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Can U-loop bridges be the low-cost solution for jam free intersections along national highways of Bangladesh?

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ABSTRACT: Despite significant growth in quantity, the highway network in Bangladesh lacks severely in terms of quality. Until recently, there were practically no expressway/freeway with proper intersections or access control, and encroachment of the Right of Way is a common phenomenon. Existence of haats and bazars and frequent road intersections along these major transport arteries are ominously reducing their level of service and operational efficiency, thus choking the national economy. The focus of this study was to evaluate U-loops or U-turn bridgesas a potential cost-effective and less space-restrained solution to this problem. The outcome of this research is quite impressive and promising. Implementation of the proposed U-loops showed significant improvement in traffic operating conditions- an 86.9 % increase in average speed, 62%decrease in average delay per vehicle and 73% decrease in total stopped delay. Moreover, the proposed U-loop bridgescan be entirely designed and constructed using local resources.

1 INTRODUCTION

A well-developed and evolving communication network is a must-have lifeline to keep an edge in today's global economy and this reality which is fathomed by almost all nations- whether under-developed, developing or developed. The scenario is no different for Bangladesh which envisions itself as a developed country by 2040. To achieve this goal, The Government of Bangladesh is investing heavily on transport infrastructure development projects especially in the road transport sector. The transport system of Bangladesh has come a long way since its independence 49 years ago, with effectively no national or regional highways except for a few roads connecting Dhaka with the rest of the country. Although transport demand for both passenger and freight has increased manifold, the share of different transport modes did not increase in the same proportion and road act as the major player catering for about 70% of the total trips (Hoque, 2006). As of 2019, the total length of 99 national and 139 regional highways in the country are 3,906.03 km and 4, 766.91 km respectively. (RTHD, 2019) Some of the major highway corridors in Bangladesh include- Dhaka-Chattogram National Highway (N-1), Dhaka-Sylhet National Highway (N-2), Dhaka-Northern Region Corridor (N-5, N-6), Dhaka-Aricha Road (N-5, N-7) and the highly anticipated Dhaka- Mawa Road (N-8) to Southern region.

Despite having seen significant growth in terms of quantity, the highway network in Bangladesh lacks severely in terms of quality. Before now, there were practically no expressway or freeway with proper intersections or access control, and encroachment of the Right of Way (ROW) is a common phenomenon. Existence of haats and bazars along the highway were identified as the major cause for reduced operational efficiency followed by traffic volume (RHD, 2005). Also, frequent road intersections along these major transport arteries are significantly reducing their level of service and operational efficiency, which in turn is choking the national economy. For instance, the Dhaka– Chattogram National Highway (N1) which connects the port city of Chattogram and other major destinations (e.g. Cumilla, Teknaf), economic zones and several tourist spots with Dhaka is one of the most important economic corridors in terms of passenger and freight movement with an ever-increasing traffic demand. 92% of country's total trade (export and import) and 81% of National Ready-Made Garments (RMG) is transported by this highway with very few alternatives available (Uddin, 2020). Also, this highway is projected to be an essential part of three regional corridors: (1) ASIAN highway corridor, which will connect with ASEAN countries and China; (2) Part of SAARC highway corridor; and (3) Part of SASEC highway corridor, which focuses on road infrastructure to improve regional connectivity between Bangladesh, Bhutan, India and Nepal (BBIN). Regrettably, starting from Dhaka, there are more than forty major intersections along the national highway, up to Chattogram. The major traffic hotspots on N1 are located at Katchpur, Madanpur, Daudkandi, Madhaiya, Comilla Cantonment, Padua Bazar, Biswa Road Intersection (Comilla), Uttar Krishnapur, Feni and Baraiyarhat (Figure 1).

