STATE OF THE ART TECHNOLOGY OF THE HIGHWAY ALIGNMENT DESIGN IN CHINA

JIANCHUAN CHENG, GUIFANG SHI and SHUNXIN YANG

Transportation College, Southeast University, Nanjing, 210096, P.R. China.

ABSTRACT

In the past two decades, highway construction in China has progressed rapidly with improved quality and standards. It has greatly benefited from the results of a series of research projects that have contributed to the updating of some highway geometric parameters. This paper presents a state-of-practice review of the design concept and its applications to highway alignment design and the recent developments in China. Key design parameters that have been changed are further assessed. The changes cover highway classification, design speed, level of service, traffic capacity, and intersection and interchange design. We expect it to give a better understanding of current highway alignment design policies and provide help to professionals.

Keywords: Highway Alignment, Highway Geometric Design, China

1. INTRODUCTION

In China, there are two major design codes for highway alignment design: the *Technical Standards of Highway Engineering* (hereinafter referred to as the *Standard*) and the *Design Specifications for Highway Route* (hereinafter referred to as the *Specification*). The *Standard* specifies only the principal policy and is used for primary issues, whereas the *Specification* applies to the detailed technical parameters for alignment design. The *Specification* is similar to the AASHTO Green Book, but covers only the contents on highway geometric design and route selection without the contents on urban streets.

Seven revisions have been made since the *Standard* was first issued in 1951. The latest amendment came into effect in March 2004. The new edition of the *Specification* has been completed for comments and will be issued soon. In both the latest *Standard* and *Specification*, key issues have been changed such as highway classification, capacity, level of service, design speed and operating speed. The interrelationships among these issues have been improved.

This paper focuses on the concepts and technical parameters that directly impact on highway alignment design in China.

2. HIGHWAY CLASSIFICATION

The functional classification of highways as arterial, collector and local is accepted world-wide. However, systems of classification according to technical standards differ amongst countries.

It has long been practice in China to classify highways into five grades from one to five. Since 1997, the functional classification was emphasised in the *Standard*. Highways are thus classified as arterials (expressways, grade-one and grade-two highways), collectors (grade-three highways) and locals (grade-four highways).

It is noteworthy that in the *Standard* (1988) there is the concept and practice of classifying highways as those used exclusively for automobiles and those for common use. In the 1980s, highways were constructed for mixed traffic due to a lack of contract investment. The problems caused by mixed traffic were so serious that construction of a highway exclusively for automobiles was proposed. Only the width of the new highway was different, and other technical parameters were the same as the common grade-two highway.

Table 1. Highway classification and design speed (km/h).

Class / Standards	Expressway				Grade-One			Grade-Two		Grade-Three		Grade-Four	
JTG B01-2003	120	100	80	-	100	80	60	80	60	40	30	20	
JTJ 001-97	120	100	80	60	100	60	-	80	40	60	30	40	20
JTJ 001-88	120	100	80	60	100	60	-	80	40				
	Highway exclusive for automobiles												
								80	40	60	30	40	20
								Common highway					
JTJ 001-81	120	100	80	60	100	60	-	80	40	60	30	40	20
Design speed is graded according to the terrain types from flat, rolling, hilly to mountainous. Four **Standards** were issued respectively in 2003,1997,1988 and 1981.													

Highways exclusively for automobiles were considered mainly for the following conditions: 1) a high traffic volume of non-motorised vehicles and slow trucks (and tractors, etc.), which has a serious impact on automobiles; 2) a high automobile traffic volume and the difficulty of meeting the demands of mixed traffic; 3) when conditions do not require the building of grade-one highways because of the small traffic volume predicted for the future. However, there are two sides to this argument. Although highways exclusively for automobiles can eliminate vertical interference through traffic management, they cannot eliminate horizontal interference, as embankments might have to be raised and at-grade intersections might have to be switched to grade-separated junctions, which would result in increased cost of the project. This would go against the original idea. In addition, such a highway may raise some other questions as well, such as safety. The idea of a highway exclusively dedicated to automobiles was ultimately dropped.

3. DESIGN SPEED AND OPERATING SPEED

1) *Design speed*: Two methods are in current use to determine the design speed for alignment. One is the operating speed method adopted by Australia, France, Germany, etc., and the other is the design speed method widely adopted by many other countries, including China. In China, each section of the highway can use its own design speed as the minimum speed. Once it is fixed, all of the pertinent features of the highway should be related to the design speed to obtain a balanced design.

