

Kuril flyover – ingenious design solution of a nagging congestion problem

M. Azadur Rahman & Sohrabuddin Ahmad
Acumen Consulting House Ltd, Dhaka, Bangladesh

Md. Shamsul Hoque
Bangladesh University of Engineering and Technology, Dhaka, Bangladesh

ABSTRACT: Recently commissioned Kuril ‘flyover’ in Dhaka city is a traffic interchange solution designed and constructed to eliminate a traffic congestion problem that has been nagging city dwellers and commuters for too long. Prior to commissioning of the interchange in August 2013, Kuril intersection was a skewed T-junction of two arterial dual-carriageway roads meeting over a railway level crossing, with railway gate closures more than sixty times a day stalling road traffic for nearly five hours and causing more than 1km long tailbacks. Another major road connecting Kuril with Purbachal was planned to join the intersection close to the existing level crossing. Traffic at the intersection arrives from five origin-destination nodes resulting in twenty directional flow demands. This paper describes development of a non-standard interchange solution at Kuril that has ensured uninterrupted flow of traffic through the junction along these twenty directional routes.

1 INTRODUCTION

Kuril intersection was a traffic nightmare at the international gateway to Dhaka city. Airport Road, a major dual-carriageway thoroughfare from the International Airport to city, runs alongside a multi-track intercity railway line at the location. Another major dual-carriageway road joins the Airport Road crossing the railway lines to form a complex skewed T-junction cum level crossing. A third dual-carriageway road was under construction that would meet the intersection in yet another T-junction a few meters from the existing level crossing (Fig. 1). A solution to the problem by adopting a standard intersection form was not available; certain amount of ingenuity was required to devise a simple yet effective solution.

The development of this interchange solution aimed to improve traffic handling capacity of Kuril intersection, improve level of service of Airport Road, reduce vehicle operating cost and passengers’ value of time cost, and reduce junction operation cost by eliminating level-crossing. Desired features of the solution would include full segregation of road and rail traffic, elimination of traffic signal, removal of right and U-turning movements, and provision of both ways free flow of traffic among five origin-destination nodes. The solution was to fit in a very limited right of way and be aesthetically pleasant befitting the gateway to a capital city.

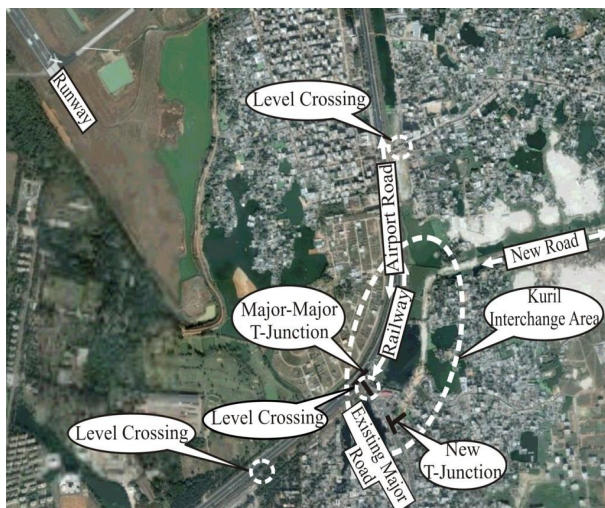


Figure 1. Project setting

2 INVESTIGATION

A thorough investigation of present day traffic and its projection to future considering land use pattern in the influence zone was necessary before any attempt to devise a solution could be made.

2.1 *Traffic Study*

A comprehensive traffic survey comprising manual and video traffic count, pedestrian count, origin-destination survey, axle load measurement, train count and gate closure time, and travel time through the intersection was undertaken in 2007. Salient findings from the study are as follows.