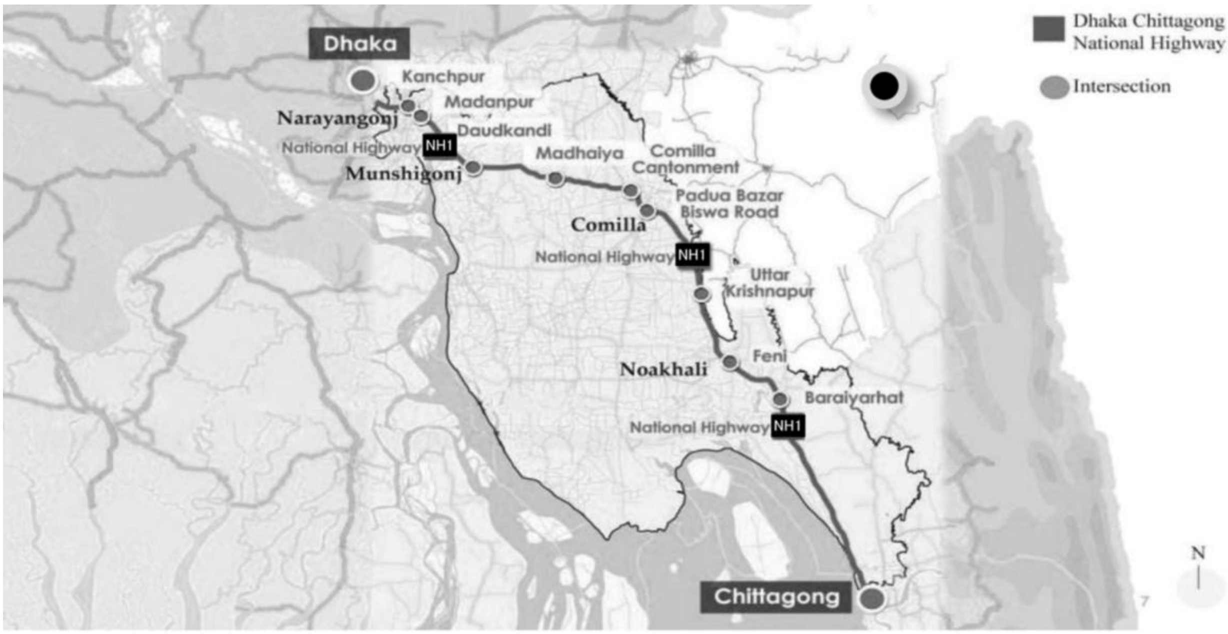


Figure 1. Layout of Dhaka–Chattogram National Highway (Source: Ministry of Road Transport and Bridges (MoRTB) 2015a).

In most cases, these intersections serve as the start or end point of public transport services that connect the area with Dhaka, Chattogram, Chandpur and other-southern regions. People use easy-bike or CNG for their drop-off or pick-up needs which in turn generate severe queue and traffic congestion. The deteriorated traffic conditions result in increasing traffic delays, and seriously compromise the ability of the transport sector to serve and sustain economic growth and quality of life. One obvious way-out of this deteriorating traffic operating conditions at the major junctions is to adopt high-end intersection designs i.e. directional or non-directional interchanges. However, implementation of such solutions demands considerable space availability around the junctions. Unfortunately, lack of foresight and absence of considerations for provision of future expansion and intersection improvement in the planning process resulted in insufficient ROW's along the highway corridors. On top of that, unregulated development of commercial (i.e. haats, bazars, restaurants, hotels) and religious facilities along these corridors puts forward significant hindrance from the local community for any highway expansion project.

The objective of this study is to evaluate a potential cost-effective and less space-restrained solution i.e. U-loops or U-turn bridge for implementation at the major intersections along these highway corridors. The next few sections will highlight on some alternatives for improvement of highway intersections, different configurations of U-loops, impacts of U-loops on a test intersection, structural design considerations of U-loops followed by conclusions.

2 ALTERNATIVES FOR IMPROVEMENT OF HIGHWAY INTERSECTIONS

Junctions along the national highways are critical points governing its overall operational efficiency, especially at the crossings with regional highways. Any mismanagement of such intersections can cause serious traffic disruption as well as severe safety concern. This section explores some potential traffic management solution alternatives for such intersection considering numerous physical (ROW) and social (haat, bazar, business) constrains.

2.1 *Simple At-Grade Treatment*

In general, a four-legged intersection (Figure 2) does not operate under signalized condition when traffic flow is low. However, as a default measure for increased volume of traversing traffic, signalization could be introduced. However, field observation revealed that the traffic flow arrival pattern is somewhat unpredictable from the four approaches of these intersections during off-peak as well as peak periods. For this reason, the preset fixed signal timing cannot match the traffic demand thereby causing further geometric delay. Thus, signalization cannot improve the congestion situation because even isolated signal control will not be adequate to allocate green time proportions for the right-turning vehicles at the major approaches. More importantly, due to the uninterrupted mobility requirements on both highways, signalized intersection design in not a good option here.