The design speeds of expressways, grade-two highways and grade-three highways in the new *Standard* have been changed (Table 1). Minimum design speeds of expressways and grade-two highways have been increased from 60 km/h to 80 km/h and from 40 km/h to 60 km/h respectively to ensure a high speed. However, the maximum design speeds of grade-three and grade-four highways have been decreased because of the lateral disturbance by mixed traffic and the factor of operating speed, which tends to be higher than the design speed when conditions permit. All the above indicate that the concept of design speed in China is not just a pure concept, as it takes into account operating speed as well.

2) *Operating speed*: The operating speed is determined by the 85th percentile speed on a given section of a highway. Compared to the design speed, it is the actual speed at which the driver is driving. According to research, when the design speed is lower than 80 km/h, the operating speed will be higher than the design speed; and if the difference between the two speeds reaches 10 km/h, accidents are more likely to occur. However, the operating speed is not always consistent with the design speed. Thus, potential dangers may occur on some sections of the highway.

Only minimum design speed is stipulated in the *Standard* before 2003. It does not stipulate design parameters corresponding to higher speeds. In fact, if possible, drivers always attempt to drive at a higher speed. The trend of adopting a maximum design speed for lower grade highways is just to ensure the continuity and rationality of geometric design and driving security. The change in the new *Standard* can solve the problem of disagreement between design parameters and travelling requirements, in addition to increasing the security and smooth operation of highways.

4. DESIGN VEHICLES

In the *Standard* before 2003, two kinds of conversion system are used to calculate traffic volume: (1) the traffic volume in passenger car units (pcu), which is adopted for expressways and grade-one highways; (2) the traffic volume of medium-size trucks, which is adopted for the rest of the highway grades.

In the new *Standard* (2003), common vehicles on highways can be classified as passenger cars, medium-sized vehicles, large-sized vehicles and trailers, depending on the vehicle operation characteristics (operation speed and overall standard deviation) and taking into account the wheelbase and the structural characteristics. Studies have shown that the new classification of vehicles has many advantages. For the same type of vehicle, the operation speed is steady. For different types of vehicles, the operation characteristics are obviously different. In the new *Standard* (2003), traffic volumes on all grades of highway are calculated in pcu. Table 2 gives the equivalent factors for various types of vehicle.

Table 2. Typical vehicle types and their equivalent factors.

Vehicle Type	Equivalent Factors	Comments
Passenger car	1.0	Passenger car with seats not more than 19, truck with load not more than 2t
Medium-size vehicle	1.5	Passenger car/bus with seats more than 19, truck with load more than 2t and less than or equal to 7t
Large-size vehicle	2.0	Truck with load more than 7t and less than or equal to 14t
Trailer	3.0	Truck with load more than 14t

5. LEVEL OF SERVICE (LOS)

The concept of level of service was first put forward in the *Standard* (1997). According to the *Highway Capacity Manual* (2001, AASHTO), levels of service can be classified as four grades, namely first, second, third and fourth level. The first level in the *Standard* corresponds to level A or B in the USA, the second level is equal to level D and the fourth level corresponds to levels E or F.

The *Standard* (2003) defines the level of service, which is related to service degree in respect of speed, comfort and economy based on traffic flow conditions. In other words, it is the level road users can expect under certain traffic conditions. The level of service is usually described and measured by speed, traffic density, freedom in the degree of driving, comfort, convenience, etc. In terms of traffic flow conditions, the level of service can be also classified as four grades. However, the key parameters used for weighing the level for each grade are different because of the different facility types of highways. The main parameter are shown in Table 3.

Table 3. Different oarameters of highways.

The establishment of highways	The value parameter of level of service
Expressway and grade-one Basic sections The junction of ramp and main road Weaving sections	Density (pcu/h/n) and (v/c) ratio Density and traffic volume (pcu/h) Vehicle stream density (km/h)
Sections of grade-two and grade-three two-lane highways	Delay ratio (%) Average journey speed (km/h)
Sections of grade-one highway	Density ratio (km/h), (v/c)
At-grade intersections without signal control At-grade rotary intersections	Delay(s)

The selection of the level of service is needed not only to guarantee essential driving quality but for the cost of projects.

6. TRAFFIC CAPACITY

Basic traffic capacity, possible traffic capacity and design traffic capacity are the three major types used for theoretical analysis and application. These definitions have been adopted in the new *Standard* (2003). In this Standard, the statistical analysis model based on the actual survey data of speed, flow, etc. is used to ensure the basic traffic capacity of various grades of highways. The minimum traffic capacity that may lead to bottlenecks is also analysed.