Average daily traffic counts were 59,175 motorized vehicles for Airport-Kuril, 38,583 for Banani-Kuril and 20,798 for Rampura-Kuril approaches. A few non-motorized vehicles were also observed on all the approaches particularly during early morning period. Present ADT at the intersection in PCU terms was found to exceed 157,000. Car is the most dominant mode with 35% modal share which is followed by CNG/Auto Rickshaw with 16% and Medium Bus with 10%. Pedestrians form a major group of road users at the interchange with over 2700 people crossing the main roads per hour at peak time. Average travel time by a motorized vehicle ranged from 2.25 minutes to 8.5 minutes for the various approaches. Queue lengths exceeding 1 km were common.

2.2 *Land Use*

Land use survey indicated that during the planning period up to 2050 substantial growth of human settlement and development will occur around the project area. Regions of particular significance involve several public and private township developments. In addition to normal traffic growth the intersection will be required to facilitate additional traffic generated by these development activities.

2.3 *Traffic Forecast*

In addition to normal traffic growth the intersection will be required to facilitate additional traffic generated by future developments in the region. Traffic forecast for the planning horizon up to 2050 was performed taking into consideration traffic from three generic sources: normal, diverted and generated traffic. A traffic simulation analysis revealed that if the existing interrupted at-grade intersection is replaced by a fully grade separated interchange, average daily throughput of the junction would be augmented nearly three times to 432,552 PCU/day compared to the present traffic demand of 157,077 PCU/day. The step will also result in an improvement of Level of Service (LOS) of Airport Road from present E to C.

2.4 *Project Constraints*

Ground space available for the project was severely restricted by existence of two other railway level crossings close by and several tributary roads on the approaches close to the intersection. There was little room for flaring on all the approaches. The site is densely populated ruling out substantial land acquisition necessary for any at-grade intersection solution without demolition of major structures and rehabilitation and resettlement of affected urban population. The only available land was a limited strip of wetland alongside the railway tracks.

Restriction on height came from two sources. Being close to the International Airport and under flight path of aircrafts taking off and landing there, maximum height of any structure was limited by civil aviation authority to 14.5 m including the height of lamp posts and vehicles. On the other hand, the location being on a bend of the railway, clearance under soffit of the structure was set at 7.5 m higher than required for a straight segment.

There were also numerous underground and overhead utility lines including high pressure gas and water mains, high tension electric lines and fibre optic telecommunication lines.

3 GEOMETRICAL DESIGN

3.1 *Geometrical Layout*

Having decided that a completely no-conflict free-flow interchange facility would be created at Kuril, grade separation for segregation of road and rail traffic became a necessity. Roads meeting at the intersection convey traffic from four origin-destination (O-D) nodes; the settlement on the adjacent west neighbourhood gives rise to a fifth O-D location. These five O-D nodes each need free connectivity through the intersection to each of the other four nodes, giving rise to twenty directional flow demands. It was necessary to segregate these twenty flows through the intersection and attain uninterrupted travel for all the directions. The existence of a

railway through the junction and severe space constraint meant that standard intersection forms could not be adopted here.

Desirable solution would require channelization of all traffic through the junction in unidirectional paths merging and diverging on the left. A large at-grade roundabout could not be conceived without displacing a substantial population. Having more than one level of flyovers to separate the various flow directions was also not an option because of the height restrictions. A simple alternative was devised by creating a one-way circuitous path on ground in a strip of marshy wasteland beside the railway tracks (Fig. 2). Though elongated in shape this would serve the purpose of a conventional circular roundabout. To preserve the area bounded by this 'roundabout' from future developments and to ensure visibility across the 'roundabout', as well as to enhance aesthetic quality of the facility, a lake was to be developed there by cleaning and dressing the marshy wasteland.