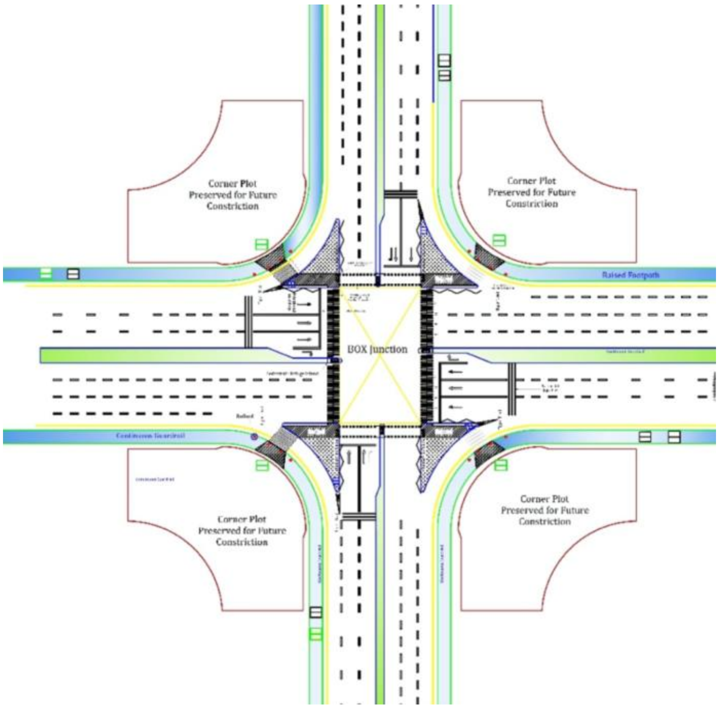


Figure 2. Four-legged intersection.

2.2 *Advanced At-grade Treatment*

From practical considerations, simple geometric treatment (channelization, refuge-island, pedestrian crossing etc.) does not hold for such high volume of traffic traversing such intersections. For this reason, an immediate solution could be the banning of right-turn from few/all the approaches (Figure 3). As a result, the operating condition of the intersection would improve notably. However, this would be a temporary solution, as the right-turning provision that is being banned at the intersection has to be provided via an at-grade U-turn facility just after the intersection influence zone and the number of vehicles approaching this U-turn provision would dictate the congestion condition of that particular approach. For example, when the vehicle volume negotiating U-turn is high at one of these approaches then there would be an imminent conflict with the through vehicles of that approach, considering normal volume of through traffic. This conflict would result in a congestion situation within a small period.

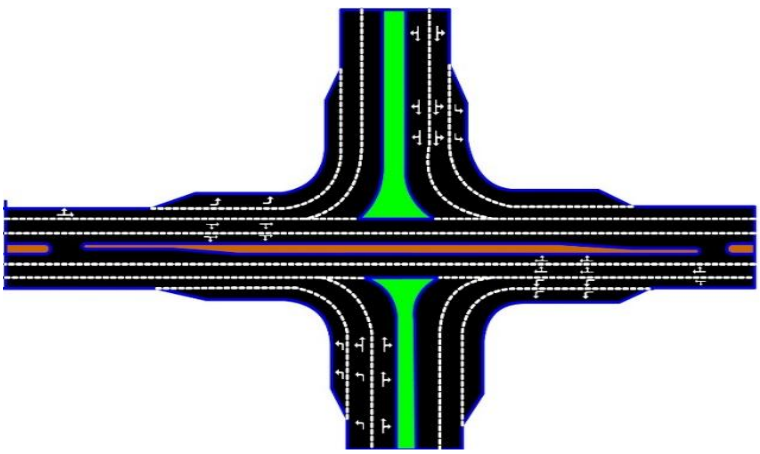


Figure 3. Schematic illustration of an at-grade U-turn along with a corridor solution.