Since the standard vehicle has been changed in the new *Standard*, the traffic capacity of grade-two, grade-three and grade-four highways has changed greatly compared to the previous *Standard*. A comparison of the traffic capacity is provided in Table 4. It is obvious that the standard for traffic capacity has become more detailed. The 1988 version of the *Standard* only stipulated design traffic capacity for various grades of highway, whereas the version of 1997 increased the number of new values corresponding to different expressway lanes. Moreover, the new version stipulates the design traffic capacity of different lanes for various grades of highways.

Table 4. Traffic capacity of various grades of highways.

Technical Standards		Expressway									Grade-One Highway					Grade-Two Highway		Grade-Three Highway		Grade-Four Highway	
JTG B01-2003	Design Speed (km/h)	120			100			80		—	100		80		60	80	60	40	30	20	
	Number of lanes	8	6	4	8	6	4	6	4	—	6	4	6	4	4	2		2		2	1
	AADT (thousand)	60 ~ 100	45 ~ 80	25 ~ 55	60 ~ 100	45 ~ 80	25 ~ 55	45 ~ 80	25 ~ 55	—	25 ~ 55	15 ~ 30	25 ~ 55	15 ~ 30	15 ~ 30	5 ~ 15		2 ~ 6		<2	<0.4
		The calculation of annual average daily traffic depends on the passenger car unit																			
JTJ 001-97	Design Speed (km/h)	120			100			80		60	100		60		—	80	60	40	30	40	20
	Number of lanes	8	6	4	4						4				—	2		2		2 or 1	
	AADT (thousand)	60 ~ 100	45 ~ 80	25 ~ 55	25 ~ 55						15 ~ 30				—	3 ~ 7.5		1 ~ 4		<1.5	<0.2
		The calculation of annual average daily traffic depends on passenger car unit														The calculation of annual average daily traffic depends on medium-sized truck					
JTJ 001-88	AADT (thousand)	>25									10 ~ 25					2 ~ 7					
		The calculation of annual average daily traffic depends on passenger car unit																			
	AADT (thousand)															2 ~ 5		<2		<0.2	
																The calculation of annual average daily traffic depends on medium-sized truck					

7. MAIN PARAMETERS FOR ALIGNMENTS

For the geometric design of highways in China, the main horizontal control parameter includes the following: minimum radius of various circular curves, minimum length of the transition curve, superelevation and overtaking sight distance. The main vertical control parameter includes: maximum longitudinal gradient, minimum grade length, maximum grade length, maximum length and radius of the vertical curve. In the past, the *Standard* and *Specification* stipulated the same parameter regardless of highway grade. In particular, the *Standard* stipulated all parameters based on design speed while the *Specification* was based on the grade of highways and their terrain. However, this was improved. Each parameter is listed according to the same form in the latest *Standard* and *Specification*. The following part discusses the design parameters that have been changed, namely circular curve without superelevation and minimum grade length.

7.1 Circular radius without superelevation

The value for circular radius without superelevation is revised in the *Standard* (2003) in order to treat properly situations of a crown slope of more than 2%. The details are shown in Table 5.

Table 5. Minimum circular radius.

Design speed (km/h)		120	100	80	60	40	30	20	Comments*
Minimum radius without superelevation (m)	Crown ≤2%	5500	4000	2500	1500	350	150	600	If Crown=1.5%, f=0.035; if crown =2.0%, f=0.040
	Crown > 2%	7500	5250	3350	1900	450	200	800	If Crown=2.5%, f=0.040; if crown=3.0, f=0.045; if crown=3.5%, f=0.050

* f – side friction coefficient, i – crown slope .

7.2 Minimum grade length

The minimum grade lengths in the *Specification* (1994) have proved reasonable. However, in some areas, they seem not to be long enough. Thus, the common grade length was stipulated in the new *Specification*. All values are based on the statistical analysis of data of the related projects completed or under construction in China. New values are shown in Table 6.

Table 6. Minimum grade length.

