Effect of Wind Pressure on Horizontal Alignment of Highways

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الخلاصة:

يتضمن التصميم الهندسي للطريق تصميم التخطيط الأفقي والعمودي. إن العامل الحاكم في تصميم التخطيط الأفقي هو إيجـاد نصـف القطر التصميمي للطريق والذي يتلاءم والمتطلبات التصميمية، لهذا فان المعادلة المستخدمة في إيجاد نصف القطر اشـتقت بفرضـية ان المركبة على الطريق تتعرض إلى قوة طاردة مركزية تدفع المركبة خارج مسار الطريق. في نفس الوقت توجد قوى تحاول تثبيت المركبـة وهذه تشمل قوة الاحتكاك بين إطارات المركبة والطريق إضافة إلى القوى الناتجة من إمالة مقطع الطريق. عند سير المركبة على الطريـق فان ضغط الرياح سيلعب دورا" مهما" في نظام القوى المؤثرة على المركبة وخصوصا" الكبيرة منها والتي تكون فيها مسـاحة التعـرض للريح كبيرة، كما ان سير المركبة على الطرق الخارجية ذات السداد العالية خصوصا سيزيد من سرعة الريح وبالتـالي ضـغط الـريح. الهدف من البحث الحالي هو لاستحداث معادلة جديدة لإيجاد نصف القطر التصميمي للمنحنيات الأفقية والتي تأخذ بنظـر الاعتبـار ضغط الرياح المؤثر على المركبة. المعادلة التي تم اشتقاقها تربط بين طول المركبة، ارتفاع المركبة،وزن المركبة، وضـغط الـريح المـؤثر بالإضافة إلى بقية المتغيرات في المعادلة المعتمدة. وقد تم دراسة تأثير كل متغير على نصف القطر التصميمي وتم اخذ الحالة التي يكون فيها اتجاه الريح مع اتجاه القوة الطاردة المركزية التي تدفع المركبة خارج مسارها ووجد بان اقل نصف قطر مطلوب للمنحني يزداد مع نقصان وزن المركبة (نوع الحمولة) أي بتعبير أخر فان السرعة المسموحة للمركبة تتناقص مع نقصان وزن المركبة. من جهة أخرى، فان نصف القطر التصميمي المطلوب يزداد مع زيادة ارتفاع المركبة (ارتفاع الحمولة). بناءا" على ما سبق، فان ارتفاع الحمولة المسموح للمركبـة يرتبط مع نوع الحمولة.يمكن اعتماد المعادلة الجديدة في تخمين السرعة المسموحة للمركبات الكبيرة على الطرق الحالية وذلك في الأجواء السيئة او العاصفة. المقارنة بين المعادلة التي اشتقت والمعادلة المعتمدة حاليا" بينت بان أعظم فرق هو بحدود 160% والذي يحصل عند ضـغط الـريح العـالي بينمـا يكـون الفـرق لحـد 20 % عنـد ضـغط الريـاح الـواطيء

Abstract

The geometric design of highway alignment consists mainly of the design of horizontal alignment and Vertical alignment. The more important step in horizontal alignment design is the curve radius determination. The equation used for horizontal curve radius determination is developed with assumption that when vehicle run on curved section, there are an acting force on it. This force include the centrifugal force that try to push vehicle out off its path , on the other hand there are resisting forces try to keep the vehicle on its path. Those include the friction between road surface and tires and forces resulting from sloping the highway cross section. When a vehicle on rural highway with high embankment the wind Pressure will play an important role in force system acting on vehicle because of increasing in wind pressure intensity at these conditions (rural highway, i.e open areas, high embankment). The purpose of this paper is to present a new equation for horizontal curve radius determination taking in to account the wind force effect in addition to other forces acting on vehicle

