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CRITICAL APPRAISAL OF TURKISH AND AMERICAN STANDARDS FOR THE DESIGN OF RURAL HIGHWAY LINKS WITH THE COMPARISON OF BRITISH APPROACH

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Abstract

The choice of design standards for rural highway links is an important issue in road planning and management. They affect directly the road investment and road users´ benefit. This paper is based on the critical appraisal and evaluation of Turkish and American geometric design standards for rural highway link design by taking into account the suggestions from British standards. AASHTO and General Directorate of Turkish Highways (GDTH) design policy suggests critical dimensions of the geometric elements of the design parameters, such as design speed, sight distance, visibility, reaction times and traffic characteristics. These parameters are compared and discussed in detail in terms of their effect on safety, reliability, applicability and construction cost.

Keywords: Highway link design, Geometric design elements, Highway engineering and planning

1. Introduction

In the process of developing road design standards, the various, generally conflicting, requirements and optimum trade – offs must be considered. The technical implications of design standards are already well known. At present the main question is the evaluation of their economic, social and human consequences.

Design standards can be examined in two ways as far as their economic effects are concerned. Firstly, the optimisation of particular layouts or designs by applying cost effectivenes models, secondly, with regard to rationalising budgetary decisions about entire road network by using cost benefit models [1].

Two classified groups may be considered in terms of human implications. Firstly, road safety; this is a domain of action where the effects of road design are the most direct and to which the public reacts in the most sensitive way. Secondly, driver behaviours; both the needs for behavioural aspects when developing road design standards and the effects that design standards exert in terms of actual behavioural models should be taken into account [2].

The share of highways in meeting the transport requirements of Turkey is considerable. Therefore, it is necessary that the construction and improvement of the highways should be realised according to the socio-economic needs and financial powerty of the country.

The main point investigated in this paper is to discuss and make critical judgement to determine the extend and the ways that the design standards developed by AASHTO [3] might and should be used by GDTH. British standards were also looked into to get some different approaches and methods applicable so that the decision process would be more accurate.

The concepts and main design parameters were studied and investigated separately and related recommendations were made.

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2. Design considerations of highway engineering

Highway geometric design deals with the dimensions of those highway features such as alignment, grades, clearances, slopes and sight distances. These features are determined in relation to the present and anticipated character and volumes of the traffic to be served.

The selection of design elements are affected by a large variety of design controls, engineering criteria and project-specific objectives, such as; functional classification of the roadway, required design speed, capital costs for the construction, traffic safety considerations and public involvement. Visible features, capacity and traffic operations, environment, safety performance, social acceptability to highway users are directly affected by the design elements.

2.1 Design speed

The selection of design speed should ensure that visibility, elements of horizontal and vertical curbs, superelevation ,etc are consistent with the expected vehicle speeds on the road. There is always a trade-off among the construction costs, operating costs and environmental costs for various design speeds of alternative alignments. For example, a relatively straight alignment in flat terrain will produce higher speeds and, hence, generate a higher design speed than a sinuous alignment located in hilly or mountainous terrain.

Comparison of suggested design speeds for rural highway links by both GDTH and AASHTO illustrated by Table 1 below.

Table 1. Design speed values suggested by GDTH and AASHTO for different terrain types

	GDTH-2005			AASHTO-2004		
Terrain Conditions	Flat	Rolling	Mountainous	Flat	Rolling	Mountainous
Number of Lanes	2	2	2	2	2	2
Design Speed(km\h)	100	100	70	110	100	80

As can be seen from the table above, recommended design speeds by GDTH and AASHTO are seems to be similar. Although GDTH advises slightly lower values for flat and mountainous terrains, it is also recommended that design speeds may be increased 10 km\h when advised design speed is 100 km\h for the road sections having high safety risks. This is quite harmonious with the suggestions of AASHTO and general trend in the world towards higher speeds (110-130 km\h) unless construction cost is very expensive.

