ARTICLE

Analysis of the Relations between Highway Geometric Design and Traffic Safety in Bangladesh, China, and America

Licai Zhang[*]   **Kai Hua**   **Fen Xiang**

China Railway Eryuan Engineering Group Co. Ltd. (CREEC), Chengdu, Sichuan, 610000, China

ARTICLE INFO	ABSTRACT
	Transportation plays a critical role in the economic sector in Bangladesh. Since its independence, infrastructure has been developing rapidly, including land, water, and air transportation. National economy is increasing at a relatively high rate, leading to the better-off of people's lives. As the living standards keep improving, people are more concerned about safety issues in transportation. This article makes an analysis of the status quo of traffic safety in Bangladesh and compares the Bangladeshi code with American code AASHTO from the geometric aspects of horizontal and vertical alignment, in an effort to provide reference to the highway design in Bangladesh. Through a reasonable design, the traffic safety will be under control and accident rate as well as economic loss will be minimized.

1. The Status Quo of Traffic Safety in Bangladesh

As an important part of Bangladesh transportation system, there is a prospect for highway to be used widely in urban areas. With the rapid economic development, traffic volume of urban roads is skyrocketing, resulting in severe congestion. Due to the mismatch of highway capacity and traffic volume, the urban traffic is highly congested, imposing adverse impact on the development of cities and people's lives. A proper highway planning can provide a safe and reliable driving environment, meanwhile, reduce accident rate, save passengers' lives, and minimize economic losses [1].

Currently, 160 deaths on average are caused per 10,000 motor vehicles, the death rate of which is rarely seen worldwide. Approximately, 70%-80% traffic accidents happen on expressway and rural roads and 70% traffic accidents endangers the pedestrians. A high traffic accident rate not only put people's lives at risk, but also impose enormous economic burden on the country, as much as 50 billion TAKA (equivalent to 710 million U.S. dollars) each year. 80% of the deaths are aged between 5 and 45 years old, adversely affecting socio-economic development.

Statistics show that the fatality per 10,000 vehicles in the U.S. and China is less than 0.9% of that in Bangla-

*Corresponding Author:
Licai Zhang,
China Railway Eryuan Engineering Group Co. Ltd. (CREEC), Chengdu, Sichuan, 610000, China;
Email: 616919389@qq.com

desh. Death toll due to traffic accidents remains startlingly high. It has become a pressing task to reduce and prevent the occurrence of traffic accidents to better the urban traffic safety [2].
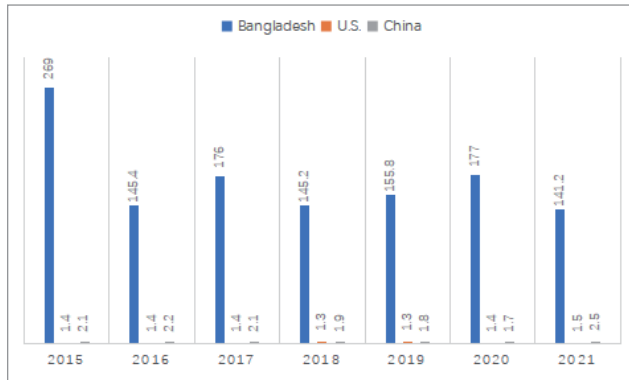

Figure 1. Fatality per 10,000 vehicles in Bangladesh, the U.S. and China.

2. Cause Analysis of Traffic Accidents

Traffic safety is worth research. Various causes lie behind the traffic accidents. The traffic facilities should be in place that take full consideration of the relationship between humans, vehicles, and roads. With safety as a priority, due attention should also be paid to the comfort, convenience, and appearance. A proper highway planning can effectively control the traffic, thus lessening the traffic accidents and economic losses. In geometric design of highway, sufficient consideration should be given to the coordination between horizontal, vertical alignment and cross section and the sight distance should be made adequate. If the alignment design lacks some considerations, the traffic capacity will be lowered and the drivers suffer from losses both in terms of time and economically [3].