The resulting equation relates vehicle length, height and weight and the wind pressure as well as the other factors in traditional equation. Effect of each parameter on design radius was investigated for the case

where the wind direction is acted with the same centrifugal force direction. It has been found that the required minimum radius increase with the decreasing of vehicle weight or in the other words the vehicle permitted speed decrease with the decreasing of vehicle weight. On the other hand, the required curve radius increases with vehicle height increasing. Consequently, permitted height of bags loaded on a truck is related to the type of loads. Derived equation can also be used for estimation of the permitted truck speed on existing roads especially in case of bad weathers

The comparison between the traditional and suggested equation showed that maximum difference is about 160 % which results at high wind pressure while the difference is up to 20 % for low wind pressure

Introduction:

Geometric design of highway alignments consists mainly of the design of horizontal and vertical alignments. Horizontal alignments of highway are made of striaght sections called Tangents connected by smooth horizontal curves. In fact, the design of horizontal curves entails the determination of minimum raduis, determination the length of curve, and then the computations of horizontal offsets from the tangent to the curve to facilitate the setting out of curve (1)

Many studies were conducted to investigate the effect of horizontal alignment design on highway safety. Raff and Smith (2) showed the relationship between curvature and small radii to high accident rate. Raff (2) argued that a high rate of accidents could be found on roads with a sharp horizontal curve following long tangents. The purpose of this paper is to present the new equation for horizontal curve radius determination for rural highways with high embankments subjected to high percentage of large trucks. This equation considers the effect of wind pressure as an additional force as well as the other forces acting on the vehicle. On the other hand, present paper try to identifying the effect of each parameter in the derived equation on the design radius. Finally, a comparison between the new equation and the traditional design equation is also presented.

Current Design Practice

When vehicle passing from straight sections to curved path, a vehicle is forced radially outward by the centrifugal force. This force try to push the vehicle out off its path and always acts in the horizontal direction (3). The centrifugal force is resisted by the frictional effect between the tires and the roadway surface. At high speed and/or bad weather, the frictional force is considered not sufficient to balance the centrifugal force. For this reason, it is customary to superelevate or slope the highway cross-section (3).The relationship between the superelevation rate, radius of horizontal curve, and design speed is given by the following equation (1,3):

$$R = \frac{v^2}{g(e+f)} \;.........(8)$$

Where:
v=design speed, m/sec.
g=acceleration, m/sec^2

The metric units equation usually used is

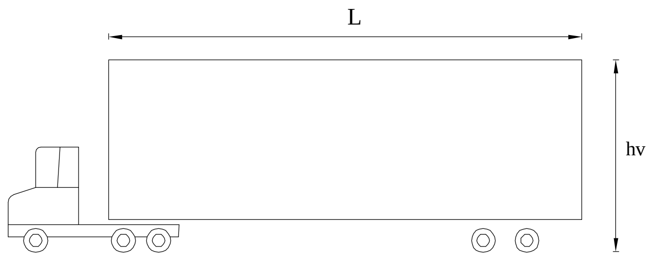
$$R = \frac{V^2}{127(e+f)} \;...........(9)$$

Where the V is the design speed in Km/h, e is the rate of superelevation, f is the side friction factor, and R is the radius of curve in meters. Values of (f) vary with the design speed and its values are shown in AASHTO Policy (3)