British standards, TD 9/93 [4], offer a selection process by the impression of constraints that the road alignment and layout impart to road users. Alignment constraints are related to the bendiness degrees per km. Layout constraints are related to the cross sections, verge width and frequency of junctions and accesses. TD 9/93 suggests design speeds in the range of 70km\h and 120km\h, depending on the alignment and layout constraints. Careful consideration of the terrain types of Turkey and Britain might justify higher design speeds in favor of Britain.

It has been discussed above that topography and traffic volume have a significant effect on the selection of design speed. In other words, if the traffic flow is low, the design speed to be selected should be low as well. This idea is generally correct. However, if the highway to be constructed has national defense or industrial significance, a higher design speed and construction standards, accordingly, may be justified than that required for normal traffic with low volume. For these kind of purposes, separate design speed criteria and values should be accepted rather than just by taking into account road type, level of service, terrain type and traffic volume. Turkish geometric design standards seem to be missing this point.

If any highway connects two important industrial cities, like commodities to be carried and transported are very important agricultural or industrial merchandises have vital values for national economy, the higher design speeds might be justified compare to those having the same or more traffic volume roads without this importance.

In Turkey the amount of heavy vehicles carrying this type of industrial commodities constitutes a large amount of traffic. The figures for 2007 state that number of buses, small trucks and trucks are 185 591, 1 837 788 and 723 971 respectively [5]. In addition these figures, the number of tractors on Turkish highways given as 1 317 180 by the same reference. This high numbers imply, on the other hand, that the amount of slow-moving vehicles should be considered in the determination of design speeds especially on grades. It is clear that, improvements in the performance of heavy vehicles may increase the design speed to be selected . For example, better braking devices or easily used steering-wheel systems can permit heavy vehicles or slow moving vehicles to operate safely at increased speed.

These two above mentioned aspects regarding the transporting high value commodities and the amount and the improvements of the heavy vehicles are not in the consideration of Turkish design standards for the selection of design speed.

The environmental factors, another missing point of Turkish design standards, should truly be taken into account in the selection of design speed. If any highway passes through an area which is environmentally sensitive, the selection of design speed should consider related environmental factors. The relation between fuel consumption and speed, as illustrated by Figure 1 and Figure 2 [6] could be used in the decision process in order to minimize the air pollution at those environmentally sensitive areas.

