UPGRADE OF THE MEXICAN STANDARDS FOR THE GEOMETRIC DESIGN OF HIGHWAYS

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ABSTRACT

In its origins, the standards for the geometric design of highways worldwide were generated from assumptions related to the conditions under which the vehicular operation would be adequate and safe, as well as from a series of field tests aimed at studying the vehicular behavior for the vehicles and conditions prevailing at that moment. Thus, the first manuals and norms incorporated many assumptions but very little experience on the real behavior of the vehicles operating in the highways.

In Mexico, the existing manuals and norms were elaborated more than 30 years ago, reason why they incorporate a great amount of assumptions and very few experiences on real vehicular behavior. Also, with the passing of the years, the vehicles and the conditions prevailing have varied significantly.

In this work some key recommendations for upgrading the Mexican standard for the geometric design of highways, are presented. The recommendations were generated from the comparison of the Mexican standard with standards of some more advanced countries in the matter as well as from the most recent studies and world approaches, particularly the Mexican ones on different safety aspects.

1. INTRODUCTION

In its origins, the standard for the geometric design of highways worldwide was generated from assumptions related to the conditions under which the vehicular operation would be adequate and safe, as well as from a series of field tests, many of them carried out by AASHO [1], aimed at studying the vehicular behavior for the vehicles and the conditions prevailing at that moment. Thus, the first manuals and norms incorporated many assumptions but very little experience on the real behavior of the vehicles operating in the highways.

In Mexico, the existing manuals and norms for the geometric design of highways were elaborated more than 30 years ago [2,3], reason why they incorporate a great amount of assumptions and very few experiences on real vehicular behavior. Also, with the passing of the years, the vehicles and the conditions prevailing (i.e. the economic and vehicular activity) have varied significantly. For this reason, it is inadequate to continue designing the highways with basis on those manuals and norms, being required an upgrade of them therefore.

In this work some key recommendations for upgrading the Mexican standard for the geometric design of highways, are presented. The current standard is contained fundamentally in the Norms of Technical Services for the Geometric Design of Highways [2] and in the Manual for the Geometric Design of Highways of the Secretary of Human Settlements and Public Works (SAHOP) [3].

The recommendations were generated from the comparison of the former documents with standards of some more advanced countries in the matter [4,5] as well as from the most recent studies and world approaches, particularly the Mexican ones on basic safety aspects for the geometric design of highways [6,7].

Although in connection with some aspects no specific upgrade recommendation is made, some definitions and concepts are described such as they were considered appropriate and adopted.

2. KEY RECOMMENDATIONS

2.1. New Aspects Included

The need to upgrade the approaches in the Mexican standard for the current conditions makes it possible to incorporate in its content, aspects that 30 years ago did not exist or were less outstanding but that now are vital, such as the carrying out of road safety audits to minimize the possibility of design errors that can be source of accidents; the carrying out of environmental impact studies to mitigate possible damages to the environment derived from the highway; and the use of intelligent transportation systems (ITS) to improve traffic smoothness, safety, reliability and comfort to the users during operation of the highway.

2.2. Design Standard Selection

It is proposed that one of the first things to carry out (during the road planning stage) is the selection of design standard for the highway. This is the geometric level of quality according to a set of specific geometric standards, to which the highway is to be designed and built. The higher the design standard, the safer the road will be. The highest design standard corresponds to freeways.

Some of the most important specific factors to consider in the selection of design standard for a highway are its functional category, the traffic volume at the end of its economic horizon (i.e. 30 years), the land type, the design speed, as well as considerations regarding capacity, economic efficiency, safety and environmental impact.