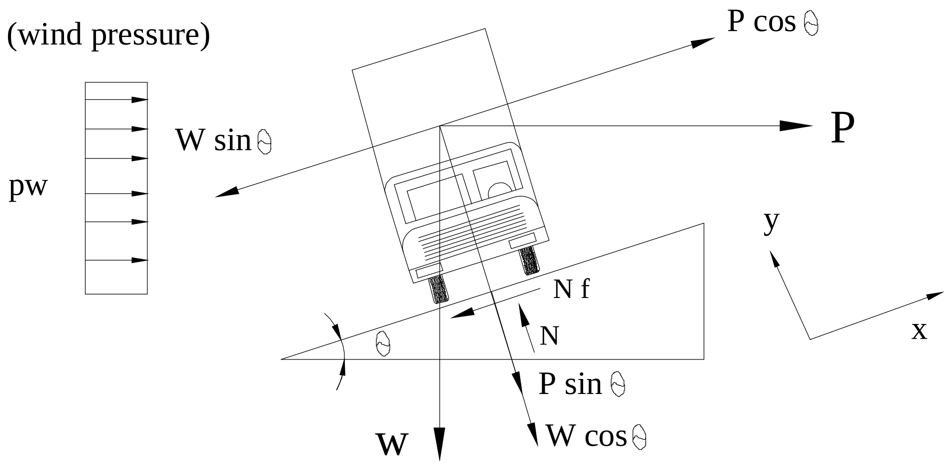
Maximum rate of superelevation are limited by the need to prevent slow-moving vehicle from sliding to the inside of the curve and , in urban areas, by the need to keep parking lanes relatively level and to keep the difference in slope between the roadway streets or driveways that intersect within reasonable bound. AASHTO Policy (3) recommends that maximum superelevation rate be limited to 12% for rural roadways, 8% for rural highways with snow or ice , and 4% or 6% for urban streets

Suggested Equation:

When a truck of given height and length on rural highway the wind pressure will play an important role in force system. In fact, pressure intensity in case of open areas (rural areas) will be greater than that on urban areas as well as this intensity increase also with elevation increasing. Moreover, the resulting wind force acting on vehicle is primarily related to exposed area i.e., vehicle length and height as shown in Figure (2) (since Force = Pressure x area). The current equation is derived assuming that there is a truck vehicle on rural highway with high embankment. It considers the effect of wind pressure (in addition to the other forces acting on vehicle as stated earlier) that may be acting toward the center of curve i.e., with the opposite direction of centrifugal force (or wind in) or acting outward the center of curve i.e., with the same direction of centrifugal force (or wind out).Actually the case in which the wind force act in the same direction of centrifugal force is more critical than this in which wind force act in the opposite direction of centrifugal force since the first case require more curve radius. Figure (2) also represent the forces acting on the truck in case of wind out

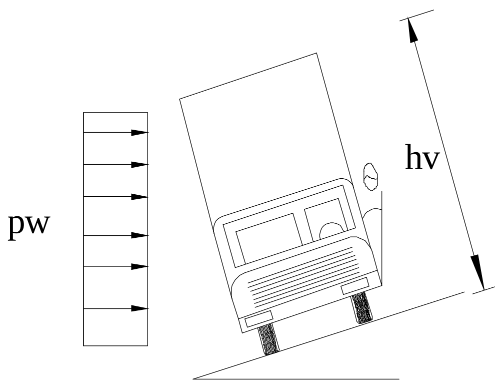


a. Vehicle Dimensions

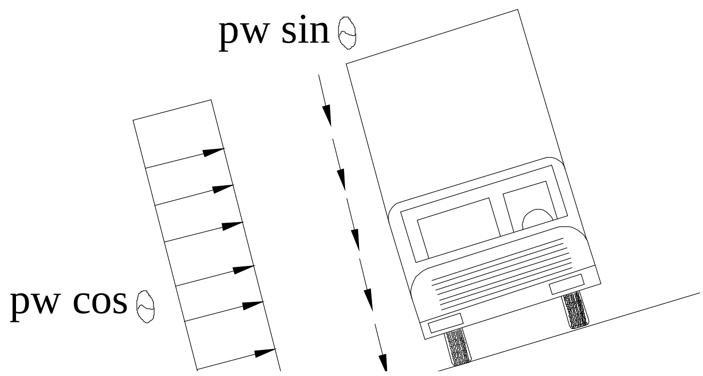


b. Forces acting on Vehicle

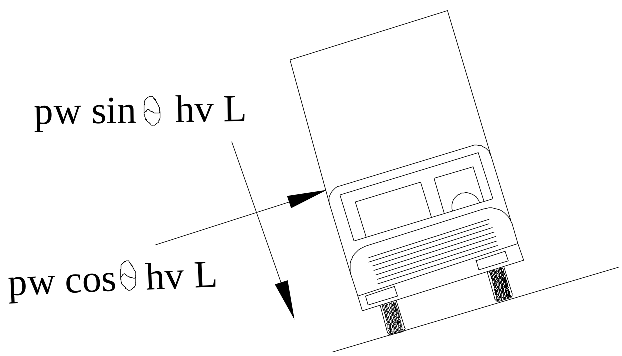
FIGURE (2): Vehicle Dimensions, Acting and Resisting Forces