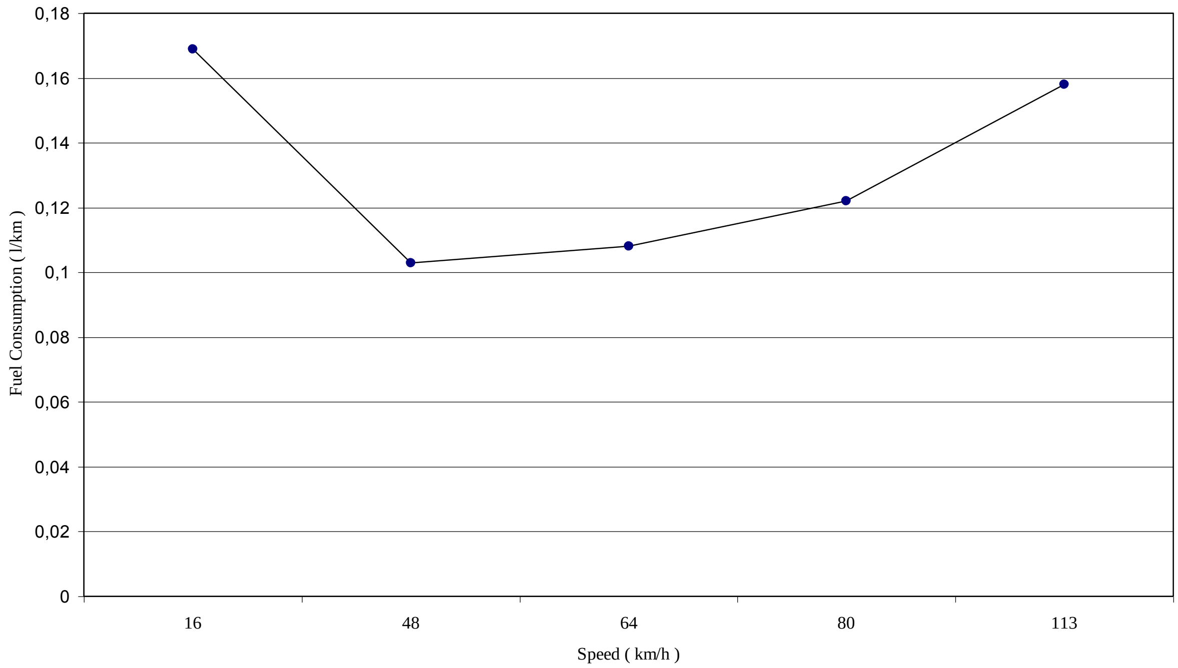


Figure 1. Fuel consumption on level roads

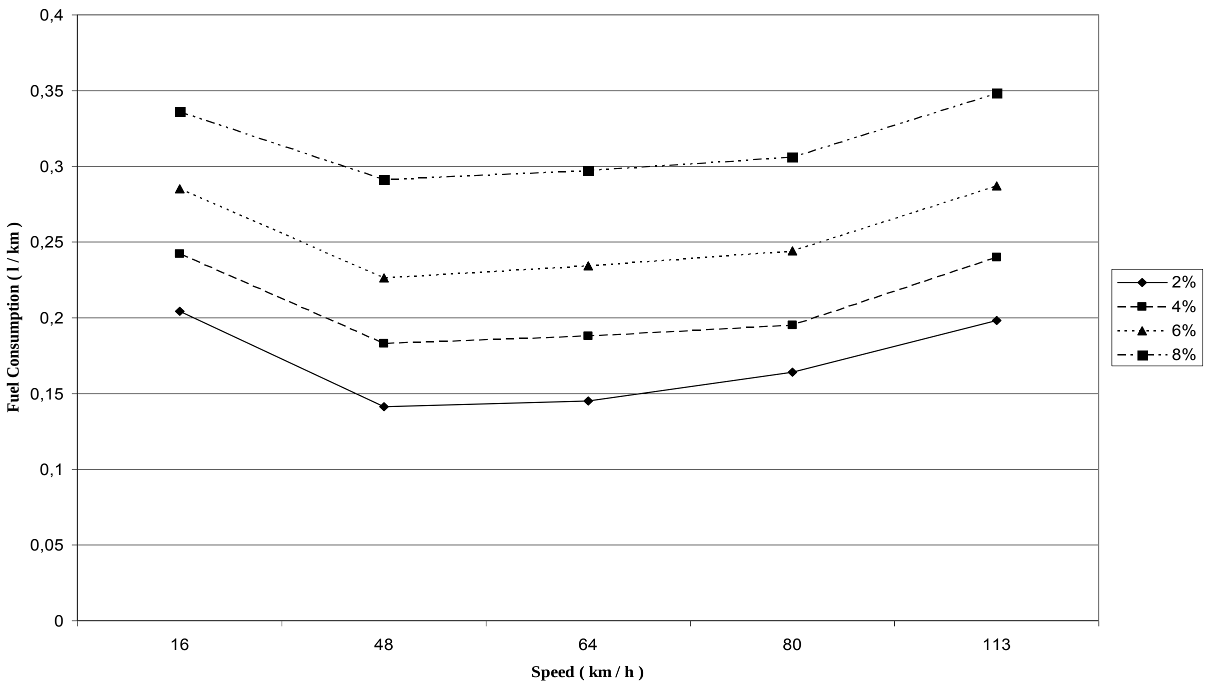


Figure 2**.** Fuel consumption on grade roads

The design speed selection process is more complicated in British design standards compare to AASHTO. In British process bendiness (degrees / km), road cross section, verge width, frequency of junctions and access are considered. In American standards the process is easier and involves rougher process and, hence, seems to be more reasonable from the practical point of view.

As the geographical and climate conditions in Turkey differ greatly from one part to another, the design speed must be selected by considering the prevalent adverse weather conditions, too. This criterion will result in a selection of safer design speeds by eliminating negative effects of the process just depending on the terrain type suggested.