2.3 *Advanced Grade-Separated Treatment Considering U-Loop*

A solution to this U-turn problem can be the provision of elevated U-loop for the vehicles negotiating the U-turn. In this case, the U-loop facilities will have to be provided (Figure 4) at both ends of the major road. The U-loops have to be located outside of the influence zone of the intersection, however not very far from the area of interest. The U-loop facilities will convert the direct conflict between the U-turn traffic and through traffic to a more docile merging movement. Also, it is worthwhile to enumerate the drawbacks of at-grade intersection before opting out for grade separated structure, which are obviously more expensive. First of all, at-grade intersection causes fixed geometric delay due to the geometric features placed on the carriageway to interrupt smooth flow and reduce speed. Likewise, the arrangement and the number of approaches cause operational delay. It is also a fact that the capacity of an intersection is much less than that of its approaches for facilitating right-turn and through movements at different times for the major approaches. Notably, grade separation is warranted when an intersection cannot cope with the increasing demand even after the application of all traditional improvement measures.

Figure 4. Grade separated U-loop facility.

3 U-LOOP BRIDGE ON HIGHWAYS: GEOMETRIC DESIGN CONSIDERATIONS

At-grade and grade-separated U-loops have recently been applied in our country to address traffic congestion incurred due to uncontrolled u turns and right turns at the urban intersections-especially in Dhaka City. Also, application of U-turn bridges or U-loops around the globe is not new as shown in figure 5.

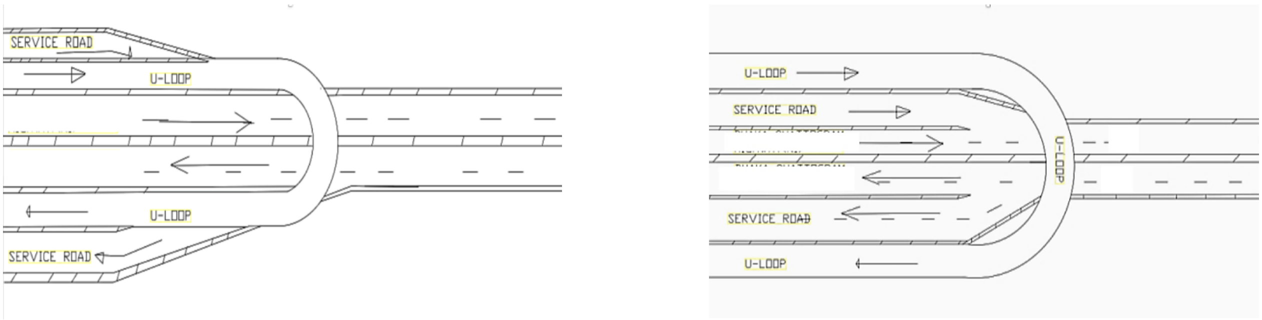
(a) (b)

Figure 5. (a) U-Turn Bridge in Thailand, (b) U-Turn Bridge in Kuwait.

Application of U-loops to enhance operational efficiency of highway junctions in uncommon and there are better options (e.g. interchanges) available for intersection improvement. However, implementation of such high-end solutions requires considerable space and funding availability. U-loops (in pairs) can serve as potential solutions to reduce conflicts in traffic movements and thus improve the overall efficiency of highway intersections.

3.1 *Configuration for U-loops*

In many cases, highways near the junction points have service lanes to reduce the impedance to through traffic movement inflicted by turning and slow-moving vehicles, local traffic movement, boarding- alighting and loading-unloading activities. Under such circumstances, two different U-loop configurations can be considered: (1) Central U-loop: A grade separated U-loop where the U-loop is located between the at-grade service road and the highway (Figure 6a); and (2) Peripheral U-loop: A grade separated U-loop where the U-loop is located on the periphery of the at grade service road (Figure 6b).



(a) (b)

Figure 6. U-loop concepts: (a) Central U-loop; and (b) Peripheral U-loop.

However, the peripheral configuration has a significant inherent shortcoming. The left turning vehicles coming from the service road will have a conflict with the through traffic coming from the down ramp of U-loop requiring severe weaving maneuver and thus result in capacity drop and severe disruption to traffic flow as shown in figure 7. On the contrary, the central U-loop configuration avoids this weaving maneuver making it a more desirable solution.