a. Wind Pressure acting with the same Direction of Centrifugal Force



b. Resolving the Wind Pressure



c. Wind force acting on Vehicle

FIGURE (3): Analysis of Wind Pressure and Wind Force Determination

From equilibrium principles

$$\sum Fx = 0$$

$$P\cos q - W\sin q - Nf + p_w \cos q.hv.L = 0....(10)$$

$$\sum Fy = 0$$

$$N = P\sin q + W\cos q + p_w.\sin q.hv.L.........(11)$$

Substituting equation (11) in (10) results,

$$P\cos q - W\sin q - (P\sin q.f + W\cos q.f + p_w \sin q.h_v.L.f) + p_w \cos q.h_v.L = 0$$

Dividing by W $\cos q$ results,

$$\frac{v^2}{gR} - \tan q - \frac{v^2}{gR}.\tan q.f - f - \frac{p_w}{W}\tan q.h_v.L.f + \frac{p_w}{W}.h_v.L = 0$$

But, $\tan q$ = e =superelevation rate, simplifying more results,

$$\frac{V^2}{127R}(1 - e.f) + \frac{p_w.hv.L}{W}(1 - e.f) = e + f......(12)$$

In Equation (12) the term $e.f$ is small as compared with one, so it can be neglected and the above equation becomes:

$$\frac{V^2}{127R} + \frac{p_w.hv.L}{W} = e + f.......(13)$$

Using the same manner, the following equation represents the case where the wind pressure acts in opposite centrifugal force direction:

$$\frac{V^2}{127R} - \frac{p_w.hv.L}{W} = e + f.......(13)$$

In the above equations V=design speed (Km/h), p_w= the wind pressure (KN/m^2), and W= the weight of vehicle (KN), L=Length of vehicle (m), while the other terms are as specified earlier.

Parametric study and Comparison with Current Design Equation:

In this section, we will investigate the effect of each parameter on minimum design radius then a comparison between the current and suggested equation is presented. Table (2) present the input parameters used for these purposes.

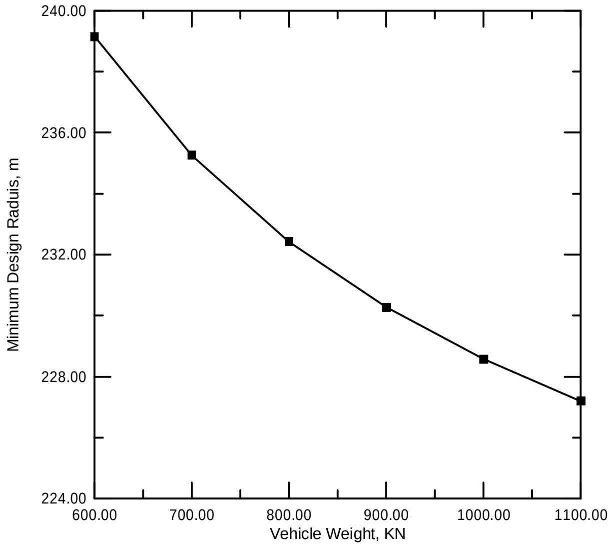
TABLE (2): Input Parameters Used in Parametric Study and Comparison

Parameters	Design Speed, Km/h	Wind[(1)] Pressure,(p_w) KN/m^2	Vehicle Weight,(W), KN[(5)]	Vehicle Height(hv), m	Vehicle length (L),m	Superelevation Rate(e),%,
Fixed Value	60	0.2[(2)]	600	4	12-22	4
Range values	20-120	0.01892[(3)]-1.2[(4)]	400-1100	3-5	16	2-12

(1) q or p_w=K V^2 where K=constant=0.0000473, V= design wind speed (km/h), Ref.(4)
(2) corresponds 65 km/h design wind speed
(3) corresponds 20 km/h design wind speed
(4) corresponds 160 km/h design wind speed
(5) 10 KN = 1 Tons.