2.2 Break reaction time and stopping sight distance

Break reaction time is the time elapsed as soon as the driver sees an obstacle on the roadway ahead and actually he applies the brake. The brake reaction time depends on driver characteristics, environmental conditions and the properties of the obstacle itself. AASHTO recommends 2.5s as the design criterion for the break raection time. This value represents the fact that 90 percent of the drivers tested reacts equal or quicker than this value.

GDTH advises the break reaction time as 2s for design purposes [7]. The recommended or used brake reaction time must be large enough to include the times needed by almost all drivers under different highway conditions. Fambro, et.all [8] illustrated that 2.5 s reflects the capabilities of most drivers for brake reaction time for stopping sight distances including older ones.

If the road conditions, average educational levels and attitude of the drivers towards obeying the traffic rules are compared between Turkey and USA, it could be concluded that the required brake reaction time for the design of rural highway links in Turkey must be at least 2.5s as far as running safer roads are concerned. The following figure illustrates the difference in terms of percentage for the required stopping sight distances for different speeds and downgrade values (%3, %6 and %9) along with the used brake reaction times in Turkey and USA.

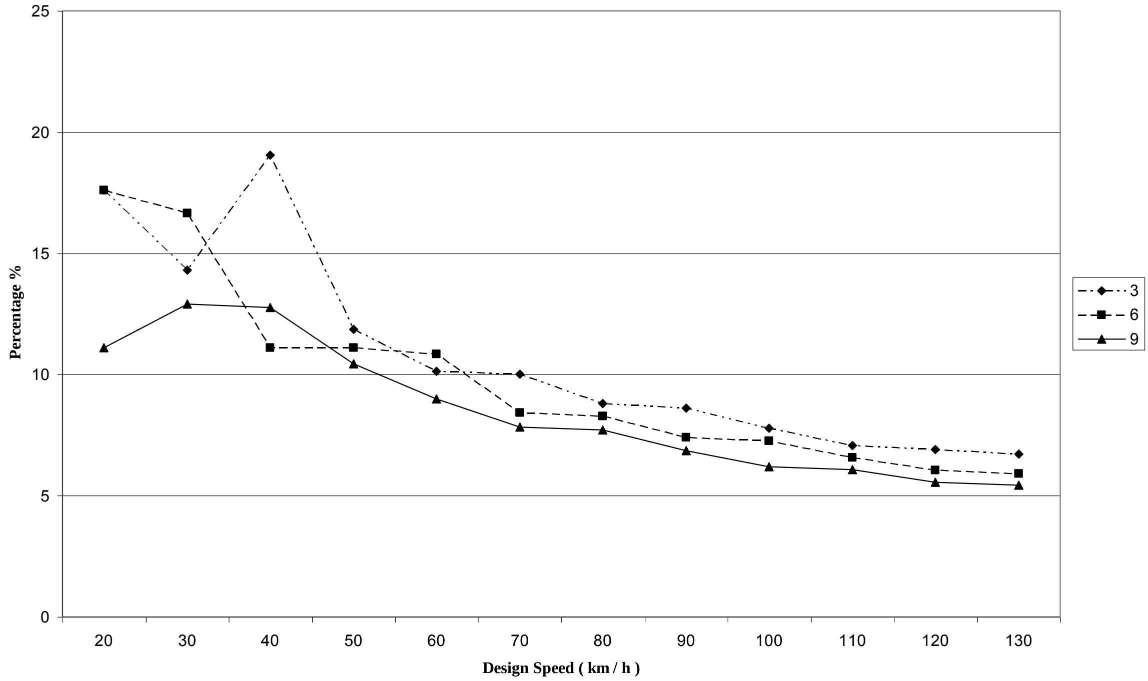


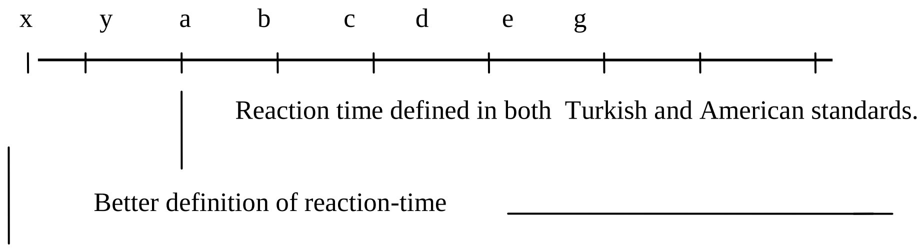
Figure 3. Extra required distances by AASHTO for safe stopping compare to GDTH.

