in design to reduce the seismic loads by restricting the dead load of the structure with the existing available methods to suit the technical requirements as per environment is a big challenge to the designer.

Inaccessible areas suffer from inadequate supervision and the problems of shortage and specified construction materials. While these problems can be eliminated altogether, judicious choice of the type of the superstructure coupled with the maximum possible involvement of the local people, both at the planning and at the execution stage is important. Correct advance planning can definitely reduce the time of execution, thereby reducing considerably the delay in the completion of the bridge.

Conclusion

This paper attempts to give an overview of lesson learnt from the field practice of Construction Development Corporation Limited. The characteristics of construction practice in Bhutan are presented including history of bridge, structural system, drawbacks of design while implementing and suggestion to beginners while constructing the bridges. While some of the practice may not be perfect but the following conclusion can be delivered for further research and practical references in the field of bridge design and construction.

1) The traditional approach of design and construction independent of one another leads to fragmentation of design and construction. This has adverse effect on the project leading to unnecessary change in design, increase in liability of structure and increase in construction time and cost. Design build model improves the efficiency in delivering the projects in terms of reduce design and construction period and contract administration.

2) The determination of a reasonably accurate soil profile at each of the propose bridge site is essential for the correct decision on the location and the type of foundation. If required the soil parameter be reviewed and referred to material testing laboratory but within the time schedule which will help to recommend revision in foundation level base on soil data.

3) The cost of the bridge project is primarily dependent upon the type of superstructure adopted. The increase in the total dead load of the superstructure increases the cost of foundation and substructure.

4) The best location of bridge abutment is away from river path as location of foundation within the river bodies incurs huge indirect cost to keep the area dry during construction of foundation and in providing protection wall to save the foundation from scouring. Providing middle pier for bridge span less than 100m span must be avoided to safeguard against scouring which is the major problem in bridge causing failure.

5) The different methods that could be considered to reduce scour around bridge piers are; (a) streamlining the pier reduces the scour depth up to about 10–20%, (b) providing a circular collar with 3b to 6b in diameter around the circular pier with 0.2D height above the river bed reduces the scour depth up to 20–55% and (c) constructing barriers upstream of the bridge pier that consist of a number of piles.

6) Understanding of water flow impact on pier is important for economical design. The result from intensity of pressure on different shape of bridge pier indicates that providing triangular shape has less impact due to water flow.

7) Adoption of accelerated construction techniques and technologies in bridge construction such as ready mix concrete, precast hand railing, pre-fabricated reinforce cement concrete or pre-stressed concrete or steel girder, design build concept, automatic concrete batching plant and use of form traveler helps to reduce construction time and in achieving quality.

8) As per IS 1893-2002, the horizontal force of 17.40% of weight of superstructure is generated at the bearing level for zone V. The superstructure with higher dead load is susceptible to seismic catastrophic. Therefore, designer must chose lighter materials like steel truss which can span very large spans with less dead load for bridge construction.

References

1. Lam Edmond WM, Chan Albert P.C, and Chan Daniel WM, "Why is design-build commonly used in the public sector? An illustration from Hong Kong," The Australian Journal of Construction Economics and Building, 2012.
2. Centre for Bhutan Studies, "Chakzampa Thangtong Gyalpo, Architect, Philosopher and Iron Chain Bridge Builder," Thimphu, 2007.
3. V. K Raina, "Raina's Concrete Bridge Practice Analysis, Design and Economics," 3rd edition, Shroff Publishers and Distributors Pvt. Ltd. Delhi, 2007.
4. Department of Roads, "General Specifications for Bridges," MoWHS, Thimphu, 2015.
5. Kalachakra Consultancy Services, "Report on detail sub-soil investigation of Hejo and Dechhencholing zam sites at Thimphu," Thimphu, 2015.
6. S. B.Tamsekar & K. S. Jangde, "Guidelines for bridge design," Mumbai, 2007.
7. Ministry of Agriculture and Forest, "Technical Guidelines of Farm Road Bridge," Royal Government of Bhutan, 2014.
8. B S Pandey, "Construction of bridge across Chenab River," Civil Engineering & Construction Review, India, August 2009.
9. Tandin Dorji, "Unbalance cantilever bridge construction over the river Mangdechu: efficient and economical solution for medium and long span bridges," Bhutan Journal of Research & Development, Institute for GNH studies, Thimphu, 2015.
10. L.J. Prendergast, K. Gavin, "A review of bridge scour monitoring techniques," Journal of Rock Mechanics and Geotechnical Engineering, 2014.
11. Entesar A.S. EL-Ghorab, "Reduction of scour around bridge piers using a modified method for vortex reduction," Production and hosting by Elsevier B.V. on behalf of Faculty of Engineering, Alexandria University, 2013.
12. Yin-huiWang, Yi-song Zou, Lue-qin Xu, and Zheng Luo, "Analysis of Water Flow Pressure on Bridge Piers considering the Impact Effect," Hindawi Publishing Corporation, Mathematical Problems in Engineering, 2015.
13. DD Sharma & Abhijit Deb, "Type of superstructure (suitability of RCC, PSC, steel or any type) with special reference to the North Eastern Region", Technical papers, Indian Highways, Sept. 2000.

Author's profile

Tandin Dorji is the General Manager of Construction Division (Roads, Bridges and Transmission Projects) at Construction Development Corporation Limited, DHI Own Company, Thimphu, Bhutan.

He has a Diploma in Civil Engineering from Royal Bhutan Polytechnic (1997), B.Tech. in Civil Engineering from Indian Institute of Technology Roorkee (2002) and MEng Sc. Civil & Environmental Engineering from University of Melbourne (2006). He has attended training in Construction Management & Quality Control of Road works from AIT, Thailand (2013) and Training of Trainers in Teaching/Learning and Curriculum Writing from Hoge School Leiden, University of Applied Sciences, Netherland (2009).

He is an alumina of Royal Institute for Governance & Strategic Studies (Senior Executive Leadership Program 3rd batch), and De-suung 17th batch (ID No. DS (17)15-1976).

His publications include: 'Unbalance Cantilever Bridge Construction over the river Mangdechu: efficient and economical solution for medium and long span bridges' in the Bhutan Journal of Research & Development, Institute for GNH Studies, RUB, Volume 4, No.1 Spring 2015 and 'Performance of Urban Water Supply System in Phuentsholing City, Bhutan' in the Journal of Research & Development, Royal University of Bhutan, Volume 1, Dec. 2007, No.1.