Figure (4) shows the change in minimum radius of curve with the vehicle weight. It obvious that the required curve radius decrease with vehicle weight increasing. This because of increasing in vehicle weight will increase the resisting force (keeping in mind that there are two forces try to push vehicle out off its path which are centrifugal and wind force). Effect of vehicle height and length on minimum curve radius is shown in Figure (5) and Figure (9). It should be notice that the required radius will increase with increasing of vehicle height and / or length since the more vehicle height and/or length will generate more wind force. This because of increasing in height and/or length will increase the exposed area which in turn increase wind force. Therefore the radius of curve must be increase to decrease the effect of centrifugal force so the combined effect of acting forces (wind force plus centrifugal force) will decrease. Figure (6) illustrate the effect of wind pressure on the required minimum radius. Its clearly shows that the required radius will increased as wind pressure increase since the wind pressure will represent force that try to push vehicle out off curve. It can also be notice from Figure (7) that the required radius will increase with design speed increasing because of centrifugal force increasing. Finally, the value of curve radius decrease with superelevation increasing as represented in Figure (8).

Figure (10 to 15) represents also comparison between the derived and traditional equations. It can be conclude that the maximum difference is about 160 % which results at high wind pressure while the difference is up to 20 % for low wind pressure; the typical wind speed distribution in Iraq is shown in Appendix III