As figures imply AASHTO recommends higher safe stopping sight distance values. For example, if the design speed is selected as 40 km\h for a highway section with 6 per cent downgrade segment, AASHTO advises 19.05 per cent extra distance compare to the those suggested by GDTH. The lowest difference is 5.42 per cent when design speed and grade is selected as 130km\h and 9 per cent, respectively. These differences come mainly from the selected brake reaction time values explained above. İt should be pointed out that the stopping sight distance values also vary for level and upgrade road sections between GDTH and AASHTO. The latter one again advises higher figures.

Although the general rough and mountanious terrain type in Turkey justifies lower stopping sight distances as far as the ecomoy and construction cost are concerned, the balance must be obtained to get safer roads for the road users, especially for the single-carriageway rural roads.

As can be seen from the definition of stopping sight distance , both American and Turkish standards take account of driver's physiological and psychological processes which are necessary to enable driver to carry out the tasks. What about the obstacle's external circumstances?. This point is not taken into account. Almost all measurements of drivers' reaction times have so far been carried out with the use of single obstacles i.e., those which can be perceived in one and the same set of attention or in one and the same direction of vision as a rule in front of the driver. The resulting standard reaction times can thus only be used corresponding road situations where the obstacles are similar in character. It cannot therefore simply be assumed that the reaction time for braking to avoid obstacles in front is the same as when taking the opportunity to overtake, which also requires examination of conditions to the rear, or when using gaps in traffic in going over a road crossing, which requires examination of conditions on both sides.

If the sense organ is to be stimulated, there are two necessary prerequisites. Firstly, there has to be some stimulus (signal, obstacles) visible (audible etc.) to a normal driver (x), secondly the driver must be attentive to the stimulus (y).



a: stimulation of the sense organ

b: transmission of the sensation by the sensory nerves and the initiation of the brain processes

c: identification of the obstacle

d: interpretation of the obstacle

e: decision-making to avoid the obstacle

f: transmission of brain impulses by the motor nerves

g: stimulation of the muscles and the initiation of movement.

When these conditions are taken into consideration, the reaction time should be defined as the time which passes from the moment an obstacle is perceptible until the moment the driver in question initiates preventive action.

What conclusion can be got from this discussion ? This is the problem. The answer to this question is that in the determination of reaction time, driver's and obstacle's external circumstances should be taken into account. This is not considered by both Turkish and American standards. For example, in situations where the driver is keenly attentive to the possible risk factor brought about by a forewarning such as a road sign, it is obvious that reaction time would be less than if driver is not warned, i.e., if the driver is just normally attentive. And it is obvious that, if the external circumstances of the obstacle is more evident, the reaction time would be lower than the situation in which the perceptibility of obstacles is not good. These concepts should be introduced to both Turkish and American standards.

It is evident that determination of design standards for stopping sight distance is broadly rely on assumed values of total driver reaction time and longitudinal coefficient of friction. In the examination of both Turkish and American standards it will be seen that driver reaction times are obtained by using a simple criterion based on limited field studies, and which is assumed that it represents the entire population of drivers. However, more detailed researches should be done on the determination of driver reaction times for the drivers in Turkey.

Design values of wet coefficient of longitudinal friction are taken into account in both American and Turkish standards. Nevertheless, some factors related to the vehicle maintenance, (tyre and brake condition) and to keep vehicle control during stopping in wet conditions are not paid enough attention.

In Australian design standards [9] manoeuvre sight distance concept has been developed. This concept can be used to achieve cost effective designs as far as construction costs are concerned and would seem attractive for low volume roads. In this concept the assumed driver behaviour of lateral manoeuvring is taken into account instead of stopping. This approach seems more reasonable for developing countries like Turkey. British design standards also accepts stopping sight distance concept rather than manoeuvre site distance one.