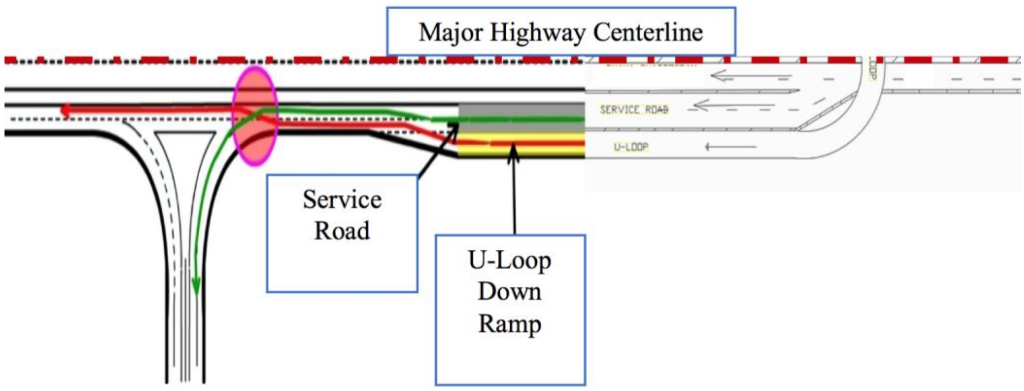


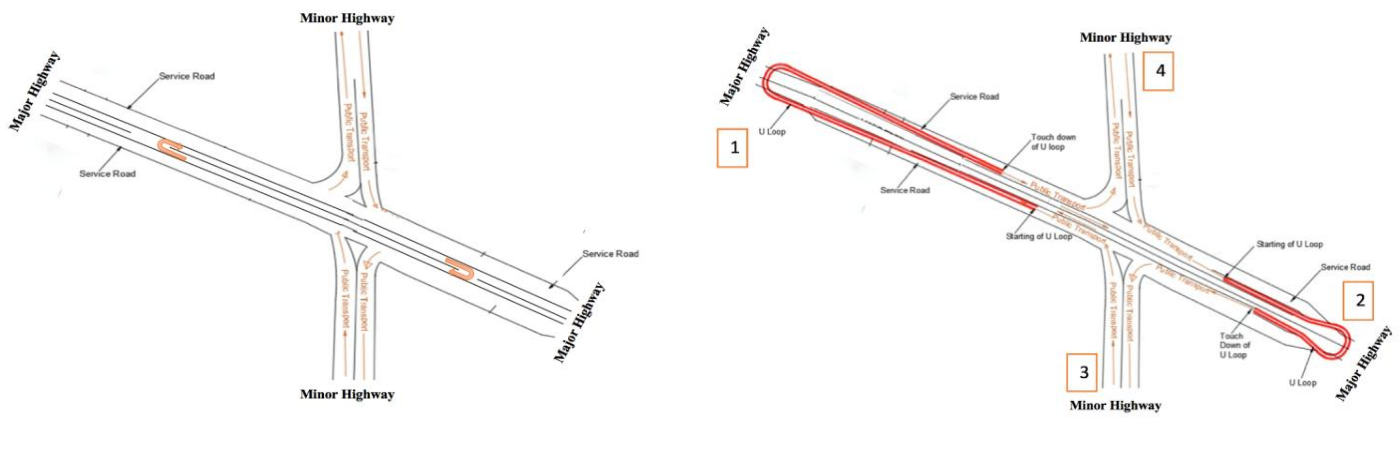
Figure 7. Conflict points for peripheral U-loop configuration.

3.2 *Considerations for Elements of Geometric Design*

For grade separated U-loops, the on-ramp should be constructed with a 3-4% gradient considering the heavy vehicles (trucks and semi-trailers) traversing this facility, as recommended by AASHTO design guidelines (Geometric Design of Highways, 2011). Likewise, the maximum permissible gradient for the off-ramp could be 5% considering the fact that the vehicles would be moving forward due to the force of gravity. Thus, considering these gradient values, the length of the on-ramp would be much greater than the off-ramp. Another important feature of the U-loop facility is the radius of curvature. Since, larger vehicles require larger turning radius the turning radius has to be designed considering the largest design vehicle that would use the facility. For this reason, the U-loop facility might resemble more of a horseshoe than the alphabet “U”. For transition curve and curve widening, The Geometric Design Standards Manual (RHD, 2005) is a comprehensive guide prepared by the Road and Highways Department. Table 5.3 of this manual shows the minimum transition lengths and can be applied readily. However, it is desirable to use a transition curve length that is one design speed and one super-elevation value higher than indicated by the input values in order to allow for future road upgrades. Also, Table 5.4 and Table 6.2 of the manual shows the requirement for minimum curve widening for curve of different radius and the minimum length of vertical curve for good appearance.