A study that applied statistical models to 5,287 horizontal curves which had speed differences from adjacent curves along 291 stretches of highway, was carried out. This study examined a total of 1,747 collisions in a three-year period. It considered nonintersection accidents –single vehicle run-off-the-road, collisions between vehicles travelling in the opposite direction, and between those travelling in the same direction. Differences between the 85th percentile operating speeds of successive alignment features (e.g., curves) were used to define good, fair and poor design. The highest accident rate was with poor, and the lowest with good designs. The poor curves had six times the accident rate of good curves. In the other words, those designs requiring drivers to make the greatest speed change from one curve to the next were most dangerous. It was concluded that the most promising measures of design consistency are:

- Predicted speed reduction by drivers on horizontal curves relative to the preceding curve or tangent.
- Average radius of curvature on a roadway section.
- Average rate of vertical curvature on a roadway section.
- Ratio of an individual curve radius to the average radius for the roadway sections as a whole.

2.3. Access Control

It should be looked for to guarantee that the access control consistent with the design standard chosen for the highway will be attained during operation. Access control refers to the restriction level established by the authority to the entry to the highway, of traffic coming from others, including intersections, public and private roads and U-turns. In a highway, the access control can be total, partial or nonexistent. Total control corresponds to the highest design standard.

Access control is the factor that affects the most by itself the safety of a highway. The accident rate increases quickly with the density of accesses. In most of the highways, of course, it is not possible or significant to eliminate the access, although its negative effects can be moderated by reducing the conflict in the access points. It is recommended to control the access, whenever it is possible, in those roads that transport the heaviest traffic flows, or that connect main activity centers, and/or are main regional arteries.

An analysis of all police reported crashes in 2009 found that 7 percent of the about 500 thousand accidents were left-turn across path (LTAP) crashes. Of these, 51.2 percent occurred at signalized intersections. The remaining occurred at nonsignalized intersections. This type of accident occurs when a subject vehicle (SV) strikes or is struck by an oncoming or principal other vehicle (POV). SV attempts to turn left across oncoming traffic. Independent of driver fault, SVs tend to be involved in more accidents at lower speeds (i.e., 0 – 35 km/h), whereas the POV involvement in accidents is at somewhat higher speeds (i.e., 36 – 75 km/h). More males (58 percent) than females (42 percent) were involved in LTAP crashes which occurred predominately in daylight (73 percent), in nonadverse weather (86 percent) and on dry pavement (80 percent). The majority of LTAP accidents occurs at intersections where the speed limit is 60 km/h or greater.

Police-reported crashes, normalized across vehicle and population densities, are highest in urban areas. Such accidents appear likely to increase with miles traveled and as urban population growth increases. Of the crashes in urban areas, 56 percent occurred at intersections. Of these, 63 percent were at signalized intersections. Unfortunately, police reports did not indicate whether signals were red, yellow, or green when these crashes occurred. Such information would assists in signal adjustment and countermeasure design.

2.4. Functional Classification of the Highways

As an old standard, the classification of highways for geometric design purposes in the current Mexican standard is based on the annual average daily traffic (AADT). It is desired now, like in any modern standard, to put a functional classification before any other one with the purpose of defining in the first place the function wanted for the road in the context of the national road network. In that sense, the following functional classification is being proposed:

2.4.1 *Primary or trunk roads*

These are segments of main national corridors that connect important population centers, generally of more than fifty thousand (50 000) inhabitants, whose activities generate or attract trips of long itinerary. In turn, they are subdivided into:

- Freeways (F). Highways of traffic directions divided physically by a median, total access control, two (2) or more lanes per direction and design speed in the range of eighty (80) km/h to one hundred and ten (110) km/h. Their AADT is larger than five thousand (5 000) vehicles.

- Express Roads (ER). Highways of traffic directions divided physically by a median, and design speed in the range of eighty (80) km/h to one hundred and ten (110) km/h; and that in connection with one or several of the other elements (access control, number of lanes per direction, etc) it does not fulfill the standards of the freeways. Their AADT goes from three thousand (3 000) to five thousand (5 000) vehicles.

- Arterials (AR). Two-lane highways with partial access control and design speed in the range of seventy (70) km/h to one hundred and ten (110) km/h. Their AADT goes from one thousand five hundred (1 500) to three thousand (3 000) vehicles.