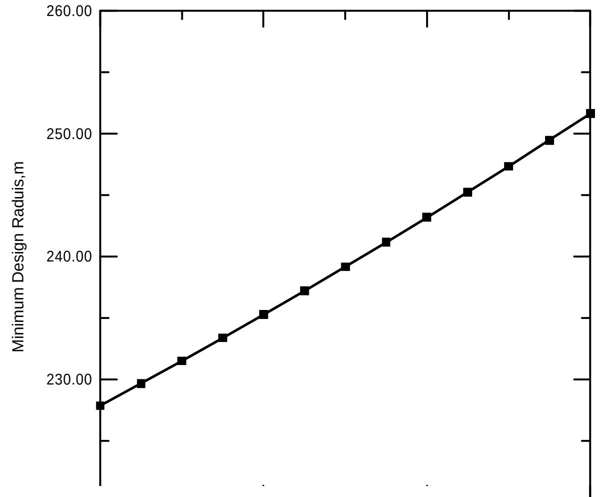


FIGURE (4): Min. Curve Radius with Various Vehicle weights

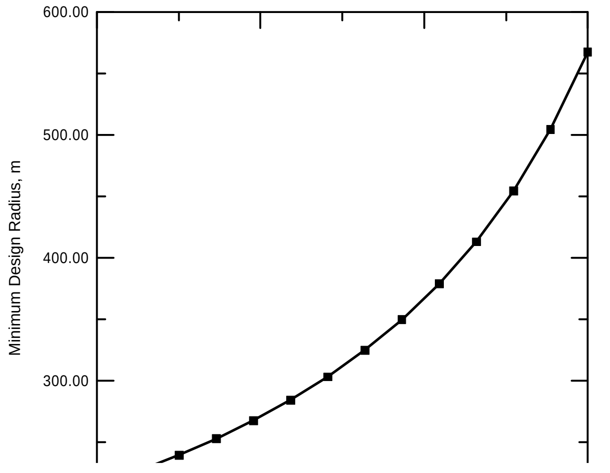


FIGURE (6): Min. Curve Radius with Various Wind Pressure

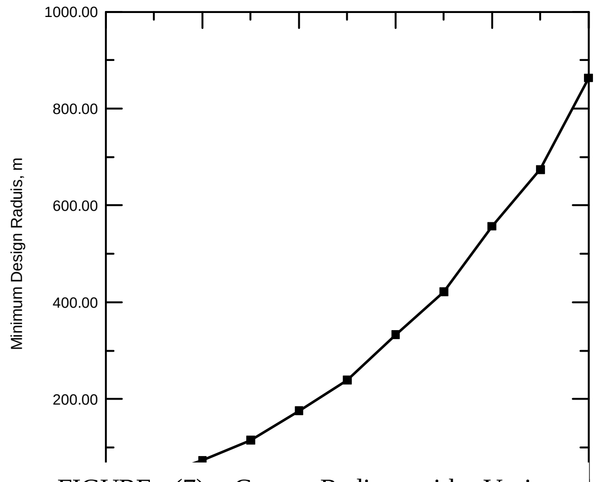
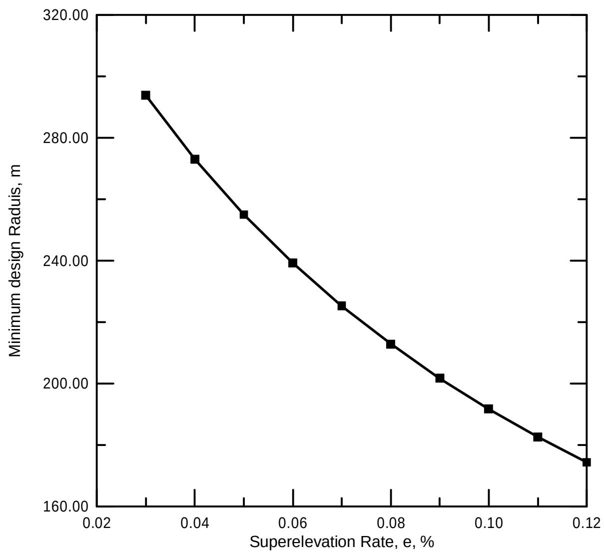


FIGURE (7): Curve Radius with Various Design Speeds



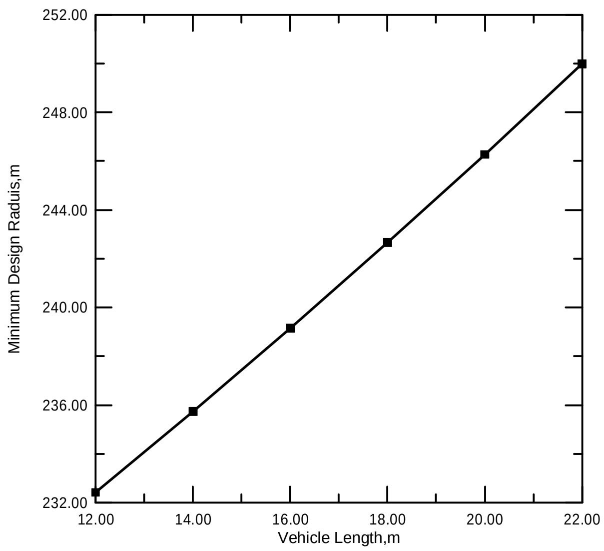
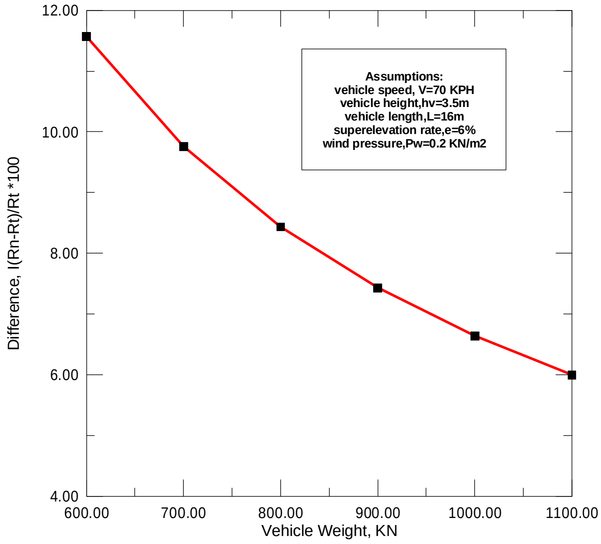