4 IMPACT ANALYSIS OF U-LOOPS ON HIGHWAY INTERSECTION EFFICIENCY

In an effort to evaluate the performance of U-loops (in pairs) at highways intersections, detail analyses were carried out within the framework of micro simulation modeling for different scenarios- including a no-project scenario. For this purpose, an artificial test intersection of two highways (figure 8) was considered along with synthetic data generated to emulate movements in typical major highway junctions in the country. It was assumed that right turn was banned at this intersection by use of continuous median along the major highway for better operating conditions. However, there were provisions for U-turn down streams of the intersection.



(a) (b)

Figure 8. Artificial test section for micro-simulation (a) without U-loops, (b) With U-loops.

After creation of network, the various links were loaded with traffic based on the synthetic data. Nine vehicle types were created to replicate traffic composition in the project site: (1) Rickshaw; (2) CNG; (3) Leguna; (4) Bicycle; (5) Bike; (6) Car; (7) HGV; (8) Bus; and (9) Truck. Local vehicles were modeled in 3D Studio-Max first and then converted into software recognizable vehicle element of the micro simulator. Vehicles were calibrated for the desired speed distribution, acceleration and deceleration as well as for the physical dimension. For operational calibration, local driving behavior was also calibrated for relevant parameters e.g. standstill longitudinal distance between the stopped vehicles, look ahead distance, minimum headway, overtaking characteristics etc. On Bangladeshi roads, because of mixed traffic condition (motorized and non-motorized), it is difficult to enforce lane discipline. Hence, vehicle occupies lateral positions on any part of road based on space availability; fast moving vehicle pass slow vehicles from both sides. So, non-lane-based driving behavior was modeled to replicate the ground reality. The calibrated model was further validated against separate data independent of the calibration dataset. Two parameters were used to validate the base model- (a) GEH, and (b) Travel Time. Simulated traffic flows were compared with the observed traffic flows which resulted in an R square value of 0.9363, which is acceptable since a value of R-square greater than 0.8 represents good relation. Geoffrey E. Heavers (GEH) statistic was also used to compare field traffic volumes with those obtained from the model to ensure compliance of the model. Figure 9 shows a snapshot of the micro-simulation model with U-loops.

With the different combinations of natural growth of traffic and project traffic, total three scenarios were analyzed using the calibrated and validated Model-

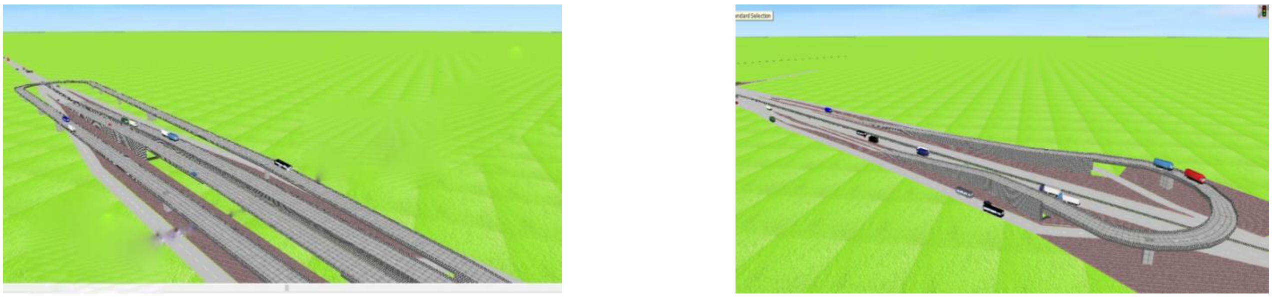
Scenario-1 (SC-1): Addressing the base traffic condition.

Scenario-2(SC-2): Forecasting the future traffic condition with two at grade U-turn after 20 years considering a 10% growth rate according to RHD manual.

Scenario-3(SC-3): Forecasting the future traffic condition after 20 years incorporating central grade separated U-loops at both sides of the intersection.

The simulated results obtained from morning peak scenario are used to assess the traffic conditions of the network and intersection on different mobility parameters. The traffic operating conditions in the test intersection were assessed using the following three parameters i.e. MOE’s (measures of effectiveness): (a) Average

Speed (veh/sec), (b) Average delay per vehicle (s), and (c) Total Stopped delay time (hr), which are summarized in Table 1 below.