2.4.2 *Secondary or Collector Roads (C)*

These are roads that connect medium or small population centers with the nodes of the primary network, which supply a great proportion of the trips of medium and short itinerary. They are two-lane highways with partial access control and design speed in the range of sixty (60) km/h to one hundred (100) km/h. Their AADT goes from five hundred (500) to one thousand and five hundred (1 500) vehicles.

2.4.3 *Feeder Roads*

These are roads used for trips of very short itinerary. They are subdivided into:

- Local Roads (L). Two-lane highways without access control and design speed in the range of fifty (50) km/h to eighty (80) km/h. Their AADT goes from one hundred (100) to five hundred (500) vehicles.

- Dirt Road (Dr). Unpaved one-lane roads without access control and design speed in the range of thirty (30) km/h to seventy (70) km/h. Their AADT is lower than one hundred (100) vehicles.

The previous classification has also the advantage that its six categories (F, ER, AR, C, L and Dr) are homologated with the six categories (ET4, ET2, A, B, C and D) of the Mexican truck size and weight regulation [8].

2.5. Terrain Type

As an old standard, the current Mexican standard considers three terrain types (flat, rolling and mountainous). For the new standard, the three terrain types are defined in terms of the horizontal and vertical alignments of the highway and of the possibilities of the heavy vehicles for circulating on them.

2.6. Design Speed

It is the minimum speed along a highway for which the segments designed with the most restraining standards allowed for that speed (minimum curvature radius, maximum grade, etc) are to be prepared. In other words, the design speed is a choice which should be consistent with the highway functional category, and which is used to determine the different geometric design elements of the road.

The current Mexican standard specifies very wide ranges of design speed for each highway type. For the new standard, narrower ranges are proposed for each category, with the purpose of preventing strong variations of design speed along a highway, which are usually an important source of accidents. Table 1 shows the range of design speed proposed for each highway category of the functional classification. The lower value in each range corresponds to the most unfavorable condition in mountainous terrain and the higher value to the most favorable condition in flat terrain.

The design speed is to be selected based on an economic sensitivity analysis carried out during the road planning study, considering several speed options within the corresponding range, making intervene in this analysis the highway construction and maintenance costs, the vehicle operating costs and all other generated costs (congestion, accidents, environment, etc).

TABLE 1 Range of Design Speed Proposed for each Highway Category

Category	Design Speed (km/h)	AADT (vehicles)	Function within the network
Freeways (F)	80 to 110	Greater or equal than 5 000	Primary Road
Express Roads (ER)	80 to 110	3 000 to 5 000	Primary Road
Arterials (AR)	70 to 110	1 500 to 3 000	Primary Road
Collector Roads (C)	60 to 100	500 to 1 500	Secondary Road
Local Roads (L)	50 to 80	100 to 500	Feeder Road
Dirt Roads (Dr)	30 to 70	Lower than 100	Feeder Road

Studies conducted have found that higher speed (60 km/h or more) may be underestimated on curves. Those driving with passengers, those with over eleven years experience, and those who were aged 31 to 50, significantly underestimated their speeds. Younger drivers are more accurate with their speed estimations. Underestimation of speed on road curves may be a factor in vehicle accidents at these locations.

2.7. Reliability and Consistency

It is suggested to incorporate the concepts of reliability and consistency in the geometric design of highways, with the purpose of making compatible the design speed selected for a highway with the speed desires of the users as it has been observed that significant differences between these two aspects is usually an important source of accidents.

Reliability R is the probability P that the speed wanted by driver Y will be greater or equal than the speed X offered by the design elements of the highway, this is:

$$R = P[Y \leq X] \qquad \text{Eq. 1}$$

Reliability R is also the difference of one minus the probability that a driver exceeds the design speed offered by a specific design element.

A set of tools (tables and graphs) are to be provided for selecting, for a certain reliability level, the corresponding design element (stopping sight distance, passing sight distance, curvature radius, superelevation rate, grade, etc.). By way of example, Figure 1 depicts the graphs of reliability versus curvature radius for primary, secondary and feeder roads.

Consistency refers to the difference of tolerable reliability between successive segments of the highway.