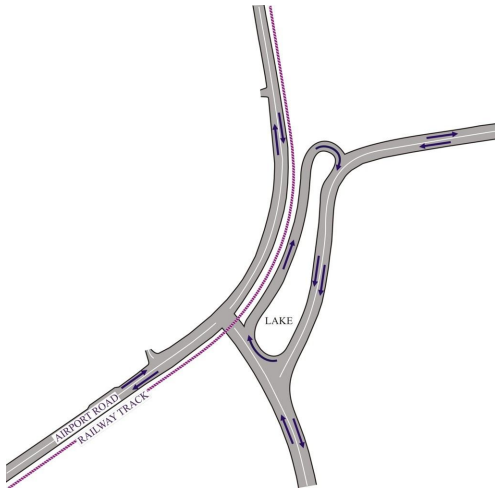


Figure 2. Elongated 'roundabout'

The 'roundabout' could be easily connected to roads on the same side of railway tracks by one way ground roads (Fig. 3). To reduce travel distance of some of the routes, an at-grade link bridge across the lake was also planned. Connection to the arterial Airport Road lying on the other side of railway tracks needed some aerial paths. An ascending (exit) and a descending (entry) path were necessary for each direction of travel on Airport Road, as outlined in Figure 4. These paths were materialized by two Y-shaped and two U-shaped flyover loops (Fig. 5). Approach ramps of the flyovers had necessarily to follow the curved alignment of Airport Road at the location, giving rise to elegant curves even for the U-loop ramps. The total interchange facility thus evolved featured complete segregation of road and rail traffic and conflict free one way travel in all twenty directional routes.

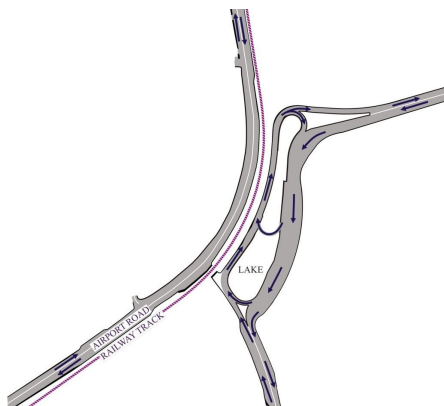


Figure 3. Ground roads connecting to 'roundabout'

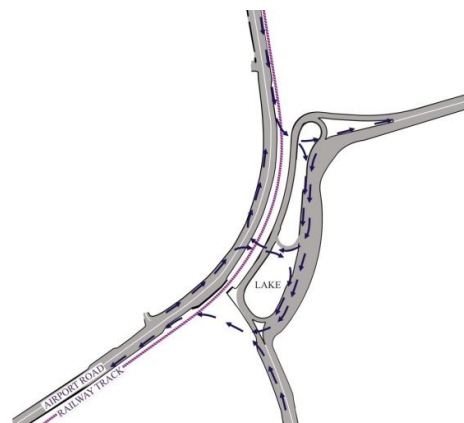


Figure 4. Aerial routes connecting Airport Road to 'roundabout'