(a) (b)

Figure 9. Snapshot of U-loops at both ends of intersection (a) Approach 1 (b) Approach 2.

Table 1. Network performance at peak period due to central U-loops implementation.

Mobility Parameters	Average Speed	Average delay per vehicle	Total Stopped delay
	km/h	second	hour
SC-1: Base condition	19.6	146.2	54.3
SC-2:After 20 years, without intervention	10.7	359.3	75.1
SC-3:After 20 years, with U-loops	20.3	136.6	20.3

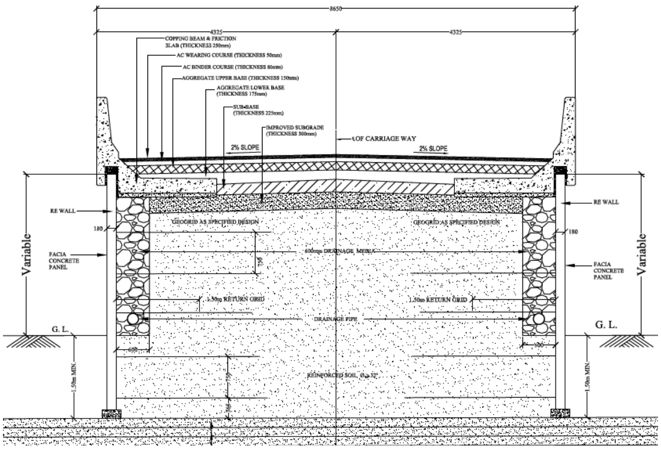


Figure 10. Roadway slab supported reinforced earth wall.

Compared to SC-1, in case of SC-2 the average speed reduced from 19.6 km/h to 10.7 km/h (45.1 % decrease), the average delay per vehicle increased from 146.2 s to 359.3 s (an increase of 145.8 %) and total stopped delay increases from 54.3 hr to 75.1 hr (a 38.3% increase). These MOE's reflect the deterioration of the network performance due to the induced traffic caused by natural growth which is quite intuitive. However, in case of SC3, with the implementation of the grade separated U-loops, the operating condition showed significant improvement compared to SC-2. The average speed increased from10.7 km/h to 20km/h(an increase of 86.9 %), the average delay per vehicle dropped from 359.3 s to 136.6 s(62.0 % decrease), and total stopped delay also reduced to 20.3 hr from 75.1 hr(73.0 % decrease). These improvements in turn reflect network improvement due to implementation of face to face U-loops and associated geometric treatment at the test intersection.

5 STRUCTURAL ASPECTS AND DESIGN CONSIDERATIONS FOR U-LOOPS

The U-loop bridge proposed to solve the traffic jam problems of national highway intersections can be constructed with locally available materials and technology already in use in the country. The proposed U-loop bride can be constructed in three different components:

1. Ramp roadway supported on Reinforced Earth (RE) retaining wall.
2. Ramp roadway slab supported on Pre-stressed I-girder, bent-cap and pier.
3. Curved loop portion consists of cast-in-situ RC box girder supported on piers.

All the piers are to be supported on pile caps which rest on cast in situ bored piles. The structural and geotechnical components as described are commonly used in Bangladesh. Analysis and designs should be carried out considering dead, vehicular (HL93) and seismic loads as per AASHTO (2012) and BNBC (2020). Typical RE wall, I-girder and box sections that can be used are shown in Figures 10 to 12.