The approach consists in that the designer will generate a design alternative for the highway and then will make the corresponding revisions so that in no place reliability is smaller than a certain percentage value (i.e. 90%) and that the difference of reliability between successive segments is not greater than another percentage value (i.e. 10%).

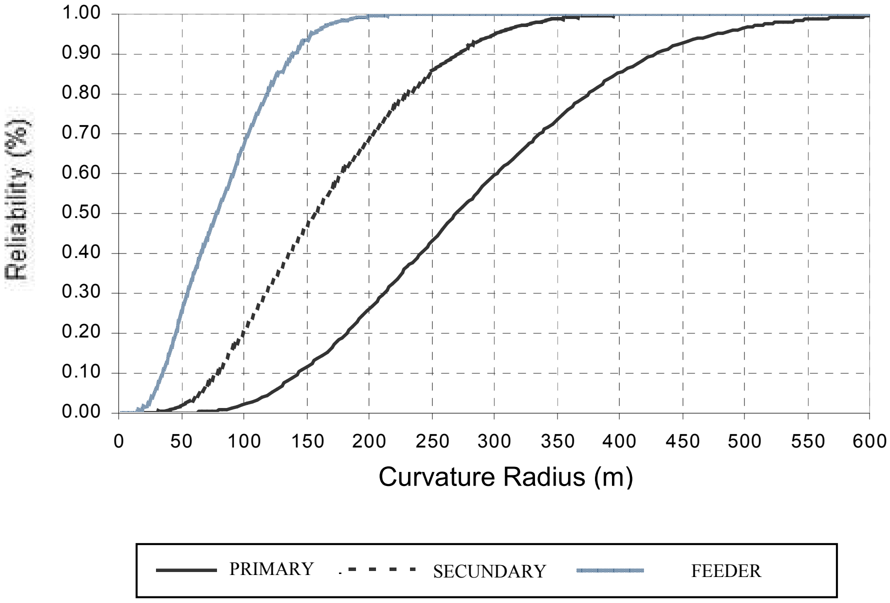

FIGURE 1 Reliability versus Curvature Radius for Primary, Secondary and Feeder Roads

2.8. Design Vehicles

From a series of field measurements carried out, Table 2 shows the characteristics of the design vehicles that are representative of the vehicles currently circulating on the Mexican national highways. The minimum turning radius for the largest of these new vehicles (DE-2970) is 15% higher than the minimum turning radius of the largest vehicle in the current Mexican standard (DE-2520). Figure 2 depicts the geometric characteristics of new design vehicle DE-2970.

In addition, the following should be considered in the selection of the design vehicle to use for the design of the different highway categories in the functional classification:

- The vehicles with the largest space requirements that travel on the primary highways (freeways, express roads and arterials) are those represented by the DE-2970.

- The vehicles with the largest space requirements that travel on the secondary highways (collectors) are those represented by the DE-1890.

- The vehicles with the largest space requirements that travel on the feeder highways (local and dirt roads) are those represented by the DE-760.

It is perhaps obvious that drivers of smaller vehicles (e.g., compact cars) are at greater risk in a collision than are drivers of larger ones (e.g., trucks and vans). Injury insurance claims and fatality records have been reviewed in order to determine the effects of vehicle size on accident severity. Injury claims per insured vehicle were about 60 percent greater for small as compared with large cars (2009 data), and likelihood of a fatality in a 500 to 900 kilogram car in collision with a 1,800 a 2,400 kilogram car was 7.04 times greater for occupants of the smaller car.

The dramatic increase over the past decade in the numbers and proportion of light trucks, sports utility vehicles (SUVs) and vans on the road has also put car drivers at a disadvantage in collisions. The overall accident picture, in terms of size differences is likely more serious now for occupants of small vehicles, since there are so many more LTVs and SUVs on the roads in recent years.

A confounding factor in all such comparisons is the difference in the driving behavior and possibly the age and experience of drivers of different size vehicles. Smaller cars are more likely to be driven by young drivers, who are less experienced and take more risks, and smaller cars are driven more in urban areas. Small trucks and SUVs appeal to younger, possibly more aggressive, drivers.