The main factors that lead to traffic accidents are drivers, road characteristics and vehicles. The drivers' capability plays decisive role in traffic safety, whereas, studies show the drivers' fault along will not give rise to the most serious accidents. A more important factor is related to the dangerous roads. That is to say, the road characteristics are the root of accidents, which directly or indirectly induce traffic accidents. The accidents due to the interaction between drivers and road features account for as much as 30%. In this article, Bangladeshi code will be compared with American code AASHTO. The influence of road factor on traffic accidents is analyzed in details to determine the relationship between road alignment and traffic safety. The key factors affecting traffic safety are extracted for reference of future design in Bangladesh.
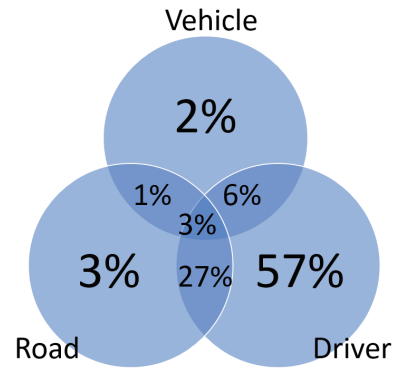

Figure 2. The distribution of causes of traffic accidents

3. The Importance of Road Geometric Design for Traffic Safety

Traffic engineering is complicated and systemic and plays a crucial part in road construction. It brings the road functions to full play by providing a fast, comfortable and safe driving experience, thus reducing traffic accidents and maximize the road capacity. The layout of traffic engineering plans the road to improve its functions according to geographical and ground features, on the basis of road geometric design. For the drivers, the advantages of a three-dimensional design lie in its safety, swiftness, and comfort.

To ensure the safety, comfort and coordination, the three-dimensional design of road shall be properly designed. Safety must come first. Effective measures shall be taken to provide safety and humane service, enhancing the transportation safety and service level. Since the landform and geography can't be changed along the route, the road geometric design shall be considered at the time of planning, which will dictate the safety of during construction and operation.

The geometry must be properly designed to ensure the driving speed and safety. A well-designed embankment is a precondition for the safety and stability. A holistic consideration shall be taken about the landform, maintenance, land utilization and environmental protection to achieve a coordinated and consistent alignment design. The road geometry is a key factor of traffic safety. An unreasonable design will lower the road capacity, cause time and economic losses, and even lead to traffic accidents.

The geometric design considers the plan & profile and coordination with cross section as well as sight distance. In highway design, sufficient consideration should be given to the steering direction, speed, distance, drivers' view, and sight distance so that expected outcome can be achieved by the drivers. Despite numerous factors that affect the road safety, including road alignment, design,

safety facilities design, location and shape of structures, the geometric design is the most important. Once the direction of road is fixed, geometry determined, other projects, like the choice of bridge structure, safety measures are based on the former.

The function of roads, driving safety as well as natural environment should all be considered at the time of route selection. Not only the safety of road facilities and operation should be combined, but also prevent accident-prone locations and safety hazards. Driving safety issues are resolved from root by means of improving horizontal & vertical alignment. Specifically, the driving safety on grade shall be given due attention.

In summary, road geometric design, among others, shall prioritize safety and take effective measures to tackle safety issues and indeed promote the traffic capacity and level of service.

4. Comparative Analysis of Geometric Design of Bangladeshi & American Highway

4.1 Basic Theory

The basic theory applied for highway geometric design is consistent in Bangladeshi and American code, with slightly different emphasis and expression forms. Some design concepts, though, are quite different [4].

Based on basic theoretical research, the Bangladesh Code specifies the geometric design of highways such as curve radius, superelevation, and gradient, which is the basis for highway design. Unlike Bangladesh highways, the US AASHTO specification is only a design guideline. It proposes a series of guidelines for the geometric design of highways. Designers can have a certain degree of flexibility in using this guideline. The book clearly states in the preface that the purpose of this book is to provide guidelines for designers, and to provide recommended design value ranges for critical dimension designs. Allowing sufficient flexibility is to encourage special design solutions that are suitable for specific situations.

4.2 Sight Distance

As a key factor in road geometry and alignment design, sight distance has a crucial impact on road traffic safety. In order to drive safely, the driver should be able to see a considerable distance in front of the bicycle at any time [5]. Once an obstacle or an oncoming vehicle is found on the road ahead, he can take timely measures to avoid collision. This shortest distance is the sight distance necessary for driving safety.