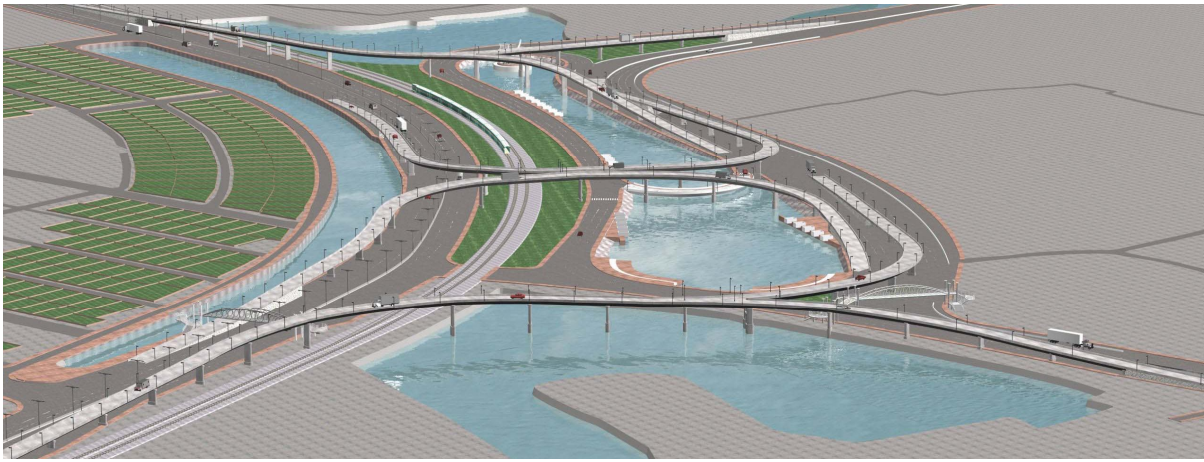


Figure 5. Total solution with Y- and U-shaped flyover loops

3.2 Detailed Geometrical Design

Geometrical design of flyover loops and ground roads at the interchange follows the stipulations of AASHTO (2004). Clothoid curves have been used as transition curves between straight segments and circular curves. Besides designing horizontal and vertical curves, the roadway was widened and super elevation provided appropriately at horizontal curves depending on horizontal curvature, vehicle size and speed. Some ancillary requirements had also to be met including limiting street light height to 4 m to realize a total obstruction height of 14.5 m stipulated by civil aviation authority, and providing glare barriers where headlight glare of approaching vehicles are likely to interfere with aircraft landing and takeoff manouvers. The glare barriers devised are closely spaced metal flags jutting out of the parapets. These ensure an effective visual barrier at the same time being permeable to wind pressure.

Lane distribution analyses were performed for both at-grade roads and flyover loops. Airport Road given its strategic importance was provided with adequate through traffic capacity considering the predicted design hour volume. In the interchange area, besides having two-lane turning ramps on each side of carriageway, the road would be a six-lane dual carriageway. All other roads in the interchange area would also have at least three lanes for each direction of travel. The major roads would be flared at approach to the interchange to ensure proper functioning.

The flyover loops would each have two lanes to cater for predicted turning demands, with branch ramps of the Y-loops having single lane widened to tackle non-recurrent vehicle breakdown events. Elevated loops of the interchange are necessarily curved in plan; a minimum radius of 58 m has been provided in consideration of a design speed of 40 km / h in ascending ramps. A carriageway width of 7 m for straight segments increasing to 8.5 m for maximum curvature segments was provided.

4 STRUCTURAL DESIGN AND CONSTRUCTION

Kuril Interchange has four flyovers or elevated road loops of which two are split type direct ramps to cater for all left turning movements and two are U-shaped grade separated loops for all right-and U-turning movements generated by the three major roads as well as Khilkhet and Nikunja residential areas. To overcome traffic weaving problems the two U-loops are placed in opposite (back to back) configuration (Fig. 5). Ascending and descending ramps of the flyover were however more or less straight. Besides structural and aesthetic considerations, span lengths of the loops were dictated by right of way considerations. Curved spans of up to 60 m length were required for oblique crossings over railway tracks. Choice of structure type depended on span length, economy, aesthetics and constructability by local contractors.

4.1 Post-Tensioned Pre-Stressed Concrete I-Girders with RC Deck Slab

Straight post tensioned concrete I-girders acting compositely with cast-in-situ RC deck slab are the most economical form of bridge construction in Bangladesh, with local contractors achieving the task at about half the international price. Spans of the relatively straight approach ramps have been standardized to 30 m to realize a fast and economical construction with post tensioned girders. The deck slab would be a cast-in-situ reinforced concrete structure. A typical deck cross section of these spans is shown in Figure 6.