2.9. Stopping Sight Distance

As an old standard, the current Mexican standard computes the stopping sight distance from the running speed, assuming that this is on average 0.875 of the design speed. It also considers a perception and reaction time of 2.5 seconds.

For the new standard, it is recommended to compute the stopping sight distance from the design speed and by considering a perception and reaction time of 4 seconds. This latter value comes from a recent human factor study showing that the driver requires from 4 to 6 seconds for adapting to a new situation that requires him to stop [9].

A study was carried out to obtain perception-response times from passing drivers by erecting an unusual sign over a hill crest. The sign read “Speed Check Ahead”. Times were measured from first possible sighting of the sign until the break lights came on. Only about a quarter of passing vehicles braked in response to the sign. This could mean a number of things, including that the situation was not one that majority of drivers viewed as urgent. The average response time for those who did brake was 3.4 seconds. The 85th percentile was 4.9 seconds. Smith felt that reading the sign required about one second and that this should be deducted from the total times. When the individual has detected and read the sign, however, this represents the end of the identification interval. All that remains is decision and response seems greatly excessive for an emergency situation, particularly when the only viable option is to brake.

TABLE 2 Characteristics of the New Proposed Design Vehicles

Characteristics	**Design Vehicles**							
	DE-335	**DE-620**	**DE-750**	**DE-760**	**DE-1890**	**DE-1980**	**DE-2545**	**DE-2970**
Overall Length (L), cm	580	1200	1360	1209	2088	2241	2740	3166
Wheelbase (WB), cm	335	620	749	762	1890	1982	2545	2971
Front Overhang (FO), cm	92	236	240	127	122	122	119	119
Rear Overhang (RO), cm	153	344	371	320	76	137	76	76
Overall Width (W), cm	214	255	260	244	259	259	259	259
Track Width (TW), cm	183	230	230	244	244	244	244	244
Trailer Length (TL), cm	-	-	-	-	1463	1615	1006	1219
Overall Height (H), cm	167	354	380	410	410	410	410	410
Height of the Driver's Eye, (Hde), cm	107	212	232	250	250	250	250	250
Height of the Front Lights (Hfl), cm	61	81	110	112	112	112	112	112
Height of the Back Lights (Hbl), cm	61	154	140	100	100	100	100	100
Angle of Deviation of the Headlights	1°	1°	1°	1°	1°	1°	1°	1°
Minimum Turning Radius, cm	732	1267	1359	1572	1372	1372	1372	1572
Average weight/power ratio, kg/hp	15	180	210	210	210	210	210	210
Vehicle Type	Passenger Car	Intercity Bus		Single Unit Truck	Truck Tractor-Semitrailer Combination		Truck Tractor Semitrailer-Trailer Combination	

The height of the driver's eye is to be upgraded to 1.08 m considering the height of modern vehicles. The height of the object is also to be upgraded to 0.60 m, which practically corresponds to the height of the back lights of the passenger car vehicles.

2.10. Passing Sight Distance

The current Mexican standard computes this distance also from the running speed (0.875 the design speed on average) based on the overtaking AASHTO model and assuming a time of perception and reaction of 3 seconds. This way, this distance, in meters, results about 4.5 times the design speed, in km/h.

For the new standard, it is recommended to compute the passing sight distance from the design speed and by considering a perception and reaction time of 5 seconds. This latter value comes from the same recent human factor study referred to above [9]. This way, this distance, in meters, results about 6 times the design speed, in km/h.

It is also recommended to provide passing sight distance preferably in forty percent of the length of each direction, and distribute this percent the most evenly possible along the direction.

The height of the driver's eye and the height of the object are to be upgraded both to 1.08 m, considering the height of modern vehicles.

2.11. Decision Sight Distance

This sight distance is the necessary minimum distance so that a driver traveling at the design speed can maneuver in advance before the presence of a situation whose complexity demands a perception and reaction time larger that those usually required. It is computed and measured using the same approaches than the stopping sight distance (height of the eye of the driver's eye of 1.08 m and height of the object of 0.60 m).