In both Bangladeshi code and American AASHTO code, stopping sight distance shall be met for the highway with median divider and intermediate sight distance met if without. Combined with terrain, set sections of road that meet overtaking sight distance.

In Bangladeshi code, the road geometry design is closely related to sight distance. Reasonable plan & profile parameters shall be selected according to the design speed. SSD, ISD and OSD are stipulated in the code as well as corresponding minimum radii. Since the minimum radii are larger than those in Chinese and American code, sight distance is met as long as the radius chosen for the curve meets the code, thus it's unnecessary to check the sight distance.

It's stipulated in AASHTO that the stopping sight distance is the sum of two distances: (1) the distance traversed during the brake reaction time, and (2) the distance to brake the vehicle to a stop. It is also stipulated that the sight distance at the most unfavorable locations, such as the inner lane of the horizontal curve and the start and end points of the vertical curve, shall be checked stake by stake. The distance is dependent on the height of the drivers' eye above the road surface, the specified object height above the road surface, and the height and lateral position of sight obstructions within the drivers' line of sight. SSD should be modified according to gradient. The computed distance on level roadways is developed from the following equation:

$$SSD = 0.278Vt + 0.039\frac{V^2}{a}$$

Also used for checking sight distance, the equation is provided in AASHTO to calculate the distance M from the center line of the inner lane on a plane curve to the roadside obstructions:

$$M = R[1 - \cos\left(28.65 \times \frac{S}{R}\right)]$$

where:
M = distance to ensure stopping sight distance
R = the plane curve radius of the inner lane, m
S = stopping sight distance, m

Under special circumstances, where the road intersection is not provided appropriately and where obstructions exist in the range of sight distance, the sight distance is not required to be checked in Bangladeshi code, leaving no room for the improvement of sight distance with technical and engineering measures, which leads to traffic accident.

4.3 Straight (Tangent)

Straight is one of the basic elements of horizontal

alignment. Being too long or too short will both cause higher accident rate. If it is too short, frequent steering adds to the workload of drivers and a rapid change in alignment is prone to induce accidents. Moreover, the combination with short straights forms a broken-back curve, which gives the drivers a wrong signal and imposes great safety risks. However, if the straight is too long, the driver's visual reaction and mental conditions are related to traffic safety. A monotonous alignment is apt to cause fatigue, lags in response and wrong perception, resulting in car crash in unexpected situations.

Bangladeshi code encourages a succession of curves and straights in horizontal alignment. By so doing, drivers are better able to assess the distances and speeds of other vehicles. They are more likely to remain alert, and there is less headlight glare at night. It's also suggested that a straight section should be inserted between two curves that go in opposite directions (reverse curves), yet no specific requirements are stipulated in terms of the maximum and minimum length of straight section.

It's stipulated in AASHTO that the maximum length of a straight is the distance traversed in 3 minutes at design speed. Assuming the speed is 100 km/h, the distance is 5 km or 50 times of the speed value. Yet, the minimum length of straights is not required.

Bangladesh is located on the delta plain in the northeastern subcontinent. Plain accounts for 85% of its territory, making it unnecessary for fit the highways to the terrain by plane curves. For this reason, the roads in Bangladesh are relatively straight. Drivers will gradually become insensitive to speed when driving on a long, straight road. Their misperception of speed incurs great safety hazards, especially when driving on a curve at a high speed. Before entry to a curve, drivers think the speed is substantially lowered while in fact, remains high. On the curve, the vehicles are prone to skid or find it difficult to steer due to high speed. In summary, too long straight section should be avoided, let alone a long straight connected with small radius curve.

4.4 Circular Curve

According to automobile mechanics, the lateral stability is lost before longitudinal stability. Therefore, the curve radius is determined based on the lateral stability of vehicles. The minimum radius should ensure that the resultant of centrifugal force and the component of vehicle gravity perpendicular to the road surface should be no more than the lateral cohesive force between tires and road surface. The comfort of passenger should also be considered.

