Eng. & Tech. Journal, Vol.28, No.19, 2010

Increased Damage to Uphill Rigid Pavements from Full-Trailers

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Received on: 5/ 8 /2008
Accepted on: 2/ 4/ 2009

Abstract

Design charts for truck equivalence factors for full-trailer on uphill rigid pavements were developed for a terminal level of serviceability p_t=2.5. Each chart is devoted to a certain rigid pavement slab thickness giving the truck equivalence factor versus the total weight of the full-trailer for an uphill gradient of 0, 6, 12 and 18% as well as a certain ratio of the height of center of gravity of each unit of the full-trailer to the corresponding wheel base (H/B). Five values for slab thickness were considered namely D = 6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5, 35.6 cm respectively) and one value for H/B ratio of 1.0 were used.

Due to axle load redistribution on upgrades, the axle loads for the full-trailers were calculated assuming uniform motion and taking into account the effect of the moment of the component of the weight of the tractor and trailer unit parallel to the upgrade and acting at the center of gravity of each unit.A strong linear correlation between the rolling resistance and total weight of the trailer unit was obtained to arrive at the pull force in the rod when travelling on uphill pavements.

The paper reveals the significant effect of the upgrade magnitude as well as of the H/B ratio on the truck equivalence factor. The truck equivalence factors increase non-linearly with increasing truck weight, H/B ratio and upgrade magnitude. This increase is quite significant for the higher values of upgrade, H/B ratio as well as the slab thickness. The critical full-trailer is that having a total weight exceeding about 400 kN beyond which the corresponding equivalency factor on uphill pavement diverges significantly from that on level highway.

الزيادة في تلف الطرق الجاسئة والناتج من الميول الصاعدة للمركبات نوع قاطرة ومتطورة

الخلاصة

طُوِّرت مخططات تصميمية للمعاملات المكافئة للمركبات نوع قاطرة ومقطورة على الميول الصاعدة لمستوى خدمة 2.5. كل مخطط خُصِصَ لسمك تبليط خرساني معين ويعطي المعامل المكافئ مقابل الوزن الكلي للقاطرة والمقطورة لميل صاعد 0، 6، 12 و 18% كذلك لقيمة معينة لنسبة ارتفاع مركز الثقل الى المسافة بين الاطارات. خمسة قيم لسُمك التبليط الخرساني تم اخذها بنظر الاعتبار وهي 6، 8، 10، 12 و 14 إنج (15.2، 20.3، 25.4، 30.5 و 35.6 سم على التوالي) بالاضافة الى خمسة قيم لنسبة إرتفاع مركز ثقل المركبة الى المسافة بين مراكز المحاور الامامية والخلفية وهي 0.2، 0.4، 0.6، 0.8 و 1.0.

نتيجة لإعادة توزيع الحمل المحوري على الميول الصاعدة، تم حساب الحمولات المحورية للمركبات نوع قاطرة ومقطورة على هذه الميول بفرض حركة منتظمة و آخذين بالحساب تأثير العزم الذي تولده مركبة وزن كل من القاطرة والمقطورة الموازية للميل الصاعد

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https://doi.org/10.30684/etj.28.19.10
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والمارة في مركز ثقل كل من القاطرة والمقطورة. لقد تم الحصول على إرتباط خطي قوي بين مقاومة الدحرجة والوزن الكلي للمقطورة للتوصل الى قوة السحب في الوصلة الرابطـــة بـــين القاطرة والمقطورة حين الحركة على التبليط للميل الصاعد.

يبين هذا البحث الـــتأثير المهم لقيمة الميل الصاعد وكذلك لنسبة إرتفاع مركـــز ثقـــل المركبة الى المسافة بين المحاور الامامية والخلفية على المعامل المكافئ للمركبة نوع قـــاطرة ومقطورة. المعاملات المكافئة للمركبات الثقيلة نوع قاطرة ومقطورة تزداد بشكل لاخطي مـــع زيادة وزن المركبة، نسبة إرتفاع مركز ثقل المركبة الى المسافة بين مراكز المحاور و مقـــدار الميل الصاعد. هذه الزيادة مهمة جداً للقيم العالية للميل الصاعد، لنسبة إرتفاع مركـــز ثقـــل المركبة الى المسافة بين مراكز المحاور وكذلك سمك التبليط.

يبين البحث بأن المركبة الحرجة نوع قاطرة ومقطورة هي تلك التي تملك وزن كلـــي يتجاوز حوالي (400 kN) والتي بعدها يصبح معدل زيادة المعاملات المكافئة علـــى التبلـــيط الصاعد أعلى بكثير مما هو على التبليط الافقي.

Introduction

The problem of increased damage to uphill rigid pavements from trucks has received attention by **Razouki and Mohee**[1]. However, **Razouki and Mohee**[1] restricted their study to single unit trucks only. However, the traffic on any road especially on rural highways consists of passenger cars and trucks of various types. The percentage of truck traffic on rural highways especially in Middle East is relatively very high[2,3] due to the fact that other modes such as railways and waterways for the transport of freight traffic are not well developed.

In her axle load survey during the period 1995-1996 **Al-Shefi**[4] observed that full-trailers on Iraqi rural highways were used mainly in connection with the transport of grains, sugar and construction materials. This fact was supported by **Almuhanna**[5] who carried out an axle load survey on highways leading to grain silos and construction materials sources in Kerbala city and he reported that 55% of the trucks carrying grains were full-trailers. This fact encouraged the development of this research work.

Types of Full-Trailers

It is well known that the full-trailer consists of two units, namely the tractor unit and the trailer unit. Both units are connected to each other by means of a hook. However,

Full-trailer can have different axle configuration leading to different types of full-trailer.

To simplify the classification of full-trailer, it is very useful to use the code introduced by **Jones and Robinson**[6] for representing axle configuration of commercial vehicles. Each axle is represented by a digit (either one or two depending on how many tires on each end of the axle). For tandem axles, the digits are recorded directly after each other and a decimal point is placed between the code for front axle and that for the rear axle of each unit. For full-trailers, the code of the tractor unit is separated from that for the tractor by means of a plus sign.

Accordingly, four types of full-trailers were observed in Iraq namely

1.2+2.2, 1.2+2.22, 1.22+2.2 and 1.22+2.22.

Axle Load Survey

To arrive at the axle load distribution for the tractor and the trailer unit, an axle load survey was carried out using permanent weighing stations. There are two types of weighing units namely, the portable and the permanent weighing system. The portable one is used in connection with wheel loads such as the equipment described by Potocki[7]. The permanent weighing system in permanent weighing stations is, generally, of a bridge type, so that each axle of the vehicle or the whole vehicle can be weighed too. However, at the time of the survey of this work, portable weighing systems could not be used because of the security conditions, so that only permanent weighing systems were used.

The permanent weighing stations selected in this study were Al-Dora grains silo, Kerbala silo, Hilla silo, the General Company for Trade of Construction Materials (Kerbala), the General Company for Trade of Food Materials (Kerbala), and some local stations used for weighing of dates (Kerbala).