FIGURE (8): Curve Radius with Various Superelevation rates

FIGURE (9): Curve Radius with Various Vehicle Lengths



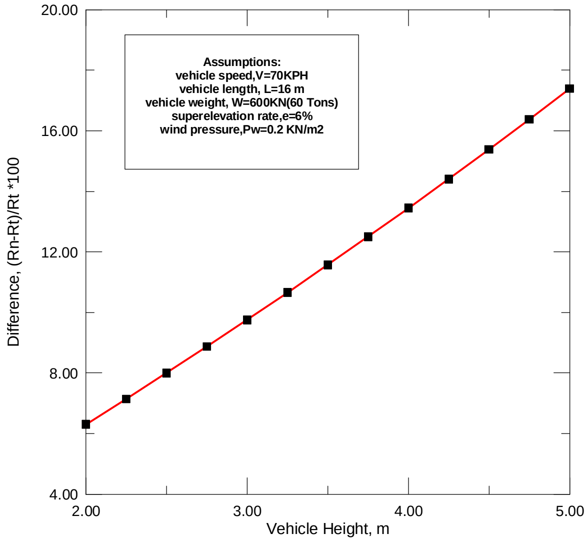
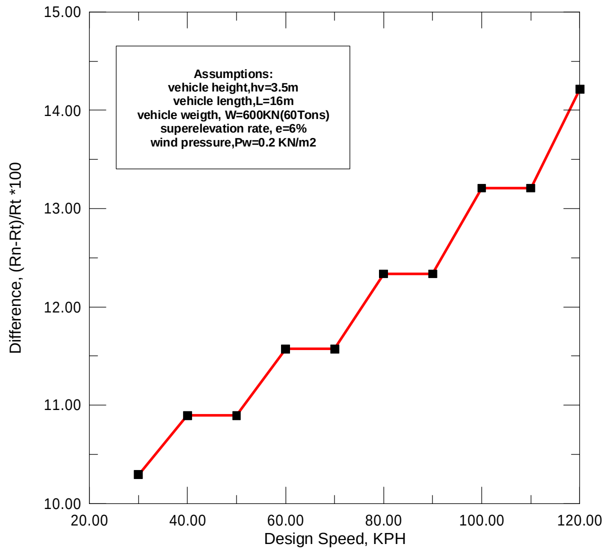


FIGURE (10): Difference between Derived and Traditional equations for various vehicle weights

FIGURE (11): Difference between Derived and Traditional equations for various vehicle heights



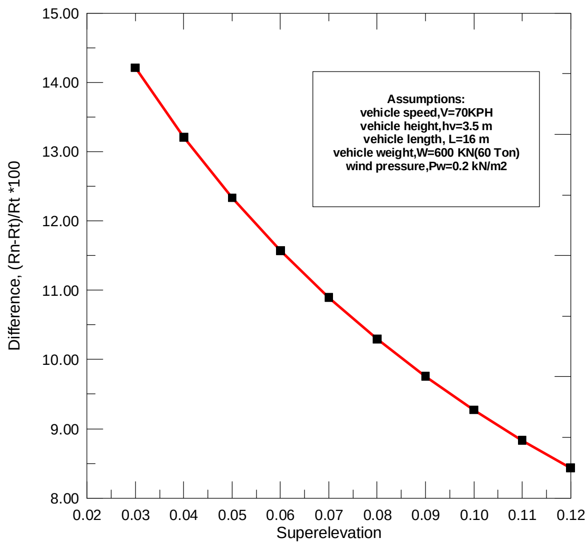


FIGURE (12): Difference between Derived and Traditional equations for various design speeds