Studies have shown that 10%-12% of accidents happen on the plane curves. The smaller the radius is, the more likely the accidents will happen. The accident rate soars if the radius is less than 400 m.

British scholar Glanville studied the relations between the curvature of plane curves and road accidents through experiment, as shown in the figure below.
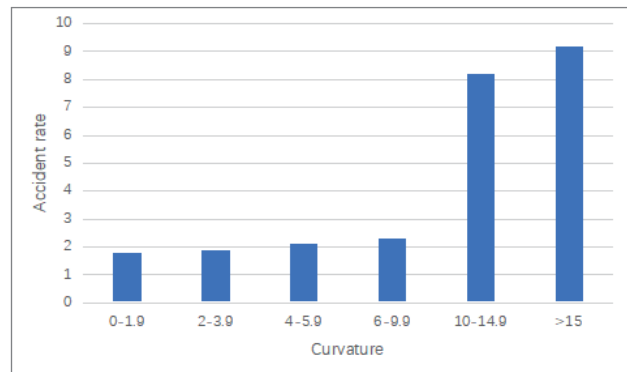

Figure 3. Relations between curvature and accident rate

In Bangladesh code, the minimum curve radii are stipulated as below according to different types of road and sight distance, to be determined by the designers based on actual situation.

In AASHTO, the minimum radii are determined on the condition that vehicles can drive safely and comfortably on the curve. The equation for calculating the minimum radii is provided in this code.

Table 1. Minmum Curve Radii (metres)-Bangladesh

Design Speed (km/h)	Single Lane Roads (3.7 m carriageway)	Two Lane Single Carriageway Roads (6.2 and 7.3 m carriageway)			Dual Carriageway Roads (2×7.3)
	ISD	SSD	ISD	OSD	ISD
30	120	35	120	500	-
40	250	65	250	1000	-
50	500	120	500	2000	500
65	1000	250	1000	4000	1000
80	-	500	2000	8000	2000
100	-	1000	4000	-	4000

$$R_{min} = \frac{V^2}{127(e_{max} + f_{max})}$$

R_{min}-Minimum radius of curve measured to a vehicle's center of gravity, m

e_{max}-Maximum rate of roadway superelevation, percent

f_{max}-Maximum side friction factor

V- Vehicle speed, km/h

The mimimum radius can be calculated based on e_{max} and f_{max}.

Table 2. Minimum circular radii under different vehicle speeds and elevation in AASHTO

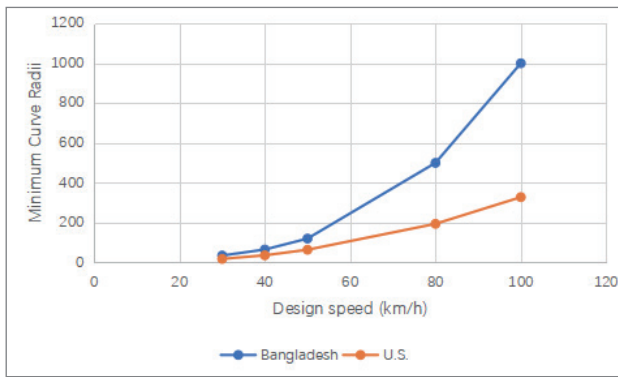| Design Speed (km/h)	30	40	50	80	100
4%	22	47	86	280	492
6%	21	43	79	252	437
8%	20	41	73	229	394
10%	19	38	68	210	358
12%	18	36	64	194	328

Figure 4. Allowable Minimum Radii in Bangladeshi and American Code

The minimum radii under different speeds in two codes are shown in the figure. It can be seen that the radii in Bangladeshi code are larger than in American code, which effectively curbs the application of small radius curve and avoids possible traffic accidents.

4.5 Maximum Superelevation

In AASHTO, there are five superelevation, i.e. 4%, 6%, 8% and 12% to choose from. And five circular curve standards are provided accordingly. For expressways, the maximum superelevation is stipulated as 8%, 10% or 12%; for elevated bridges, 6% or 8%. It's worth noting that 12% is newly added in the latest standards, reflecting the need to fit high-speed driving.