In Al-Dora grains silo, the weighing unit consists of a permanent weighing platform of ample size (3.00 m × 20.00 m) connected to a digital read out unit operating electrically and having a load range of 0-80 tonnes (0-784.8 kN). In Kerbala silo, the weighing system is the same as in Al-Dora silo but with 100 tonnes (981 kN) loading capacity. In Hilla grains silo, the weighing unit consists of a permanent weighing platform of ample size (3.00 m × 18.00 m) connected to a digital read out unit operating electrically and having a load range of 0-80 tonnes (0-784.8 kN).

For the General Company for Trade of Construction Materials and the General Company for Trade of Food Materials (Kerbala), the weighing system is the same as in Al-Dora silo. Also in the two local stations in Kerbala city for weighing of dates, the weighing unit consists of a permanent weighing platform of ample size (3.00 m × 18.00 m) connected to a digital read out unit operating electrically and having a load range of 0-80 tonnes (0-784.8 kN). Table(1) shows the number of trucks surveyed for each weighing station.

Measuring the Pull in Hook

On rising grades, there will be a redistribution of axle loads of the full-trailers due to the moment produced by the weight component parallel to the road surface of each of the tractor and trailer unit (acting at the center of gravity of each unit) as well as the moment produced by the pull force in the hook connecting the two units.

A regression analysis for a 66 pull forces obtained from the survey on level rigid pavement was done to get a generalized equation for all full trailer types correlating the pull force to the weight of the trailer unit. Fig. 1 shows the scatter diagram together with the following regressions obtained.

Two regressions were tested; the first is a linear regression with coefficient of correlation (0.9788) while the second is a non-linear regression with coefficient of correlation (0.930). As the correlation coefficient for the linear equation is greater than that for the non-linear one, the linear regression was adopted throughout this work.

$$T = 0.017 * W_2 \qquad \ldots(1)$$

(73.379 kN < W_2 < 462.443 kN)
where

W_2 = the total weight of the trailer unit in kN.

T = pull force for the case of level highway in kN.

Wheel Bases and Height of Hook above Pavement

For the case of full-trailers, the two wheel bases B_1 for the tractor unit and B_2 for the trailer are required. The wheel base B_1 is the distance between the front and the center of the rear axle of the tractor, while B_2 corresponds to the trailer as shown in Fig. 2. All these distances were measured by means of a steel tape for all vehicles surveyed. Regarding the height of the hook above the pavement, a level was used and measurements were made for the two ends of the hook and it was found that the hook is almost horizontal on horizontal pavements. The elevations of both ends of the hook were measured using the level. For the majority of cases (87%), the elevation is 100 cm and it is 95 cm for others (13%).

Center of Gravity

The center of gravity for each of the tractor and the trailer depends to a great extent upon the type, manufacturer and model of the vehicle as well as on the type of commodity carried and the degree of loading. Thus, the determination of the center of gravity is a very difficult task. For these reasons, the heights H_1 and H_2 for the tractor and H_3 and H_4 for the trailer as shown in Fig. 2 were measured for all vehicles surveyed. These heights will help in establishing the center of gravity for each unit of the full-trailer.

Table (2) shows typical results for the wheel bases and heights of the center of gravity above the pavement.

In fact and as it will be shown later, the ratio of the height of center of gravity above the pavement to the corresponding wheel base of each unit of the full-trailer is needed to arrive at the axle loads on the uphill pavement.

Axle Loads on Level Highways

For the case of no motion on a level road, the application of the equations of equilibrium on each of the tractor and the trailer units as shown in Fig. 3 yields:-

$$F_{O1} = W_1 \times {l_{12}}/{B_1} \qquad \ldots(2)$$

$$R_{O1} = W_1 \times {l_{11}}/{B_1} \qquad \ldots(3)$$

$$F_{O2} = W_2 \times {l_{22}}/{B_2} \qquad \ldots(4)$$

$$R_{O2} = W_2 \times {l_{21}}/{B_2} \qquad \ldots(5)$$

where:-

B_1, B_2 = Wheel base lengths for the tractor and trailer units respectively.

l_{11}, l_{12} = Distances from center of gravity of tractor to its front and rear axles respectively.

l_{21}, l_{22} = Distances from center of gravity of trailer unit to its front and rear axles respectively.

F_{O1}, R_{O1} = Front and rear axle load for tractor unit on a level surface.

F_{O2}, R_{O2} = Front and rear axle load for trailer unit on a level surface.

W_1, W_2 = Total weight for the tractor and trailer units respectively.

For the case of uniform motion on a level road (Fig. 4), a pull force (T_O) between the tractor and trailer units (given by Eq. 1) takes place and the equations of equilibrium can be applied because of zero inertia forces. The requirement of dynamic equilibrium yields:-

$$F_{L1} = W_1 \times {l_{12}}/{B_1} - T_O \times {E}/{B_1} \qquad \dots(6)$$

$$R_{L1} = W_1 \times {l_{11}}/{B_1} + T_O \times {E}/{B_1} \qquad \dots(7)$$

$$F_{L2} = W_2 \times {l_{22}}/{B_2} + T_O \times {E}/{B_2} \qquad \dots(8)$$

$$R_{L2} = W_2 \times {l_{21}}/{B_2} - T_O \times {E}/{B_2} \qquad \dots(9)$$

where:-

T_O = Pull force between the tractor and the trailer unit for the case of level road.

E = Height of the pull force above the pavement.

F_{L1}, R_{L1} = Front and rear axle loads for the tractor unit on a level road during uniform motion.

F_{L2}, R_{L2} = Front and rear axle loads for the trailer unit on a level road during uniform motion.

It is quite obvious from the Eqs. 6 & 7 that the pull force T_O between the tractor and trailer unit causes the front axle load of the tractor unit to decrease and the rear axle load to increase by the same amount. The reverse phenomenon is true for the trailer unit as can be seen from Eqs. 8 & 9.

Axle Loads on Uphill Pavements

On upgrade (Fig. 5), the pull force (T) between the tractor and the trailer unit becomes related to the vertical component $(\boldsymbol{W_2} * \mathbf{cos}\, q)$ as well as the component of the weight of the trailer unit parallel to the road surface. It should be noted that it was not possible to measure the pull force for the case of uniform motion of full-trailer on upgrades.

$$T = 0.017 \times W_2 \times \cos q + W_2 \times \sin q$$

$$T = (0.017 \times W_2 + W_2 \times \tan q) \times \cos q \qquad \dots(10)$$

When applying $\boldsymbol{\Theta} = 0$ to Eq. 10 $\boldsymbol{T}$ returns to $\boldsymbol{T_O}$ (the case of a level road).