2.3 Passing sight distance

The passing sight distance may be defined in general as the distance required by a vehicle to overtake with safety another vehicle travelling in the same direction. The amount of passing sight distance shows both operational quality and safety. Areas that allow overtaking should be used as much frequent as on major two-lane roads, less frequent on rural secondary roads. The provision of passing sight distance is not essential on dual rural highways or multi-lane urban highways. Required passing sight distance should be controlled both horizontal and vertical alignments.

İn deciding whether to pass another vehicle, the driver must consider the clear distance available to him against the distance needed to implement the sequence of events that make up the overtaking manoeuvre. The degree of caution that he or she exercises and the acceleration ability of his/her vehicle are the main factors which will influence the decision.

The following table illustrates the required passing sight distance suggested by GDTH, AASHTO and British standards.

Table 2. Comparison of minimum passing sight distances.

Design Speed (km / h)	Minimum Passing Sight Distance ,m (GDTH and AASHTO)	Minimum Passing Sight Distance, m TD 9/93
50	345	290
60	410	345
70	485	410
100	670	580
120	775	690

As can be seen from the table above GDTH and AASHTO suggest the same passing sight distance values. As the design speed increases, the proportion of suggested distances between British and GDTH (AASHTO) decreases. For example, while the required passing sight distance for 50 km/h in Turkish and American standards is 19 per cent more than the one suggested by British standards, the difference reduces to 14 percent fort he design speed of 120 km/h.

It should be stated that AASHTO and GDTH define the passing sight distance explicitly as the distance between the position of the passing driver begins considering decision to accelerate and pass and the position of the opposing vehicle when the passing vehicle reaches critical postion or point of no return (i.e. next to passed vehicle in the opposing lane). British standards, on the other hand, accepts the passing sight distance as the distance between the position of the the passing vehicle when first encroaching on opposing lane and the position of the opposing vehicle when the passing vehicle starts encroaching.

AASHTO (hence, Turkish) and British criteria are based largely on field data that are more than 50 years old. Although these standards concern about the maneoeuver types and speeds involved in passing, they do not pay attention on vehicle length term which allows consideration of different vehicle types.

Another missing point in AASHTO and British approach is that vehicle speeds for the passing vehicle are assumed to be less than the design speed, especially for those over 90 km/h. However, it seems in reality that majority of the drivers would be likely to go beyond the roadway design speed when overtaking.

Another interesting assumption in the standards mentioned is that the passing driver is committed to complete the pass. Nevertheless, the study conducted by St.John and Kobett [10] shows that passing drivers do abort passing maneouvers when traffic conditions dictate. From this discussion it can be concluded that there must be a relationship between traffic flow andpassing sight distance. Determination of this relationship helps to determine more realistic and economic values for passing sight distances.

On average, heavy commercial vehicles take longer than cars to complete the overtaking manoeuvre. İn other words, if the proportion of heavy vehicles is high and the road sections dictate, the required passing sight distances should be selected longer than the other road and traffic conditions. This will allow the motorists to have a longer passing opportunities when overtaking long and heavy vehicles. This argument and consideration is another week point of Turkish and American design standards along with British standards..

2.4 Horizontal alignment and curves

The horizontal alignment of a highway consists of tangent sections, circular curves and transition curves. Tangent or straight sections of the highway are linked with circular curves to create flowing and smooth alignment. Circular curves are described as either curves of a constant radius, or as a degree of curve.

The laws of mechanics as well as consideration of driver comfort are the main rules on which design of horizontal alignment is based. Superelevation is applied on highway curves to counterbalance the centrifugal forces on a vehicle and driver travelling through the curve. İn other words, whereas tangent (straigh) sections of highways cary normal cross slope, curved sections are superelevated by sloping the road surface upward towards the outside of the curve.

İn the design of highway curves it is necessary to establish the proper relation between design speed and curvature and also their joint realtion with superelevation.

The following figure illustrates the side friction factors suggested by GDTH and AASHTO in the calculation of minimum required radius of the horizontal curves with different elevation rates and design speeds.