FIGURE (13): Difference between Derived and Traditional equations for various superelevation rates

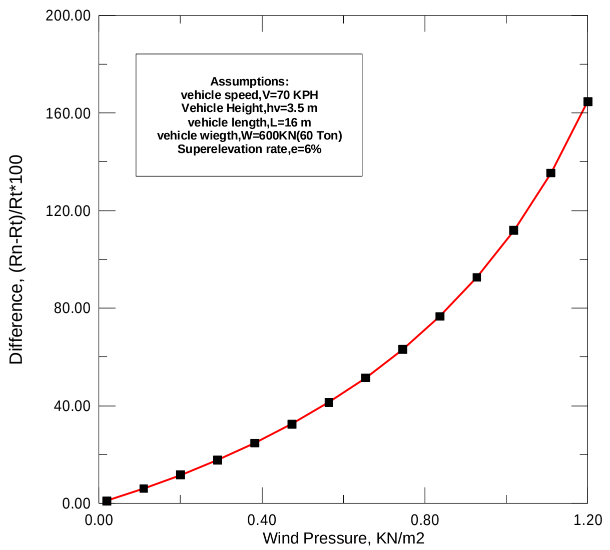


FIGURE (14): Difference between Derived and Traditional equations for various wind pressures

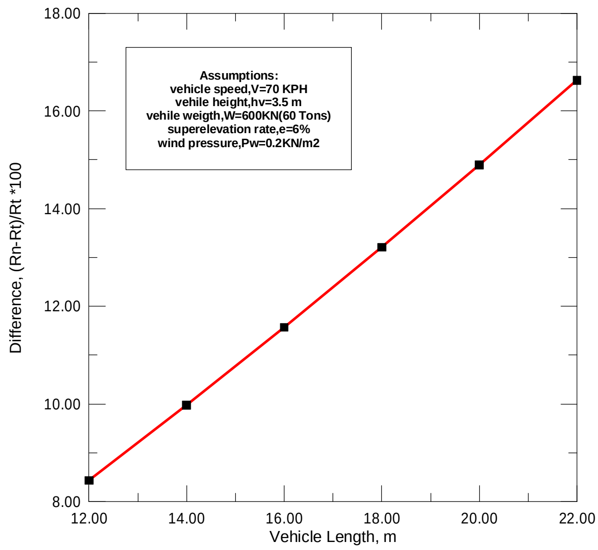


FIGURE (15): Difference between Derived and Traditional equations for various vehicle lengths

Conclusions and Recommendations:

There are several conclusions and recommendation drawn from the present study which are:

1. The developed equation introduces the effect of wind pressure, vehicle weight, length and height. Therefore it can be used to compute the minimum horizontal curve on rural highways with high embankment subjected to high percentage of large trucks
2. Required radius increase with increasing in height and/or length of vehicle or in the other words, increasing in vehicle height and/or length will reduce the design speed on curve. Therefore when truck carry a light loads such as wood or other light materials with high height the driver must reduce the speed of vehicle to balance the forces and keep his vehicle in its path.

3. From previewing the derived equation ,the effect of wind force when act in the same direction of centrifugal force is critical than the case where wind force act in opposite direction of centrifugal force since the first stated case will require more curve radius
4. It is recommended to study the effect of wind pressure on highway with compound alignment considering the dynamic effect.
5. The derived equation can be used to evaluate the permitted truck vehicle speed on highways in case of bad weather

APPENDIX I: REFERENCES

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APPENDIX II: NOTATIONS

V= Design speed. Km/h
$R_{min.}$ =Minimum Curve Radius, m
f = Side Friction Factor
e= Superelevation rate, m/m
h_v= Height of Vehicle, m
p_w= Wind pressure, KN/m^2
L= Length of Vehicle, m
W=Weight of vehicle, KN
g= acceleration, m/sec^2

APPENDIX III: Wind Speed Zones in Iraq (Ref.5)

Zone	Wind Speed(KPH)
A	108
B	126
C	144
D	162