For the case of uphill pavement and assuming that the full-trailer is traveling at a constant velocity the requirement of dynamic equilibrium yields:-

$$F_{G1} = W_1 \times \cos q \times {l_{12}}/{B_1} - W_1 \times \sin q \times {H_1}/{B_1} - T \times {E}/{B_1}$$

$$F_{G1} = \left(F_{O1} - W_1 \times \tan q \times {H_1}/{B_1} \right) \times \cos q - T \times {E}/{B_1} \qquad \dots(11)$$

$$R_{G1} = W_1 \times \cos q \times {l_{11}}/{B_1} + W_1 \times \sin q \times {H_1}/{B_1} + T \times {E}/{B_1}$$

$$R_{G1} = \left(R_{O1} + W_1 \times \tan q \times {H_1}/{B_1} \right) \times \cos q + T \times {E}/{B_1} \qquad \dots(12)$$

$$F_{G2} = W_2 \times \cos q \times {l_{22}}/{B_2} - W_2 \times \sin q \times {H_2}/{B_2} + T \times {E}/{B_2}$$

$$F_{G2} = \left(F_{O2} - W_2 \times \tan q \times {H_2}/{B_2} \right) \times \cos q + T \times {E}/{B_2} \qquad \dots(13)$$

$$R_{G2} = W_2 \times \cos q \times {l_{21}}/{B_2} + W_2 \times \sin q \times {H_2}/{B_2} - T \times {E}/{B_2}$$

$$R_{G2} = \left(R_{O2} + W_2 \times \tan q \times {H_2}/{B_2} \right) \times \cos q - T \times {E}/{B_2} \qquad \dots(14)$$

Where:-

F_{G1}, R_{G1} = Front and rear axle loads for tractor on upgrade.

F_{G2}, R_{G2} = Front and rear axle loads for trailer unit on upgrade.

Θ = Angle of slope, $\tan\Theta = grade = G$.

H_1, H_2 = Height of the center of gravity for the tractor and the trailer unit respectively (perpendicular to the pavement) above the pavement.

Regarding the magnitude of uphill slope, it is worth mentioning that according to the AASHTO Policy[8], for a design speed of 50 km/hr, the maximum grade ranges from 7% to 12% depending on the topography, while for the more important highways, the maximum grade of 7% to 8% is considered suitable. However, the vertical road alignment for some highways in Iraq showed uphill slopes of 18% in mountainous topography. For the magnitude of G = 18%, $\cos\theta$ becomes 0.984 indicating that $\cos\theta$ can be taken as unity to simplify the axle load equations.

Thus, eqs. 10, 11, 12, 13 and 14 can be written as follows:-

$$T = 0.017 \times W_2 + W_2 \times G \qquad \dots(15)$$

$$F_{G1} = F_{O1} - W_1 \times G \times H_1/B_1 - T \times E/B_1 \qquad \dots(16)$$

$$R_{G1} = R_{O1} + W_1 \times G \times H_1/B_1 + T \times E/B_1 \qquad \dots(17)$$

$$F_{G2} = F_{O2} - W_2 \times G \times H_2/B_2 + T \times E/B_2 \qquad \dots(18)$$

$$R_{G2} = R_{O2} + W_2 \times G \times H_2/B_2 - T \times E/B_2 \qquad \dots(19)$$

Truck Equivalence Factors

The Truck equivalence factor for the case of full-trailer is the sum of loads equivalency factors for all axles of the tractor and trailer.

The most popular axle load equivalency factors are the AASHTO factors[8] based on Liddle's[9] analysis as they are given in ASTM E1318-94[10].

Thus, the equivalence factor for each axle load of the surveyed full-trailer can be determined for each uphill slope magnitude, ratio of the height of center of gravity to the wheel base of each unit of full-trailer, terminal level of serviceability and slab thickness of the rigid pavement.

The truck equivalence factor for the full-trailer can be calculated using the following equation:-

$$T_e = \sum_{i=1}^{N} (F_j) \qquad \dots(20)$$

where:-

T_e = Truck equivalency factor.

F_j = Equivalency factor for j^{th} axle obtained from Equation in AASHTO guide for design of pavement structures.

N = Total number of axles in the truck (N=4 for Full-Trailer).

Overloading Phenomenon in Developing Countries

Razouki and Razouki[3] and Pearson Kirk[11] reported that especially in the Middle East, the phenomenon of overloading of commercial vehicles is very serious.

In order for the intended charts to be developed in this work to be of significant use worldwide, it is assumed that the AASHTO equivalence equations still valid for axle loads beyond the AASHO road test axle load limits.

Design Charts

To enable the pavement engineer to take into account the effect of uphill slope on the destructive effect of full-trailers on rigid pavements, charts should be developed for the practical ranges of all parameters involved. Figs. 6, 7, 8, 9, 10 and 11 show the truck equivalence factor versus the total weight of full-trailer for two full-trailer types (1.2+2.2 and 1.22+2.22) for different values of H/B ratio namely 0.2, 0.6 and 1.0 respectively.

Each figure consists of five charts. Each chart is devoted to a certain pavement slab thickness of D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm respectively) and shows the truck equivalence factor for four different upgrade magnitude of 0, 6, 12 and 18%.

Conclusions

Based on the results obtained from this paper the following conclusions can be drawn:-

1. On uphill rigid pavements, the maximum increase in axle load due to axle load redistribution takes place in connection with the rear axle of the tractor while the maximum decrease occurs in connection with the front axle of the tractor.
2. For the same total weight of the truck, the damage caused by the truck type 1.2+2.2 and 1.2+2.22 is much greater than that caused by truck type 1.22+2.2 and 1.22+2.22. For slab thickness D=14 inches (35.6 cm), H/B=1.0, total weight of 600 kN, upgrade of 12% and p_t=2.5 the truck equivalence factor for 1.2+2.2, 1.2+2.22, 1.22+2.2 and 1.22+2.22 full-trailer is 221.6902, 131.8083, 69.6295 and 33.0557 respectively.
3. The destructive effect of full-trailer trucks on uphill slopes is greater than on a level pavement. This is especially true for type 1.2+2.2 & 1.2+2.22. For full-trailer type 1.2+2.2 the percent increase in equivalence factor is 150% when the grade increases from 0 to 18% while for 1.22+2.22 full-trailer the percent increase is 63% for D=10 inches (25.4 cm), H/B=1.0, total weight of 600 kN and p_t=2.5. The destructive effect of full-trailer trucks on uphill slopes increases with increasing H/B ratio and upgrade magnitude.
4. For each truck type, the average truck equivalency factor increases with upgrade magnitude and H/B ratio for the same terminal level of serviceability and slab thickness. The maximum average truck equivalency factor for truck type 1.2+2.2 was 107.32 corresponding to slab thickness (D) = 14 inches (35.6 cm), upgrade of 18%, H/B=1.0 and p_t=2.5. The corresponding minimum value was 33.01 for slab thickness (D) = 8 inches (20.3 cm), upgrade of 0%, H/B=1.0 and p_t=2.5.
5. On upgrades, the amount of increase in the rear axle load is equal to the decrease in the front axle load for both the tractor and trailer unit, but the increase in damage caused by the rear axle is much greater than the decrease in damage caused by the front axle on upgrades. This increase in the rear axle load or decrease in the front axle load depends on the total weight of both the tractor and trailer unit, magnitude of upgrade, and the ratio of the height of center of gravity to the

wheel base of both of the tractor and trailer unit.

6. There is a strong non-linear correlation between the rolling resistance and the weight of the trailer unit for all types of full-trailer surveyed.
7. The increase in the destructive effect of full-trailer on an uphill rigid pavement is quite significant for full-trailers having total weights exceeding 400 kN.
8. The increase in pavement slab thickness due to the increased truck equivalence factors on upgrade increases with upgrade magnitude and H/B ratio. This increase is more pronounced in the case of 1.2+2.2 & 1.2+2.22 than 1.22+2.2 & 1.22+2.22 full-trailers.

References

[1]Razouki, S. S. and Mohee, S. O. (1999), "Concrete Pavement Truck Equivalence Factors for Upgrades", Engineering Journal of University of Qatar, Vol.12, pp. 91-105.