Design speed (km/h)		120	100	80	60	40	30	20
Minimum grade length (m)	Common	400	350	250	200	160	130	80
	Exceptional	300	250	200	150	120	100	60

8. APPROACH TO INTERSECTION AND INTERCHANGE DESIGNS

Some of the changes to the design of intersections and interchanges in the new *Specification* are described as follows:

1) *Channelisation*: This is an important measure to solve problems such as traffic capacity and safety of intersections owing to the rapid increase in traffic volume in China. In the new *Specification*, the channelisation issue is emphasised: a distinction is made between unchannelised and channelised intersections according to their structures. However, intersections are classified in the *Specification* (1994) as a “T” type or “Y” type of intersection, a cross-road and roundabout intersection according to their geometrical shape. Generally, the unchannelised intersection classification is applied to an intersection with two-lane intersecting roads where both design speed and traffic volume are low; the channelised intersection is proposed for an intersection with high grade intersecting roads or high traffic volume.

2) *Sight Distance*: To avoid vehicle collisions, the stopping sight distance is increased in the new *Specification* based on the intersection sight distance in the 1991 *Specification* (including stopping sight distance and ramp sight distance). The new *Specification* points out that in some cases stopping sight distance requirements for intersecting roads cannot be satisfied, so the requirements can be down-graded. However, the safe stopping sight distance requirements of intersecting roads should be satisfied. The new *Specification* recommends a distance that ensures safe driving and exact judgment of access positions on ramps. Generally, sight distance is included in safety design.

3) *Roundabouts*: Because some existing roundabouts have serious problems of operation and safety, "yield-at-entry roundabouts" are recommended in the new *Specification*. As Figure 1 indicates, road markings are used to regulate driver behaviour at the entries to roundabouts. In China, the diameter of the centre islands of roundabouts should be more than 10 m. The minimum size is 5 m as in Australia. The length of the waiting lane is 25 m, and its width at the stop mark is 3.0 m. The jumping-off length of the increased lane is 2.5 m. Compare this with other countries where vehicles are mainly passenger cars. The values mentioned above are increased by 0.5 m.

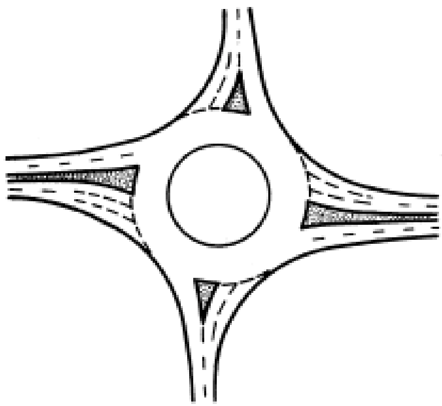

Figure 1. Yield-at-entry roundabout.

4) *Traffic islands*: Traffic islands are an important aspect of channelising design. In the 1994 *Specification*, traffic islands are composed of channelisation islands and refuge islands. However, after considering the prevalent classification, islands can be classified as dividing islands and channelisation islands. The new *Specification* stipulates the alignment and design details of the common traffic islands. The alignment of common traffic islands mainly depends on the alignment of the adjacent lane. According to the structure, traffic islands are divided into three kinds: the kerbed isolated island, the latent island and the shallow dish island. The use of the isolated island and the latent island in China is different from that in other countries. In China, isolated islands are always used on four-lane highways, while latent islands are used on two-lane highways. This is because isolated islands on two-lane

highways are apt to lead traffic jams and can be damaged easily. Thus, two-lane highways should use latent islands.

5) *Interchange type*: In the new *Specification*, highway interchanges are clearly classified according to system interchanges for connection between expressways and service interchanges for the rest. Obviously, this classification is the same as its counterpart in the AASHTO Green Book and will guide the correct selection of interchange type in China.

6) *Ramps*: In the new *Specification*, a speed change on ramps is definitely recommended. It also stipulates the definition of design speed, namely the maximum safe speed that every section can guarantee. The basic type of cross-sections include: one-lane ramps, two-lane ramps without emergency parking strips, two-lane ramps with emergency parking strips and two-direction separate two-lane ramps with emergency parking strips. Two-lane ramps with emergency parking strips and the transition methods of interchange entrances and exits are new in the new *Specification*.

The new *Standard* emphasizes that horizontal alignment should be suitable for speed change. Meanwhile, the new *Standard* stipulates the length of convoluted lines of ramps. In the new *Specification*, the value of the longitudinal gradient has been changed (Tables 7 and 8).

Table 7. Longitudinal gradient in the specification (1994).

Design speed of ramp (km/h)	Common area (%)	Snow and frost area (%)
80	4	5
60	5	6
50	5.5	6
≤40	6	-

Table 8. Longitudinal gradient in the new specification.