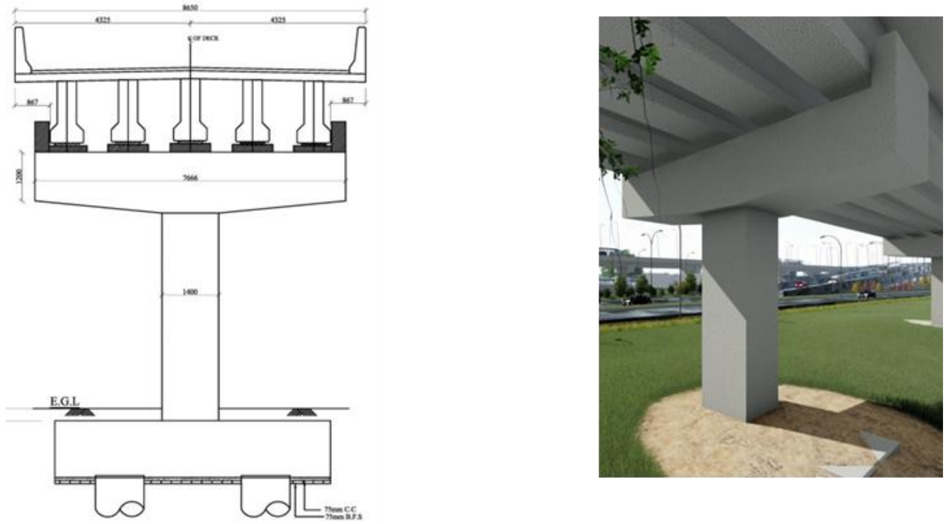


Figure 11. Roadway slab supported on prestressed I-girder, bent-cap and pier.

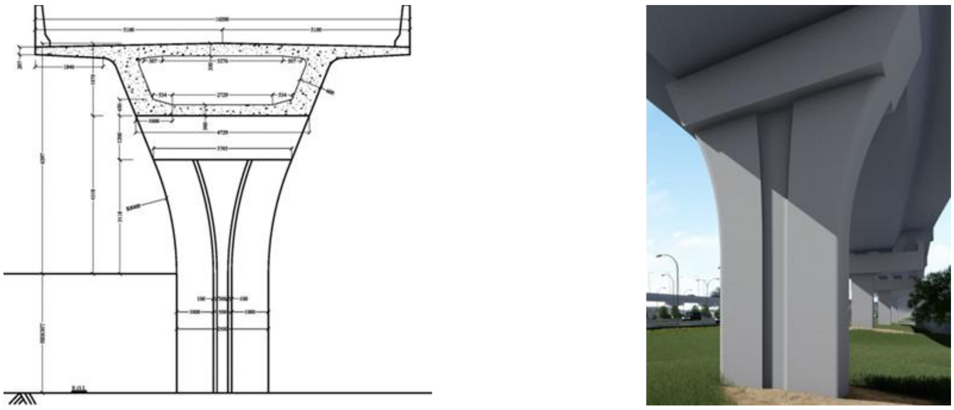


Figure 12. Curved loop portion consists of cast-in-situ RC box girder supported on piers.

6 CONCLUSIONS

Inadequacy of appropriate turning facilities at most of the major junctions along national highways causes enormous delay and serious disruption to both passenger and goods movement which in turn hampers national productivity and economic growth. Also, at-grade u-turning facilities existing at some major junctions are ill-designed and do not provide enough turning radius for large high-speed vehicles which (bus, truck) need to attain the radius from existing carriageway by blocking the path of through traffic. Moreover, insufficient ROW's along most of the highway corridors and unregulated development of commercial (i.e. haats, bazars, restaurants, hotels etc.) and religious facilities along these corridors puts forward significant hindrance from the local community for any highway expansion project. Although, adoption of high-end intersection designs i.e. directional or non-directional interchanges may solve these problems but their implementation require considerable availability of space and funding. In an effort to find a viable option two overcome both of these hurdles, U-loops or U-turn bridges (in pairs) was evaluated to be a cost-effective and less space-restrained solution. This study clearly revealed the necessity and urgency of improvement of the highway junctions through implementation of U-loops and associated facilities ensuring high speed, high mobility, and improved safety. Also, as outlined in the micro-simulation analysis, in absence of timely and proper intervention i.e. under no-project scenario, traffic conditions at the major intersections are bound to deteriorate significantly in the next 20 years with significant decrease in average traffic speed (by a factor of almost 2), and significant increase of average delay per vehicle (by a factor of over 2) and total stopped delay (by a factor of about 1.5).

Nevertheless, implementation of the U-loops showed significant improvement in operating conditions- the average speed increased from10.7 km/h to 20km/h(an increase of 86.9 %), the average delay per vehicle dropped from 359.3 s to 136.6 s(62.0 % decrease), and total stopped delay also reduced to 20.3 hr from 75.1 hr(73.0 % decrease). Furthermore, the proposed U-loop bridge scheme is technically feasible as it canbe designed entirely by local expertise and constructed with locally available materials and technology already in use in the country.

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