[2]Hussain, S. F. (1985), "Effect of Type of ***Loading on Axle Loads of Commercial Vehicles in Baghdad",*** *M.Sc. Thesis, University of Baghdad, Baghdad.*

[3]Razouki, S. S. and Razouki, Seham S. (1993), "The Status of Axle Loads and their Damaging Effect on Pavements in Iraq", Journal of Engineering and Technology, Vol.12, No.2, pp.34-54.

[4]Al-Shefi A. M. (1997),"Computer Aided Structural Design of Flexible Pavements for Rural Highways in Iraq", M.Sc. Thesis, Baghdad University.

[5]Almuhanna, R. R. (2008),"Rigid Pavement Equivalency Factors for Full-Trailers on Upgrades", Ph.D. Thesis, University of Technology.

[6]Jones, T. E. and Robinson, R. (1976), "1975 Turkey Traffic Survey (Ankara-Istanbul Expressway): Axle Loads", Transportation and Road Research Laboratory, Department of the Environment, TRRL Report LR 713, Crowthorne, Berkshire, England.

[7]AASHTO (1994), "AASHTO-Policy Manual", American Association of State Highway and Transportation Officials, Washington, D.C.

[8]AASHTO (1993), "AASHTO Guide for Design of Pavement Structures", Part I, American Association of State Highway and Transportation Officials, Washington, D. C.

[9]Liddle W. J. (1962),"Application of AASHTO Road Test Results to the design of Pavement Structures", Proceedings of an international Conference on the Structural Design of Asphalt Pavement, University of Michigan, Ann Arbor.

[10]American Society for Testing and Materials (1995),"Standard Specifications for Highway Weigh-in-motion (WIM) Systems with User Requirements and Test Method", ASTM E1318-94, Vol. 04-03.

[11]Pearson-Kirk, D. (1989), "Damage from Heavy Goods Vehicles-The Middle East Experience", Highway and Transportation, Vol. 36, No.4, pp.18-21.

Table (1) Axle load survey stations.

Location of weighing stations	Types of trucks surveyed	Number of trucks surveyed		Total number of trucks	
		Loaded	Empty		
Al-Dora Silo	1.2+2.2	3	0	3	18
	1.22+2.2	3	3	6	
	1.2+2.22	2	1	3	
	1.22+2.22	3	3	6	
Kerbala Silo	1.2+2.2	12	7	19	105
	1.22+2.2	34	26	60	
	1.2+2.22	7	3	10	
	1.22+2.22	10	6	16	
Hilla Silo	1.2+2.2	14	6	20	54
	1.22+2.2	14	7	21	
	1.2+2.22	4	2	6	
	1.22+2.22	4	3	7	
The General Company for Trade of Construction Materials (Kerbala)	1.2+2.2	2	4	6	15
	1.22+2.2	3	2	5	
	1.2+2.22	0	0	0	
	1.22+2.22	1	3	4	
The General Company for Trade of Food Materials (Kerbala)	1.2+2.2	3	2	5	18
	1.22+2.2	4	3	7	
	1.2+2.22	2	0	2	
	1.22+2.22	3	1	4	
Al-Noor Station for weighing of dates (Kerbala)	1.2+2.2	2	2	4	13
	1.22+2.2	3	2	5	
	1.2+2.22	0	1	1	
	1.22+2.22	2	1	3	
Al-Hindiya Station for weighing of dates (Kerbala)	1.2+2.2	5	4	9	31
	1.22+2.2	6	6	12	
	1.2+2.22	4	2	6	
	1.22+2.22	3	1	4	
	Total	153	101	254	

Table (2) typical results of the geometrical characteristics for 1.22 Tractor*.

S_{11} (mm)	S_{12} (mm)	B_1 (mm)	H_1 (mm)	H_2 (mm)	H^*/B_1	
					Lower limit	Upper limit
5420	1360	6100	1300	3000	0.352	0.492
4200	1500	4950	1390	3200	0.464	0.646
4050	1390	4745	1350	3100	0.469	0.653
5500	1200	6100	1390	3000	0.359	0.492
4000	1475	4737.5	1400	3700	0.538	0.781
5200	1400	5900	1320	3580	0.415	0.607
3150	1520	3910	1400	3950	0.684	1.010
			Average		0.469	0.669

Table (3) Increase in slab thickness for the case of 1.2+2.2 full-trailers.

Upgrade (%)	Slab Thickness on Level Highway		Increase in Slab Thickness	
	(inches)	(cm)	inches	cm
6%	10	25.4	0.5	1.27
12%	10	25.4	1.0	2.54
18%	10	25.4	1.5	3.81

Table (4) Increase in slab thickness for the case of 1.2+2.22 full-trailers.

Upgrade (%)	Slab Thickness on Level Highway		Increase in Slab Thickness	
	(inches)	(cm)	inches	cm
6%	10	25.4	0.4	1.016
12%	10	25.4	0.9	2.286
18%	10	25.4	1.4	3.556

Table (5) Increase in slab thickness for the case of 1.22+2.2 full-trailers.

Upgrade (%)	Slab Thickness on Level Highway		Increase in Slab Thickness	
	(inches)	(cm)	inches	cm
6%	10	25.4	0.25	0.635
12%	10	25.4	0.65	1.651
18%	10	25.4	1.1	2.794

***** Total number of trucks surveyed = 159.
H^*= height of center of gravity of the tractor abovepavement.

Table (6) Increase in slab thickness for the case of 1.22+2.22 full-trailers.

Upgrade (%)	Slab Thickness on Level Highway		Increase in Slab Thickness	
	(inches)	(cm)	inches	cm
6%	10	25.4	0.15	0.381
12%	10	25.4	0.5	1.270
18%	10	25.4	0.82	2.083

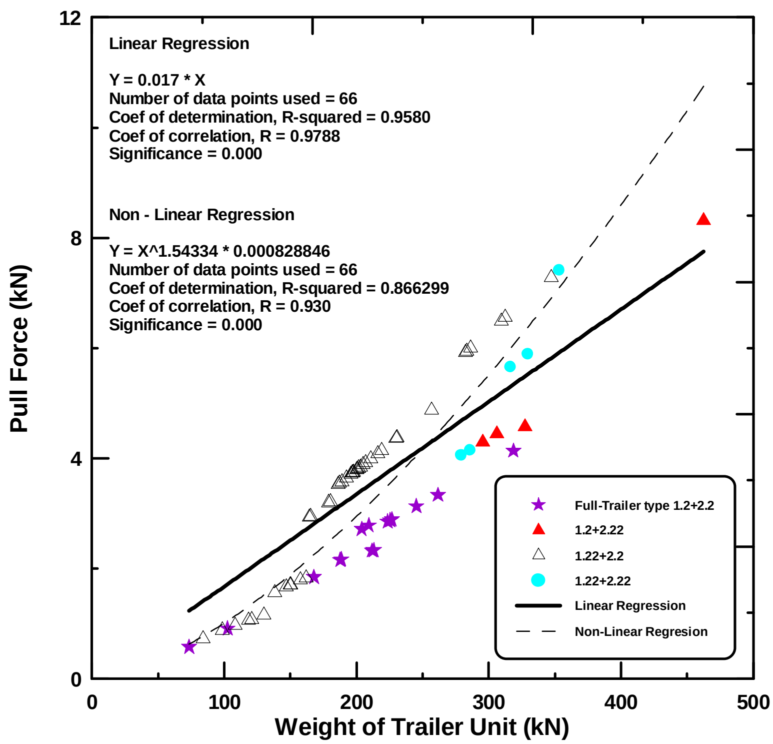

Figure (1) Correlation between pull force and weight of trailer unit.