<table>
<tr><td colspan="3">Design speed of ramp (km/h)</td><td>80, 70</td><td>60, 50</td><td>40, 35, 30</td></tr>
<tr><td rowspan="4">Maximum longitudinal gradient (%)</td><td rowspan="2">Exit</td><td>Upgrade *</td><td>3</td><td>4</td><td>5</td></tr>
<tr><td>Downgrade</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td rowspan="2">Entry</td><td>Upgrade *</td><td>3</td><td>3</td><td>4</td></tr>
<tr><td>Downgrade</td><td>3</td><td>4</td><td>5</td></tr>
</table>

The length of the speed-change (acceleration/deceleration) lane stipulated in the 1994 *Specification* is the same as in Japan and Germany, but shorter than in many other countries. It proved insufficient and caused problems especially on expressways with high traffic volumes. Therefore, the new *Specification* increases the length of the speed change lane.

7) *Nose*: Curve parameters at the nose (area around merging or diverging points of interchanges) are stipulated in detail. According to US and German values, the nose radius in China is larger than before. The new *Specification* also considers the sharp transition of the exits of older expressways. All the values are shown in Table 9.

Table 9. Minimum radius and length of vertical curves nearby nose.

Design speed of main road (km/h)			120	100	80	60
Minimum radius of vertical curve (m)	Convex	Common	3500(2000)	2000(1800)	1600	900
		Exceptional	2000(1400)	1400(1100)	800	450
	Concave	Common	2000(1500)	1500	1400	900
		Exceptional	1500(1000)	1000(850)	700	450
Minimum length of vertical curve (m)		Common	90(70)	75(65)	60	40
		Exceptional	60(50)	50(45)	40	35

Values in brackets are stipulated in the 1994 *Specification*.

9. DESIGN CONSISTENCY

Design consistency has been accepted in China recently. In the highway alignment policy in China, the following guidelines are available in practice:

- Operating speed difference between any adjacent sections should usually be less than 15% or 10%, and not more than 20 km/h.
- The lengths of sections with different design speeds along a highway should be long enough.
- For the junction between sections with different design speeds, the main technical parameters should transit gradually in accordance with the terrain so as to make horizontal and vertical alignments well-balanced and a avoid break.

10. SUMMARY AND CONCLUSIONS

The technical approaches used for highway alignment design in China were carefully examined and the new changes for the concepts and technical parameters were stressed using the information of the newly amended *Standard* and *Specification*. The changes in the new versions of the two codes will definitely impact highway alignment design in the future.

These changes are summarized as follows:

- Both technical and functional classifications of highways will certainly benefit the selection of the grade of highways and provide more flexibility in design.
- Design parameters and their relationships are discussed for a better understanding of highway selection. These parameters include design speed, operating speed, level of service, traffic capacity, standard vehicle and vehicle equivalent factors.
- Some key alignment parameters such as circular radius and length of grade have been revised or adjusted.
- The contents for at-grade intersections and interchanges have been greatly changed. It is believed that the updated policies will be able to guide practical design better than before.
- Some new design concepts such as operating speed and design consistency are accepted and are being used preliminarily in practice.

11. REFERENCES

[1] Chen Shengying, Wang Yagan, Zhang Jianfei, 2000. Guide for Highway Design. People's Communications Press, China.

[2] Hoffman S., Kölle M., 2000. New Standard Design Vehicles for Road Design in Germany. Proc. 2nd International Symposium on Highway Geometric Design, p313-326.

[3] Kempa J., Szczuraszek T., 2000. Design Speed, Actual Speed and Road Designing. Proc. 2nd International Symposium on Highway Geometric Design, p352-363.

[4] Krammes R. A., Garnham M. A., 1995. Worldwide Review of Alignment Design Policies. Proc. 1st International Symposium on Highway Geometric Design, paper No.19.

[5] Ministry of Communications, China, 1981. Technical Standard of Highway Engineering (JTJ 01-81). People's Communications Press, China.

[6] Ministry of Communications, China, 1988. Technical Standard of Highway Engineering (JTJ 01-88). People's Communications Press, China.

[7] Ministry of Communications, China, 1994. Design Specification for Highway Route (JTJ 011-94). People's Communications Press, China.

[8] Ministry of Communications, China, 1997. Technical Standard of Highway Engineering (JTJ 001-97). People's Communications Press, China.

[9] Ministry of Communications, China, 2003. Design Specification for Highway Route (revised for comments now). People's Communications Press, China.

[10] Ministry of Communications, China, 2003. Technical Standard of Highway Engineering (JTG B01-2003). People's Communications Press, China.