The decision sight distance considers five different degrees of maneuver complexity, each one with a different perception and reaction time. It is suggested to include this sight distance in the upgrades Mexican standard since it is not considered in the current one.

2.12. Sight Distance in Horizontal Curves

The minimum distance m from the center of the internal lane to obstacles inside horizontal curves depends on the degree of curvature and on the sight distance (stopping or passing). For this reason, as the stopping and the passing sight distances are to be upgraded, the values of m should also be upgraded so as to provide only one (stopping sight distances) or both as desired.

The removal of vegetation or other obstacles inside horizontal curves is a profitable measure to improve visibility of horizontal curves of all highway categories.

Perception research on visual illusions has shown that curvature is underestimated for smaller curves lengths, which may explain, in part, why sharp curves and those with little preview (partially obscured) are more hazardous. They are not judged to be as sharp as they really are. A horizontal curve presents difficulties, since it is viewed in perspective from a limited eye height. A bird´s-eye view would lead to more accurate perception of curves. There is a good deal of evidence that accident rates are higher on both horizontal and vertical curves than elsewhere, and that rates increase with increasing curvature.

2.13. Sight Distance in Vertical Curves

For the vertical curves in crest, the K values are to be upgraded for the new stopping sight distances and to allow the driver to see the object of 0.60 m of height without interference of the pavement surface, being the height of the driver's eye equal to 1.08 m.

For the vertical curves in sag, the K values are to be upgraded for the new stopping sight distances and to allow the driver, for the condition of night visibility, to see the pavement surface when being illuminated by the headlights of the vehicle, being assumed a height for the headlights of 0.60 m, a height of the object of 0 m and an angle of divergence of the luminous cone of the headlights of 1°.

2.14. At Grade Intersections

Along the accesses of an intersection there should exist areas free of obstructions that allow the driver to see potentially conflicting vehicles approaching. These specific areas are known as sight triangles.

In the case of intersections without traffic control, the catheti of the arrival sight triangles should be similar to the distance traveled during the perception and reaction time of the driver, plus an additional time to brake or to accelerate, as required, to the design speed of the corresponding access. In the current standard, a perception and reaction time of 2 s and an additional time to brake or to accelerate of 1 s are used, giving a total calculation time of 3 s.

Based on the same recent human factor study referred to above [9], it is proposed to upgrade the length of the catheti for a larger equivalent total time of 5 s for safety reasons. With this larger total time, the length of the catheti will be increased by 33% with regards to their value in the current standard.

Major impediments to sight distances for the detection of hazards and roadway features are hills, curves and vegetation. Hence, warning signs are needed at many locations. Formulae have been established for sight distances based on vehicle speed, assumed driver response time, the roadway coefficient of friction and grade.

2.15. Horizontal Alignment

Important upgrades regarding horizontal alignment are those derived from the smaller ranges of design speed and the new design vehicles recommended for each highway category of the functional classification. The previous elements define the widening, superelevations and length and type for the transitions (mixed or spirals) of the horizontal curves, being the widenings those that experience the largest modifications, derived basically from the larger swept path widths of the new design vehicles.

2.16. Cross Section

The most outstanding recommendations in connection with the cross section and its elements (roadway, lanes, shoulders, median, etc.), are:

- When two or more lanes are required by direction, it is more advisable to have a separate roadway for each direction of travel.

- The most convenient lane width for the most important roads is 3.6 m. Lane widths of less than 3 m contribute to multiple vehicle accidents.

- It is not advisable to provide a circulation width (traveled way) for three lanes and only to paint two. It is more advisable in safety terms, quality of service and cost, to install a third passing lane for one or the other travel direction (i.e. in 10% of the highway length). More detailed recommendations for this type of facilities are provided later on.

- For the most important two-lane two-way highways (express roads and arterials), a 2.5 m wide shoulder is recommended at each side, specifying a minimum width of 1 m at each side for the roads of lower category. In the case of freeways, a minimum external shoulder width of 3 m is recommended for each roadway as well as a 1.5 m width internal shoulder.