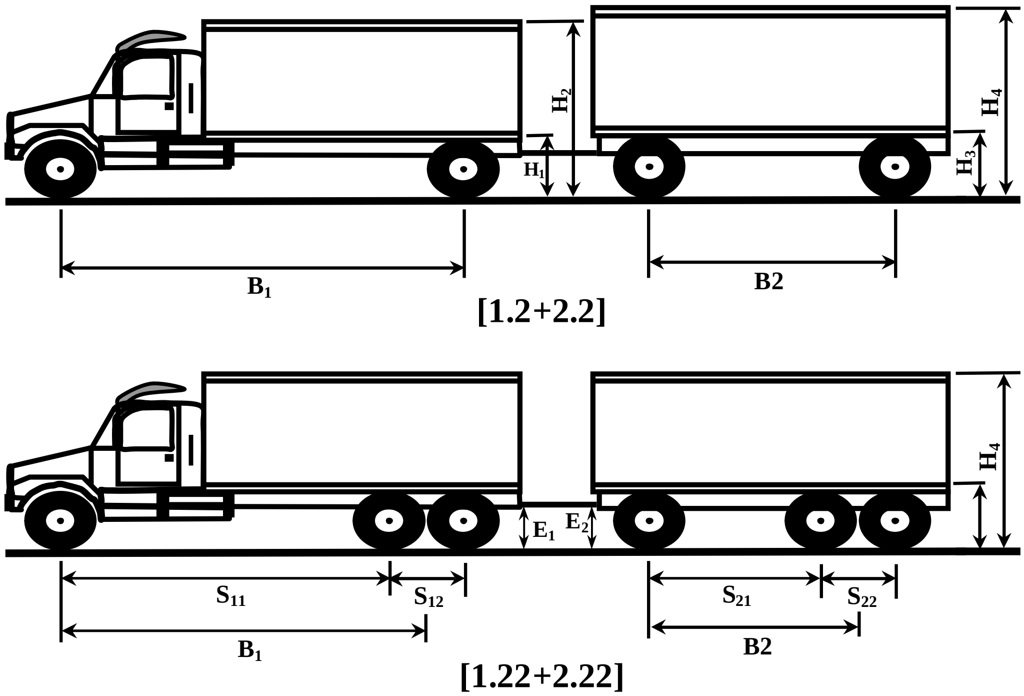

Figure (2) Vehicles dimensions for (1.2+2.2) and (1.22+2.22) full-trailers.

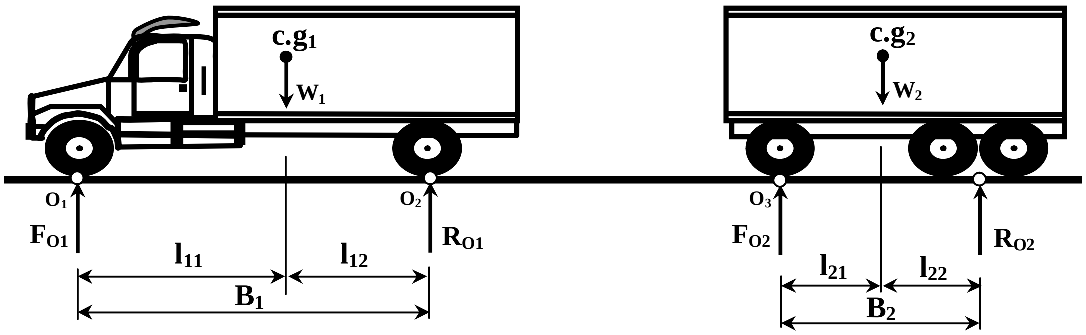

Figure (3) Forces acting on a full-trailer standing on a level road (no motion).

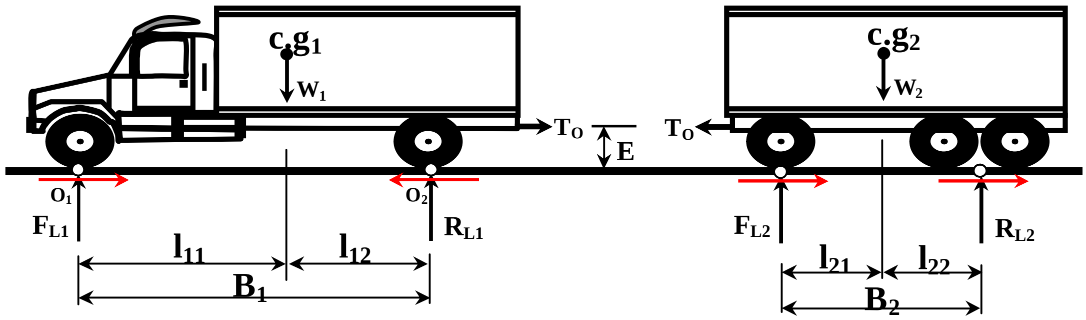

Figure (4) Forces acting on a Full-trailer on a level road moving with uniform motion.