It's stipulated in Bangladeshi code that for the section with curve radius less than the minimum radius not requiring the superelevation, crossfall towards inner side of

curve is required. The maximum superelevation crossfall is 7%. In the code, the superelevation of circular curve is clearly stipulate. The designers can choose values in the table according to design speed and radius of circular curve.

The maximum superelevation is determined according to actuation situation like climate, topographical conditions, and the percentage of low-speed vehicles.

4.6 Transition Curve

Both American and Bangladeshi code are basically consistent in the principles of providing transition curve: when the radius of the circular curve is less than the minimum radius of the circular curve without the transition curve, in order to adapt to the driving trajectory of the vehicle and meet the needs of superelevation transition, the transition curve should be set for the horizontal curves. Generally, spiral is used as transition curve. The length of the spiral is determined based on the driving comfort and the offset of the vehicle. When the vehicle enters the curve, the appropriate length of the spiral will not make the driver feel uncomfortable with the increase of the centripetal acceleration, and it can also ensure that the vehicle runs on a normal trajectory, and its lateral offset will not exceed its own lane. However, if the length of the spiral is too long, the driver will be misled into thinking that the radius of the circular curve ahead is small, and there will also be potential safety hazards.

The starting point of the superelevation transition is fixed on a straight line at a certain distance (Lt) from the T.S. point. At T.S. Point, the crossfall of outer side has been rotated to be flat. This approach helps the driver better adjust the driving state. Besides, it can provide visual comfort and driving safety without reverse-superelevation section on transition curve.

In Bangladeshi code, the minimum length of transition curve is related to design speed and superelevation and is provided accordingly.

Table 3. Minimum Design Transition Length(m)-Bangladesh

Design speed (km/h))	7%	5%	3%	
	Tab.3 Minimum Design Transition Length(m)Bangladesh			
30	25	15	10	10
40	35	20	13	13
50	45[55]	25[35]	15[20]	15[20]
65	55[65]	35[45]	20[25]	20[25]
80	65[75]	45[55]	25[35]	25[35]
100	75[95]	55[65]	35[45]	35[45]

The equation for calculating the minimum, maximum and expected radii is provided in this code.

$$L_{smin} = 0.0214 \times V^3/RC$$
$$L_{smax} = \sqrt{24(P_{max})R}$$

where:

L_{smin}- the minimum length of spiral, m

L_{sman}- the maximum length of spiral, m

V- Design speed, km/h

R-Circular curve radius, m

C-Maximum rate of change of centripetal acceleration (1.2 m/s^3)

P_{max}-Minimum offset of the vehicle on the transition curve between the straight and the circular curve (0.2 m)

It's considered in AASHTO that when the length of the spiral is approximately equal to the length of the natural trajectory of the vehicle, the driving state of the vehicle is the most ideal. If they are too different, steering problems will occur. At the end of transition curve, the vehicle produces excessive lateral velocity and lateral displacement. Therefore, AASHTO provides the expected length of spiral, equal to the distance traversed by vehicles in 2 seconds at design speed.

Table 4. Desirable Length of Spiral Curve Transition(m) in AASHTO

Design speed (km/h)	80	90	100	110	120	130
Desirable Length of Spiral Curve Transition (m)	44	50	56	61	67	72

In actual design, for circular curves of different radii, if the desirable length of the spiral is less than the minimum value calculated by the above formula, the minimum value calculated by the formula should be used in the design.

Meanwhile, it is suggested that the length of the spiral should be the same as that of the superelevation transition. If the length of the superelevation is less than the minimum value of the spiral calculated by the formula, the length of the superelevation should be adjusted appropriately to make it close to the length of the spiral.

It can be seen from the above analysis that the American AASHTO code has more detailed requirements for the transition curve and superelevation transition, which enables the designer to design the most suitable horizontal alignment according to the actual situation of each project; while the Bangladesh code is relatively simple, so It may cause a sharp superelevation transition, the driver's reaction time is too short;or it may cause the superelevation transition too gentle, resulting in the risk of water logging and hydroplaning.