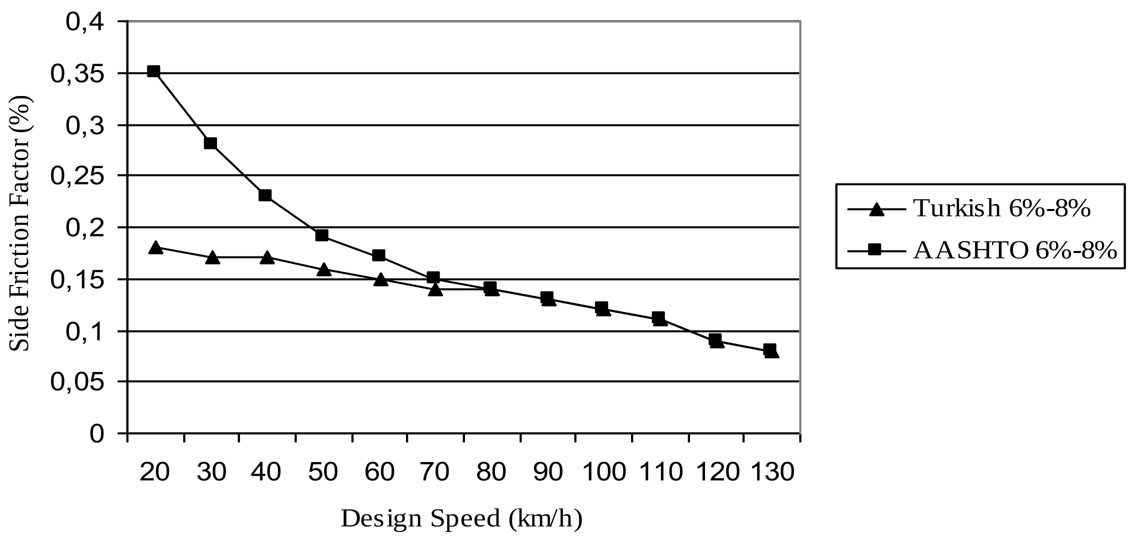


Figure 4. Side friction factors by GDTH and AASHTO

As can be seen from the figure above, GDTH suggests higher values for the speeds lower than 80 km/h. After 80 km/h the suggested friction factor values are the same for both standards. This results in higher horizontal radius of the curves fort he speeds below 80 km/h.

Since the elevation rate of 4% is used for urban roads rather than rural roads , there are no friction values given corresponding this elevation rate.

The table below shows the relationship between the horizontal radius and design speed for different elevation and friction factors.

Table 3. Required minimum radius for horizontal curves

Design Speed (km/h)	GDTH		AASHTO	
	Elevation Rate:%6	Elevation Rate:%8	Elevation Rate:%6	Elevation Rate:%8
	Min.Radius (m)	Min.Radius (m)	Min.Radius (m)	Min.Radius (m)
20	15	10	8	7
30	30	30	21	20
40	55	50	43	41
50	90	80	79	73
60	135	125	123	113
70	195	175	184	168
80	250	230	252	229
90	335	305	336	304
100	435	395	437	394
110	560	500	560	501
120	755	665	756	667
130	950	830	951	832

The suggested values of minimum radius vary up to 80 km/h and become almost the same after this design speed. This is quite the nature of the different values for friction factors given by GDTH and AASHTO up to 80 km/h.
The AASHTO recommendations for the low speeds seems to be forcing the road users to utilize the friction factors on all curves to the accepted maximum or near-to-maximum limit, which will result in lower operating speeds. GDTH suggestions are more appropriate and reasonably acceptable by the drivers for safer and smoother driving.

Maximum elevation rate accepted by British standards is 7 %. The following table gives an idea about the minimum radius values by AASHTO and TD 9/93.

Table 4. Comparison of american and british standards for minimum horizontal curve radius

Design Speed (km / h)	Elevation Rate (%)	Min. Radius. AASHTO (m)	Min. Radius. TD 9/93 (m)
50	5	94	180
60		142	255
70		203	360
85		316	510
100		463	720
120		810	1020
50	7	86	127
60		129	180
70		184	255
85		284	360
100		414	510
120		708	720

The difference is mainly because of the effect of superelevation on centrifugal force. In British standards the value of minimum radius increases when the rate of elevation decreases. This is mainly because of getting a good level of comfort on curves. As the adverse effects of centrifugal force, which influence comfort level, cannot be counterbalanced by lower elevation rates, the minimum radius required increases while the elevation rate decreases.