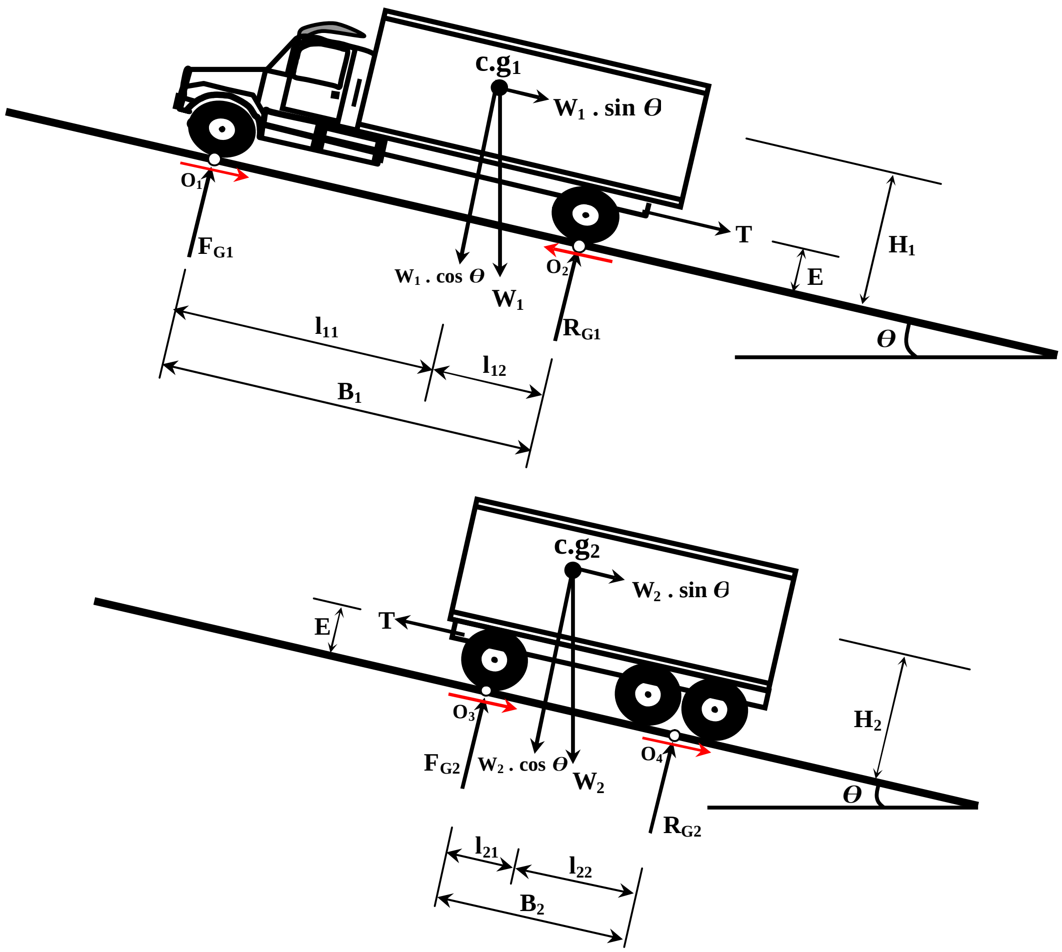

Figure (5) Forces acting on a Full-trailer moving on an upgrade with uniform motion.

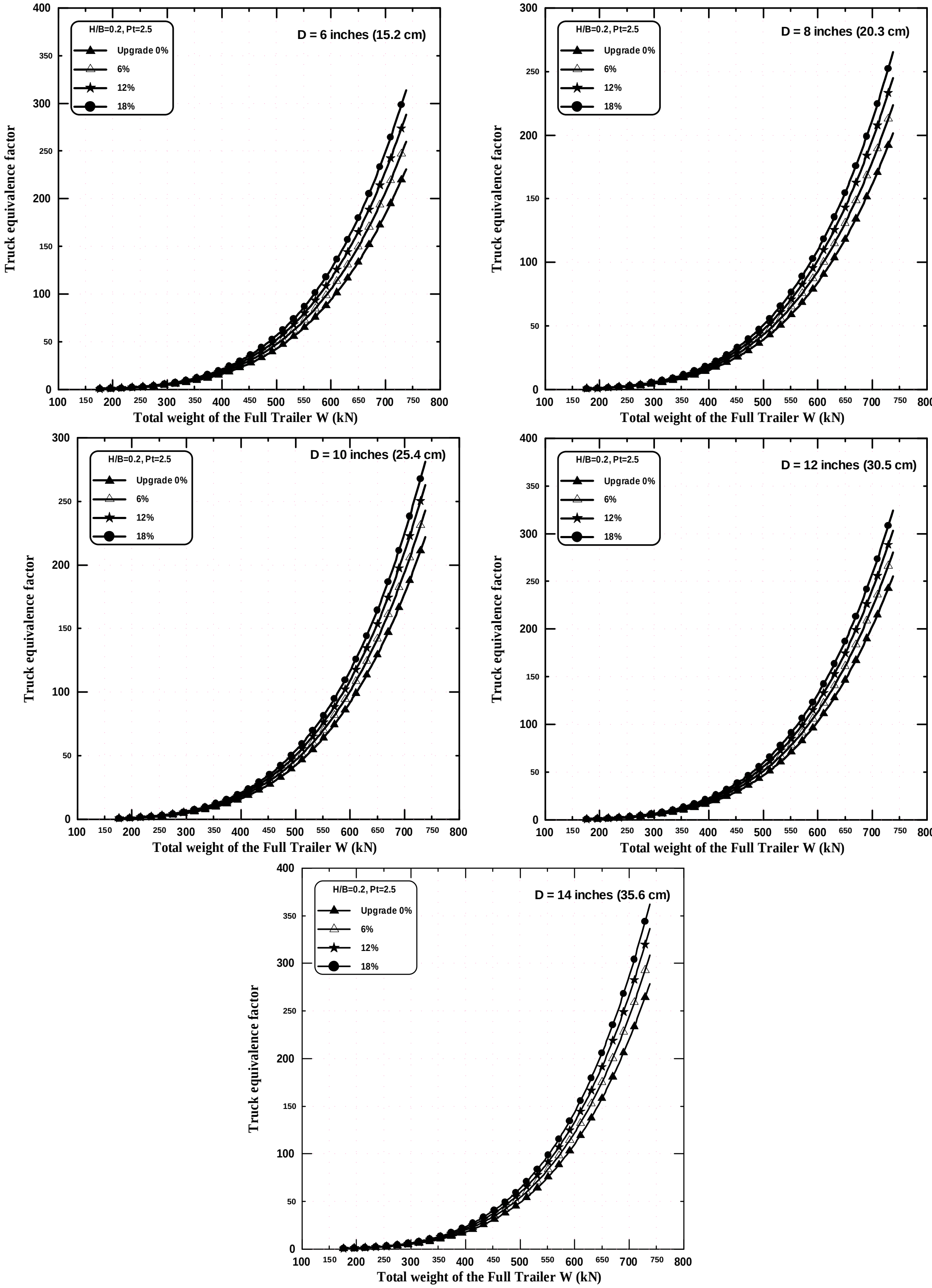

Figure (6) Equivalence factors for Full-Trailers of type 1.2+2.2 on upgrades, for H/B =0.2, p_t=2.5, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm).