4.7 Gradient

The vertical alignment also has a significant influence on the traffic safety and it is often the direct cause of traffic accidents. The climbing ability of vehicles is an important factor in limiting the gradient. Therefore, the impact of the longitudinal slope on the heavy-duty vehicles is more significant than that on the cars. When the car is going up a steep slope, it will inevitably lead to a reduction in the speed of the vehicle. If the steep slope is too long, the climbing will cause the car water tank to boil and steam resistance so that the driving is slow and weak and the wear and tear of the parts increases. With the driving conditions deteriorating, the engine even stalls and traffic accident occurs. When going down a long steep slope, due to the need for a long time to decelerate and brake, it will cause the heat failure or burnout of brake, resulting in traffic accidents.

German scholar Biezlu investigated the relationship between the gradient of German highways and the road traffic accident rate, and concluded that the steeper the slope, the greater the accident rate. When the gradient is greater than 4%, the accident rate will rise sharply.
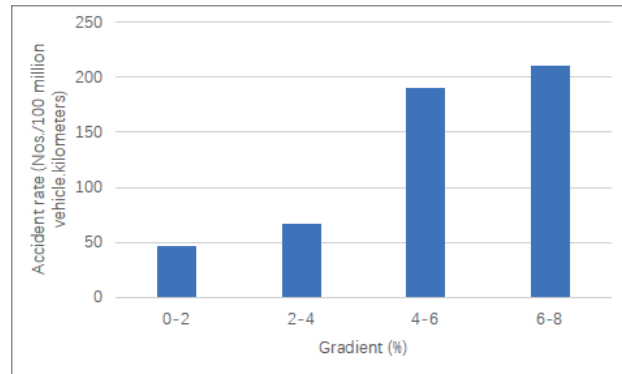

Figure 5. Relations between Gradient and Accident Rate in German Highways

The maximum gradient stipulated by the Bangladeshi Code is only related to the terrain. For highways of various grades and design speeds, it is 0 to 3% in the plain area, 1% to 5% in the hilly area, and 1% to 7% in the mountainous area.The code does not specify the maximum slope length.

It's stipulated in AASHTO that the maximum gradient is determined based on types of terrain and design speed. Maximum grades of about 5 percent are considered appropriate for a design speed of 110 km/h. For a design speed of 50 km/h, maximum grades generally are in the range of 7 to 12 percent, depending on terrain. If only the more important highways are considered, it appears that maximum grades of 7 or 8 percent are representative of current

design practice for a 50-km/h design speed.

The requirements on the minimum gradient are relatively loose and are determined after comprehensive consideration.

On the road without curb stones, if the road camber is sufficient to satisfy the lateral drainage of the road surface, then a gentle gradient can be used in the design; On the road with curb stones, in order to facilitate the lateral drainage of the pavement, a minimum gradient of 0.5% is usually used.But on high-grade highways where the roadbed is firm and it requires precision for the road camber design, a minimum gradient of 0.3% can also be used.

The minimum slope length is not clearly specified, and the maximum slope length has nothing to do with the design speed, and is determined on the basis of the speed reduction of the loaded vehicles' speed lower than the average speed.

The recommended value of the speed reduction is 15 km/h.

Due to the lack of relevant requirements on the maximum slope length in the Bangladeshi code, if the road adopts a long and steep slope, and the performance of vehicles in Bangladesh is generally low, traffic accidents are more likely to occur in practice.

5. Conclusions

Due to the multiple factors for traffic accidents, the geometry design is not the only one to blame. However, a well-thought-out geometry design effectively ensures the traffic safety and reduces traffic accidents and causalities involved.

This article made an analysis of the causes of high traffic accident rate in Bangladesh, and the relations between the three components of road transport, i.e. humans, vehicles and roads, concluding the relations between the road geometry conditions and traffic safety. Starting from the relationship between the geometric elements including Plan & Profile and traffic safety, the influence of various indicators in the geometry design on safety is elaborated, and the relevant requirements and differences between the Bangladeshi standard and the American AASHTO standard are analyzed. It's found that the Bangladeshi code lacks the detailed requirements on multiple road elements, possibly leading to "compliant with code yet unreasonable" design in practice. The findings of this article can provide reference for the road design in Bangladesh.

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