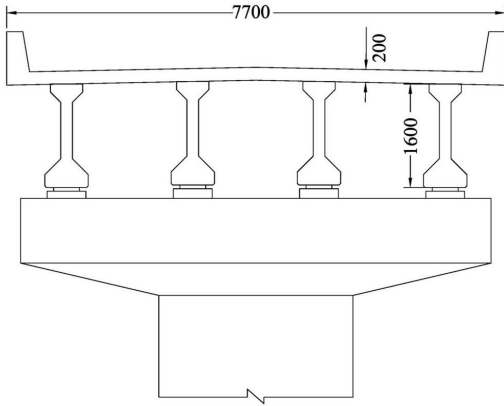


Figure 6. Cross section of I-girder deck

4.2 RC Box Girder for Curved Spans

Obvious choice for the two-lane curved spans was single cell box girders for their inherent torsional efficiency. Such curved structures find common application in interchanges or ‘flyovers’ (NCHRP 2008). As it was decided to appoint only local contractors to ensure economy, available local experience was a major criterion in the selection of material and method. Concrete was preferred to imported steel for economy in material cost. Prestressing of curved concrete box girders would require additional details and precautions for containing the lateral forces induced by tendon tensioning, for which local construction industry had no experience or expertise. The choice therefore narrowed down to cast-in-situ reinforced concrete box girders.

Prestressed concrete box girders have economically been constructed to spans up to 130 m, with frequent applications to spans around 100 m. However, a maximum span of 60 m is suggested for continuous non-prestressed RC box girders (ACI 2004, Schlaich & Scheef 1982). The maximum span in Kuril being 60 m, it is one of the longest RC box girder spans. Up to a span length of about 90 m a constant depth is sensible (Schlaich & Scheef 1982). A typical cross section of box girder of Kuril is shown in Figure 7. To simplify construction and economize on false work a constant cell cross section has been used throughout, with required variation in deck width being achieved by varying the cantilever lengths. Super elevation has been created by tilting the top flange keeping the bottom flange of box horizontal. This simplified the pier head configuration and bearing seat arrangement. A constant depth of 2950 mm resulted in a maximum span-to-depth ratio in excess of 20. This is somewhat more than 18 recommended for continuous spans (ACI 2004, Schlaich & Scheef 1982, AASHTO 2002), but deflection calculations satisfied the limits set for road bridges (AASHTO 2002). Another curved structure in the project is an at-grade link bridge across the lake. This bridge has the shape of a circular arc in plan, for which a three-span continuous RC box girder configuration has been used.

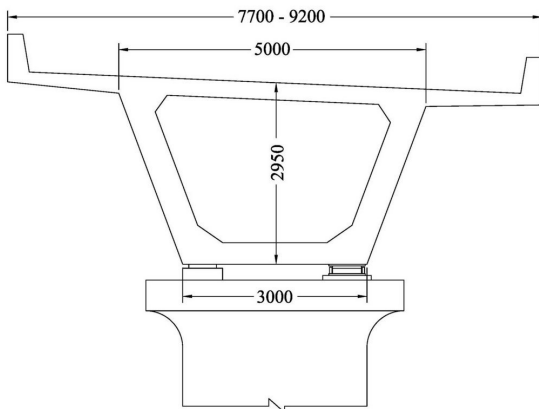


Figure 7. Typical cross section of box girder deck

4.3 Flyover Foundation

Piers are the most visible elements of obstruction for ground surface traffic. A narrow rectangular section with rounded ends was chosen for pier shape. This gave a sleek look especially along the narrow end.

The foundation soil both on dry ground and in water bodies is constituted of typical Dhaka clay to depths up to 12 m overlying medium to dense sand. Bored cast-in-place piles 1 m in diameter and up to 40 m in length were found to be the most economical choice.

AASHTO (2002) HS20 loading was used for all structures with seismic forces and wind loading conforming to Bangladesh standards (BNBC 1993).

4.4 Pedestrian Over Bridges

The project consists of three pedestrian over bridges. These bridges were designed to be minimally invasive to surface traffic and visually pleasant. A single span through-type tied-arch truss configuration bridging over the entire six-lane carriageway as well as the flanking footpaths was chosen for these structures (Fig. 8). The members are made of mild steel pipe sections. The freestanding stairs on both sides are of RC construction.