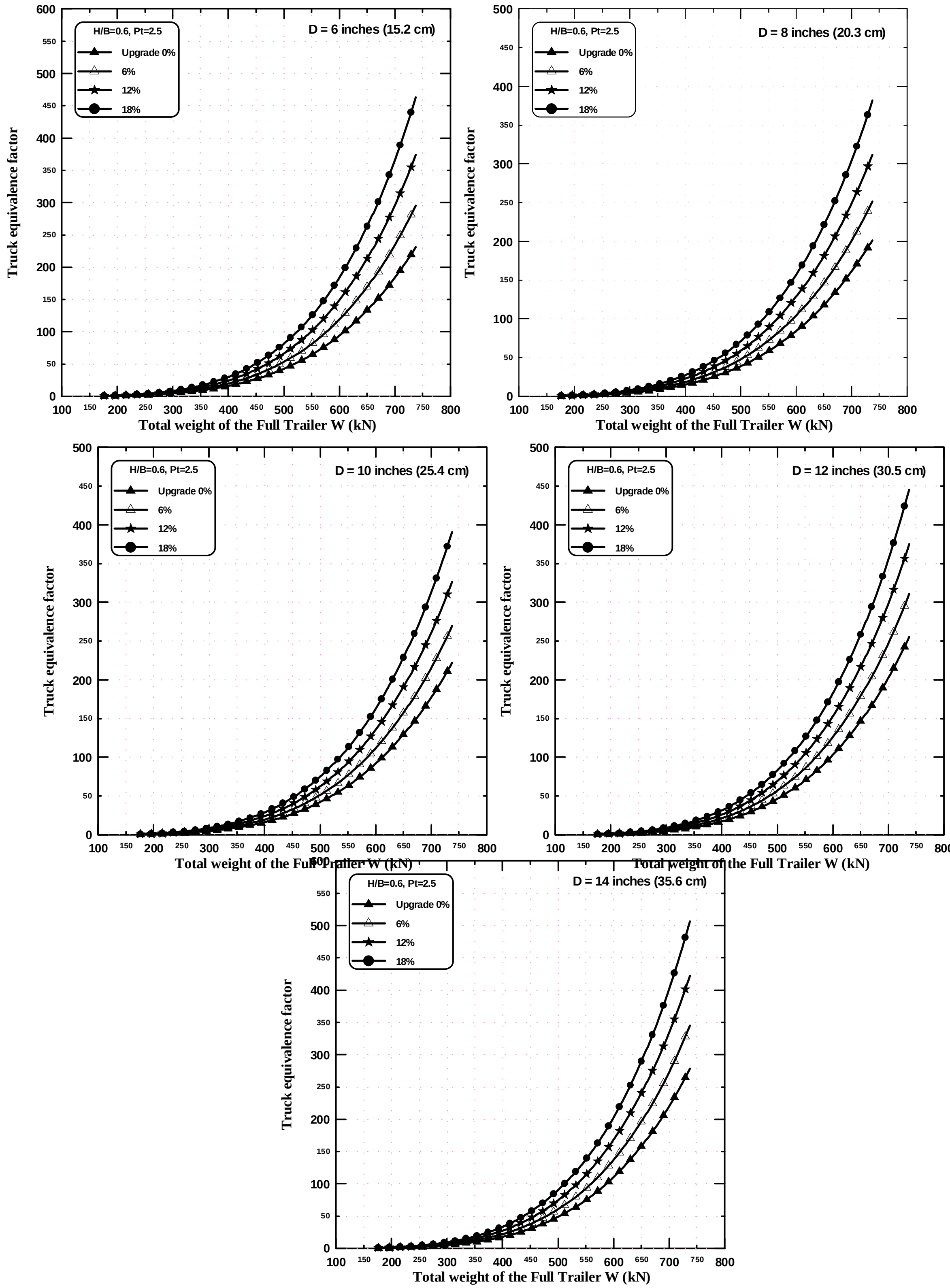

Figure (7) Equivalence factors for Full Trailers of type 1.2+2.2 on upgrades, for H/B =0.6, p_t=3, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm).

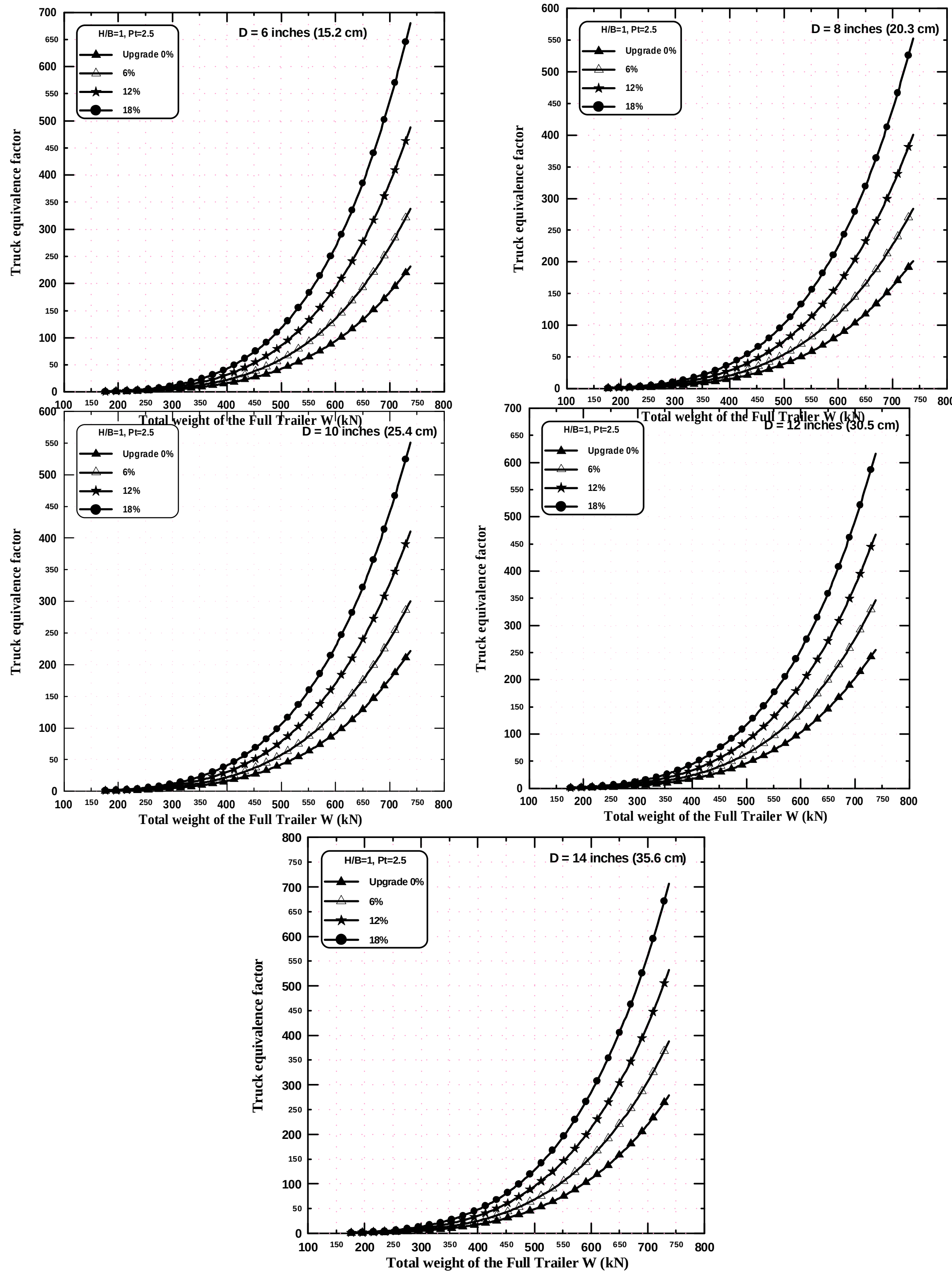

Figure (8) Equivalence factors for Full Trailers of type 1.2+2.2 on upgrades, for H/B =1.0 p_t=2.5, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm).