This exemplify the difference of design philosophy between British and American, as well as Turkish, standards in a way that British standards are based on the short-tangent sections with long curves when needed reflecting the fact that British standards are more sensitive about drivers` comfort on curves. This results in higher construction costs on the one hand, but causes the operational savings, particularly accident related ones, to increase. Turkish and American standards, however, provide the designers with more flexibility in difficult areas and can help to reduce land-take (right-off-way) costs.

3. Conclusions and Recommendations

The share of highways in meeting the transport requirements of Turkey is considerable. Therefore, it is necessary that the construction and improvement of the highways should be realized according to the socio – economic needs and financial power of the country.

In the determination of design standards some assumptions on which the standards are based to determine where they are appropriate for conditions found in individual countries are made. The examination of British, American and Australian design standards, as discussed above, will reveal this fact. Turkish design standards, hence, should be based upon the assumptions appropriate for the conditions of Turkey, rather than American or any other countries. Some fundamental researches must be done to determine these assumptions that needed. Vehicle speed distribution on straights, gradients and horizontal curves, accident rates, driver reaction times and skid resistance requirements are some them. This would enable the design of individual elements to be related to observed driver behavior and an overall consistency of standards.

The movement of pedestrians on rural highways is worth consideration in the development of design standards. In addition, many slow agricultural vehicles, animal drawn cars are often important components of the traffic mix on Turkish roads. Lorries and buses sometimes represent the largest proportion of the motorized traffic. This is the quite nature of the Turkish economy. It is reasonable to construct the rural roads by baring in mind the needs of the pedestrians and slow moving vehicles. The adoption of AASHTO design standards, directly or with minor modifications, will result in ignorance of the requirements of pedestrians and slow moving vehicles. It would be quite appropriate to provide wide and strong hard shoulders to allow their use by agricultural and heavy vehicles at the cost of some reductions in the standards of alignment. These reductions might be related to the comfort level provided rather than road safety. The design levels of comfort used by AASHTO may well be quite luxury that cannot be afforded by Turkish economy resulting in lower design levels of comfort. The development of design standards requires some research to be done to bring up the nature and components of the accidents involving these types of road users.

Apart from motor vehicle running costs, accident costs and the value of travel time, there are other factors of direct benefit to highway travelers. These factors can be collected under the general heading of Preferences of Drivers and Passengers. Dust free air, independency, mental and physical comfort, relaxed driving, traffic density, uniform speed and view from the road might be mentioned as some of these factors. The provision of these can be taken into account in well developed counties, like America. Nevertheless, the design standards might be selected by considering as minimum as these factors in developing countries, like Turkey. As long as it is not essential to consider such items, they should be avoided to determine Turkish standards as the provision of such preferences increases the construction costs significantly.

Since the illumination facilities are poor in Turkey compare to America and Britain, accidents are more likely to happen during night time. A special attention, thus, should be paid for the provision of sufficient illumination along with proper design of the geometric roadway elements for night time travel of the road users, especially for the lorries and buses.

Turkish standards should also be determined for some part of the country in a way that the lowest possible and practicable standards are available in order to maximize the length of road network so that basic and essential connectivity and transportation is provided. This seems to be more important in the east and south eastern part of Turkey.

Mutual weighting of all socially and economically relevant consequences of decisions will be necessary in the decision making procedure of design standards. In other words, the transportation and traffic policy should be consistent with the general social policy. The general policy should aim at a choice of measures such that maximum outcome would be obtained in terms of a weighted sum off all effects on relevant welfare components.

There is no official institution in Turkey to establish Turkish highway geometric design standards. The only institution is General Directorate of the Turkish Highways and the main functions of this institution are to construct, operate and maintain the roads needed. Hence, it is fundamental that a research institution must be set up immediately to set up Turkish standards. It seems to be extremely difficult to establish the required design standards appropriate to Turkey without the existence of this institution.

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