Figure 8. Pedestrian over bridge

5 INGENIOUS DESIGN SOLUTION

Traffic congestion problem at Kuril was unique in many respects compared to other similar congested junctions. Existence of major railway tracks alongside a major road and two adjacent skewed T-junctions across the railway, coupled with height limitations and space constraints, made solution of the problem extremely difficult. No standard or ‘textbook’ solution could be adopted. Certain amount of ingenuity was called for to devise a solution to the nagging congestion problem.

A roundabout is a good solution for roads meeting at grade at an intersection, but when traffic volume is large this may not work unless a very large diameter roundabout can be created. Roundabouts at intersections such as Shahbagh, Gulshan 1 and Gulshan 2 in Dhaka city which worked satisfactorily when traffic volume was lower, had to be dismantled and replaced by signalled and channelized intersections. Creating a conventional circular roundabout of sufficient diameter was not possible at Kuril because of space limitations. Besides, the roundabout could be placed only on one side of the railway tracks with the problem of integrating traffic of road(s) on the other side still remaining. The solution was found by utilizing the narrow strip of lowland beside the railway tracks to create an elongated circuitous one-way path which is long enough to serve the purpose of a large conventional roundabout. The problem of integrating traffic of Airport Road lying on the other side of railway tracks into the roundabout was solved by creating elevated structures (flyovers) to cross the railway. Four such structures were required, one each for entry and exit of northbound and south bound traffic. The result has been quite effective in channelizing and segregating conflicting traffic streams separating the road and rail traffic.

6 AESTHETICS

Kuril flyover was intended to be elegant and an urban signature project. Elegance has often been considered synonymous with beauty, and beauty and its study, aesthetics, are highly controversial subjects guided by individual observer’s preconceptions (Taly 1998). While there is considerable debate (Gauvreau 2002) on what consideration should guide aesthetic design of a bridge project, in the words of Nervi (Taly 1998), “*The true essence of good design consists in the full satisfaction of functional, statical, constructional and economic means, and the creation of a well balanced arrangement; a project which satisfies these conditions may be aesthetically significant or expressively beautiful but will never be aggressively annoying*”. Menn (1991) lists the priorities in bridge design as safety, serviceability, economy and aesthetics, in that order. The essence of observation by both Nervi and Menn is that satisfaction of functional requirements and economy precede that of aesthetics. In other words, form follows function.

Geometrical layout of the facility evolved strictly around functional requirements. The design yielded four flyovers and an at-grade bridge spread over the interchange area like carefully laid ribbons with the lake being the central flower in the bouquet (Fig. 9). The Y-loops are naturally elegantly curved. Monotony of the U-loops has been alleviated by aligning the approaches with the curved road layout at the location. Channelization and spread of traffic from a point of concentration to a wider area have helped create a serene environment within a chaotic city (Fig. 10).

Span distribution of the flyovers was dictated mostly by right-of-way considerations at the road and railway crossings. Gradually rising uniformly spaced piers in the approach ramps produced visual continuity beyond the triangular reinforced earth embankment walls. Curved segments of the flyover coincided with road crossings under which surface traffic will flow. Box girders were a natural structural choice whose flat soffit is less obtrusive to visual experience. Though somewhat less efficient in shear, inclined webs have been chosen for the box sections to create an inviting visual effect for the traffic to pass under. Deck overhangs were provided for both PC girder and box girder spans to enhance visual slenderness of the superstructures. For the same reason, height of the concrete safety parapets was kept to a minimum and compensated by a steel pipe rail on top.

The lake, central attraction of the interchange, was adorned with edge treatments in the form of brick and concrete sculptures. Two fountains placed in the lake are to spray water upwards to produce a cool ambience in a hot city. The at-grade bridge across the lake was laid in a curve to match with the curved flyovers above. The foot over bridges and their free standing stairs were carefully planned to be inviting for both pedestrians walking above, and vehicles passing below.