It is necessary to have a good surface drainage, since a layer of water as thick as 6 mm can generate hydroplaning by reducing the friction coefficient to near zero, making virtually impossible the braking operations as well as the U-turns. For these reasons, the following is recommended:

- A minimum cross slope of 2% in high category highways (arterials and above) is advised, and of 3% or more in lower category ones.

- It is recommended to increase the minimum cross slope up to 2.5% in high category highways for severe rainfall conditions or where the surface drainage is longer than the width of a lane.

- In divided highways, it is advisable to provide to each roadway the same minimum cross slope toward one side.

There is also a set of recommended cross slopes depending on the surface type (including that of the shoulders).

Bridges, structures and sewers can be significant in terms of their effect in road exit accidents. It is recommended that new bridges be 1.8 m wider than the circulation width (or two 0.9 m wide shoulders). The bridge width should include the total width of the shoulders.

Superior crossings require piles designed against impact. The piles should not be in the borders of the highway. The piles and the extreme supports of the bridge should be far from the circulation lanes.

The bridges should have longitudinal handrails designed to prevent significant deflection in the presence of impacts. Likewise, a stiffness transition from the adjacent barrier toward the initial (final) post of the bridge should be provided.

A study was conducted to examine the relationships between accidents experience and cross-sectional roadway elements, along with accident reductions expected because of related roadways safety improvements. Such elements include lane width, shoulder width, shoulder type, roadside features, bridge width, and median design. It was revealed that accident types related to cross-sectional elements on two-lane roads include run-off-road (including fixed-object and rollovers), head-on, opposite direction sideswipe, and same directional sideswipe. Lane widening can reduce these related crashes by up to 40 percent, shoulder widening can reduce related accidents by up to 49 percent, for addition of 2.5 meter paved shoulders. Improving roadsides can also contribute to a reduction of as much as 44 percent, for a 6.1 meter increase in clear zone, whereas side slope flattening can reduce single-vehicle crashes up to 27 percent, for flattening a 2:1, side slope to 7:1 or flatter. Bridge widening can reduce total bridge crashes by as much 80 percent, depending on the width before and after widening. On multilane roads, wider and flatter medians were associated with a reduced rate of total crashes. Lower-cost multilane design alternatives found to reduce crashes, compared to two-lane roadways, include two-way left-turn lanes, passing lanes, and turnout lanes. Suburban and rural multilane designs found to significantly reduce crashes, compared to two-lane roads, include those roads having two-way left-turn lanes with three or more total lanes.

2.17. Passing Lanes

Recommendations for the geometric design of passing lanes are to be provided in the new standard. These are additional lanes that are added to the conventional cross section of two-lane two-way highways with the purpose of accommodating the slower vehicles and to increase the overtaking opportunities of the faster vehicles, in segments where important restrictions exist to overtaking due to restricted sight distances or to heavy traffic in the opposite direction.

When they are provided in the upward direction of sustained grades, they receive the name of climbing lanes.

Their location in around ten (10) percent of the highway length can provide most of the benefits of the widening to four lanes (two lanes per direction).

It is more convenient to provide a frequent number of short passing lanes along the highway that some isolated long passing lanes.

Their implementation is to be warranted when the passing opportunity along a travel is smaller than thirty (30) percent of the time of that travel.

Appropriate locations for passing lanes include bottle necks (sustained grades), places with high incidence of accidents due to overtaking, locations where their construction cost is low (i.e. cuts and embankments are not required, neither bridges, etc.) and segments with adequate sight distance in the divergence and convergence transitions. Their installation is to be avoided in segments near urban areas, segments that include intersections or segments with a great number of accesses.

In the case of climbing lanes, its beginning should coincide with the site where the upward critical length of grade finishes, and its termination with the site where the vertical point of the curve (VPC) in crest finishes.

2.18. Truck Escape Ramps

Truck escape ramps are facilities aimed at segregating from the traffic flow those vehicles out of control due to overheating, failure or mechanical flaws of the brakes, stopping them safely in appropriate locations outside of the highway.