Figure 9. Panoramic view of constructed interchange



Figure 10. Serenity amid chaotic city traffic

7 ECONOMY

The total interchange project comprises some 3.1 km of flyover and bridge structures, 2 km of ground roads, a lake, three pedestrian over bridges, and ancillary O&M buildings etc. Total cost of the project exclusive of land price and utility relocation costs has been under US \$25 million. Cost of the structures alone has been about US \$15 million, which comes to under US \$600 per square meter of deck. The cost figures are low compared to international prices, reflecting the designers' conscious attention to economy and local contractors' ability to build at low prices.

A techno-economic analysis performed during feasibility study revealed an economic benefit-cost ratio (BCR) of 3.35 and a financial BCR of 3.73. The Economic Internal Rate of Return was 28.7 and the Financial Internal Rate of Return was 29.52. The results demonstrated high attractiveness of the project as a public investment. In reality, after fierce competitive bidding, the contract has been executed at a lower cost than estimated, resulting in yet more attractive economic benefit figures.

8 CONCLUSIONS AND ACKNOWLEDGEMENT

Result of the conscious effort to satisfy functional, structural, economic and aesthetic requirements has been a total interchange solution which has brought relief to city traffic at Kuril. Besides being functionally effective and adequate, it can also boast a natural elegance. The elegance stems from the fact that it is a simple yet extremely effective solution to a seemingly chaotic traffic congestion problem. The solution evolved as natural

answer to complex travel demands and site restrictions. The finer touches to structural details and landscape have enhanced this elegance. Besides solving the congestion problem, it has already earned accolade from road users and city dwellers for its grace and elegance.

Kuril Flyover stands out as an example of elegance achieved through ingenuity in finding a simple yet effective solution (Rahman 2015). The project demonstrates that ingenious solutions come naturally when problem and site specific considerations are carefully attended to by professionals conversant with local problems and practices.

The authors are indebted to RAJUK, development authority of Dhaka city, for granting opportunity to design and execute the project, and BRTC, BUET for their valuable contribution in traffic analysis and preliminary conceptual layout planning.

REFERENCES

- AASHTO 2002. *Standard Specifications for Highway Bridges*, American Association of State Highway and Transportation Officials, 17th Ed, p. 194, pp. 20-42.
- AASHTO 2004. *A Policy on Geometric Design of Highways and Streets*, American Association of State Highway and Transportation Officials, 5th Ed.
- ACI 2004. *Analysis and Design of Reinforced Concrete Bridge Structures*, 343R-95 (reapproved 2004), American Concrete Institute, Sec 6.4.2.2.
- BNBC 1993. *Bangladesh National Building Code*, Housing and Building Research Institute and Bangladesh Standards and Testing Institution, pp. 6-27 - 6-61.
- Gauvreau, P. 2002. "The Three Myths of Bridge Aesthetics", *Developments in Short and Medium Span Bridge Engineering*, Eds. Brett, P.H., Banthia, N., and Buckland, P.G., Montreal: Canadian Society for Civil Engineering, pp 49-56.
- Menn, G. 1991. "Aesthetics in Bridge Design", *Bridge Aesthetics around the World*, Committee on General Structures, Subcommittee on Bridge Aesthetics, Transportation Research Board, Washington DC, p. 177.
- NCHRP 2008. *Development of Design Specifications and Commentary for Horizontally Curved Concrete Box-Girder Bridges*, NCHRP Report 620, Transportation Research Board, Washington DC, p. 1.
- Rahman, M. A. 2015. "Kuril Flyover – Elegant by Natural Solution", Session Keynote Presentation, IABSE Conference – Elegance in Structures, Nara, Japan, May 13-15.
- Schlaich, J. & Scheef, H. 1982. *Concrete Box-girder Bridges*, IABSE Structural Engineering Documents 1e, 1982, pp. 14-15.
- Taly, N. 1998, *Design of Modern Highway Bridges*, McGraw-Hill, p. 1219, 1223.