In Mexico more than 20 truck escape ramps showing a very successful performance, have been implemented in toll freeway. For this reason, it was decided to generate a norm for these facilities, which is already published and into force [10]. This norm presents the detailed warrants and design considerations for these facilities.

2.19. Pedestrian Facilities

Pedestrian deaths represented approximately 25 percent of all traffic fatalities in 2009. Deaths are highest among pedestrians over the age of 65 (older men have highest rate). The age group 0 to 15 accounted for 11 percent of these fatalities, and 68 percent of these were males. The total injuries to pedestrians that year was 50 thousand, which represented about 10 percent of all traffic injuries.

Numerous countermeasures have been used to enhance pedestrian safety. The most effective way to prevent pedestrian accidents is to separate them from vehicles in space or time. The first requires the use of pedestrian overpasses or tunnels, or the prohibition of each of these transportation modes on the others` territory (e.g., no pedestrian of freeways, no vehicles in occupied crosswalks, no right turn on red). Separation in time can be accomplished by providing dedicated movements times at intersections for each road user with the use of appropriate sign and signals. However, the success of these measures depends upon each road user complying with traffic control devices and rules of the road. Failure to comply is the source of many vehicle-pedestrian conflicts. The new standard includes recommendations for the design of these facilities, as well as facilities for other vulnerable road users (cyclists, motorcyclists, etc.).

CONCLUSIONS

In this work some key recommendations for upgrading the Mexican standard for the geometric design of highways have been presented. Such recommendations were generated as a result of considering the vehicles and operating conditions prevailing in the Mexican highways, as well as the state of the art on the matter at the national and international levels.

REFERENCES

1. AASHO (1965). A Policy on Geometric Design of Rural Roads, American Association of State Highway Officials (AASHO), Washington, D.C., USA.
2. DGST (1984). Normas de Servicios Técnicos, Libro 2, Parte 2.01, Proyecto Geométrico, Título 2.01.01, Carreteras. Dirección General de Servicios Técnicos (DGST), Secretaría de Comunicaciones y Transportes (SCT), México, D. F.
3. SAHOP (1977). Manual de Proyecto Geométrico de Carreteras. Secretaría de Asentamientos Humanos y Obras Públicas (SAHOP), México, D. F.
4. AASHTO (2004). A Policy on Geometric Design of Highways and Streets. American Association of State Highways and Transportation Officials (AASHTO), Washington, D.C., USA.
5. DGC (2000). Trazado: Instrucción de Carreteras; Normas 3.1-IC. Dirección General de Carreteras (DGC), Ministerio de Fomento, Centro de Publicaciones 2000, Series Normativas e Instrucciones de Construcción, Madrid, España.
6. Mendoza, A., Quintero F. L. and Mayoral E. F. (2002). Consideraciones de Seguridad para el Proyecto Geométrico de Carreteras. Publicación Técnica No 218, Instituto Mexicano del Transporte, Sanfandila, Querétaro, México.
7. Magallanes, R. (2003). La Implicación del Concepto de Seguridad en el Proyecto Geométrico de Carreteras. Primer Congreso Nacional de Ingeniería Vial, Asociación Mexicana de Ingeniería de Vías Terrestres, A C, México, D. F.
8. DGST (2003). Reglamento de Pesos, Dimensiones y Capacidad de los Vehículos de Autotransporte que Transitan en Caminos y Puentes de Jurisdicción Federal. Dirección General de Servicios Técnicos (DGST), Secretaría de Comunicaciones y Transportes (SCT), México, D. F.

9. Birth, S., Demgensky B. and Aubin D. (2009). Space Perception and Road Design for Vulnerable Road Users (VRU), PIARC International Seminar, Promoting Road Safety for Vulnerable Road Users, Cape Town, South Africa, October.
10. SCT (2009). Norma Oficial Mexicana, NOM-036-SCT 2-2009 Rampas de Emergencia para Frenado en Carreteras. Secretaría de Comunicaciones y Transportes (SCT), México, D. F. http://www.economia.gob.mx/work/normas/noms/2009/036sct209.pdf