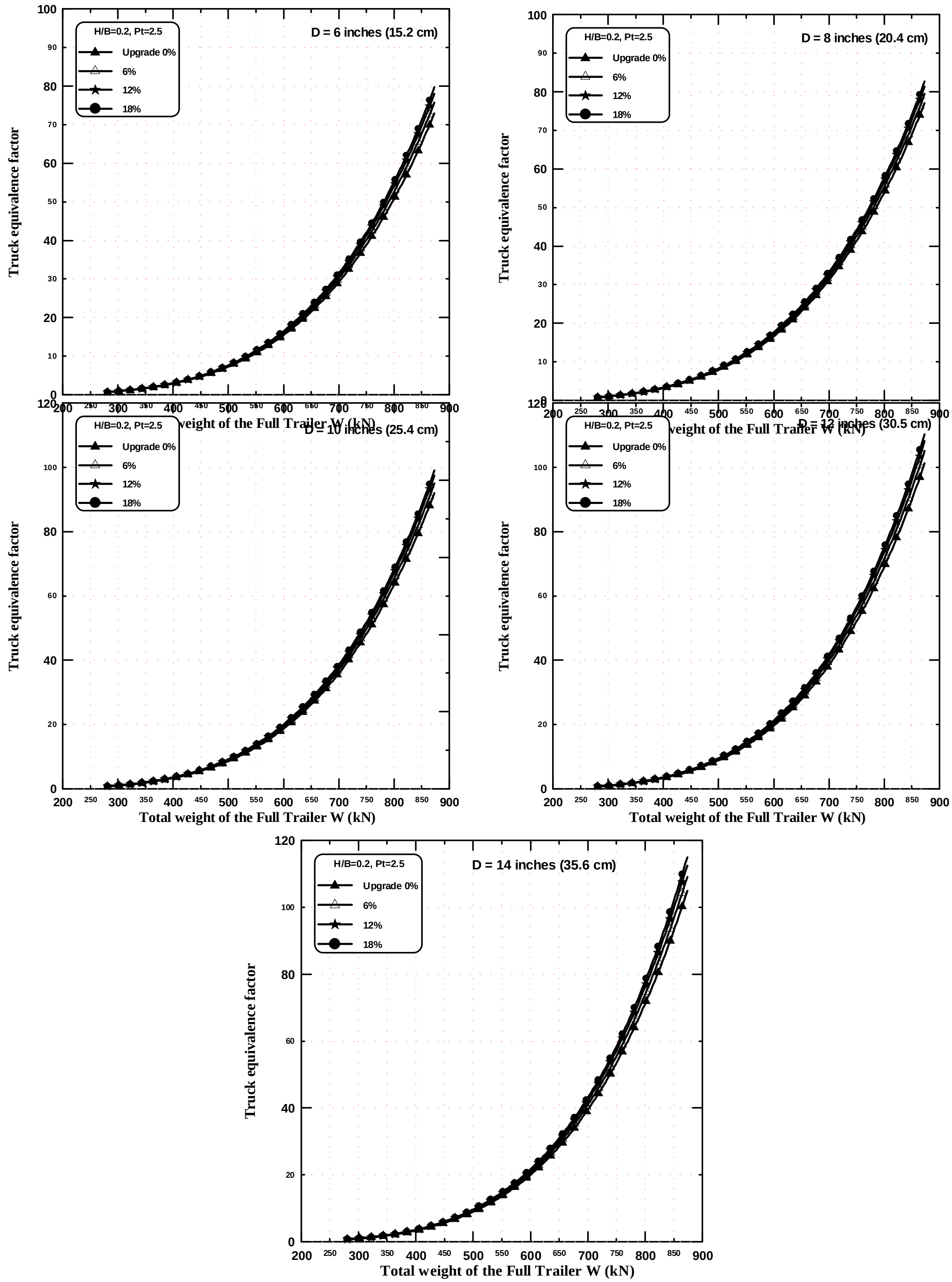

Figure (9) Equivalence factors for Full Trailers of type 1.22+2.22 on upgrades, for H/B =0.2, p_t=2.5, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm).

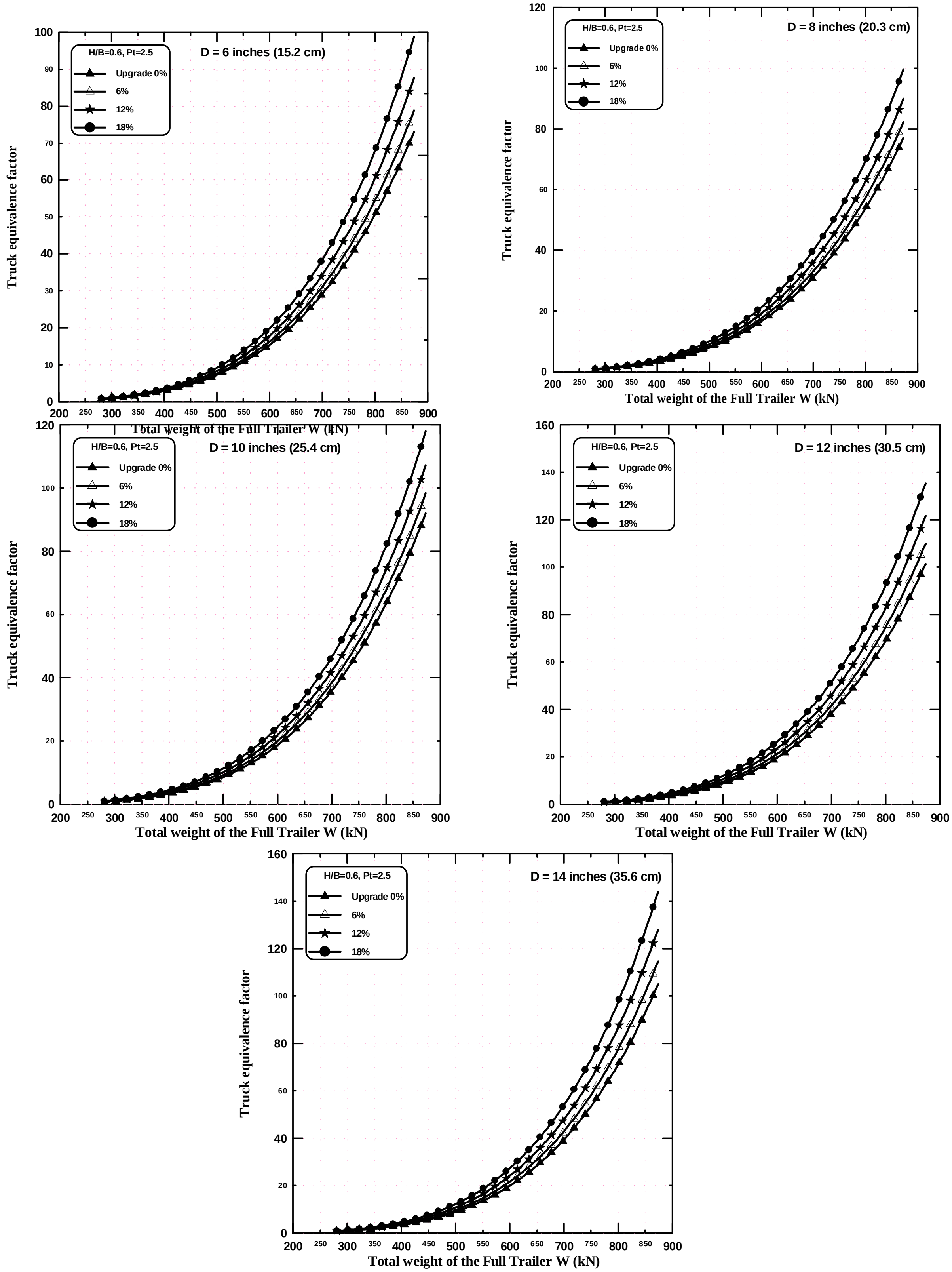

Figure (10) Equivalence factors for Full Trailers of type 1.22+2.22 on upgrades, for H/B =0.6, p_t=2.5, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4 , 30.5 and 35.6 cm).

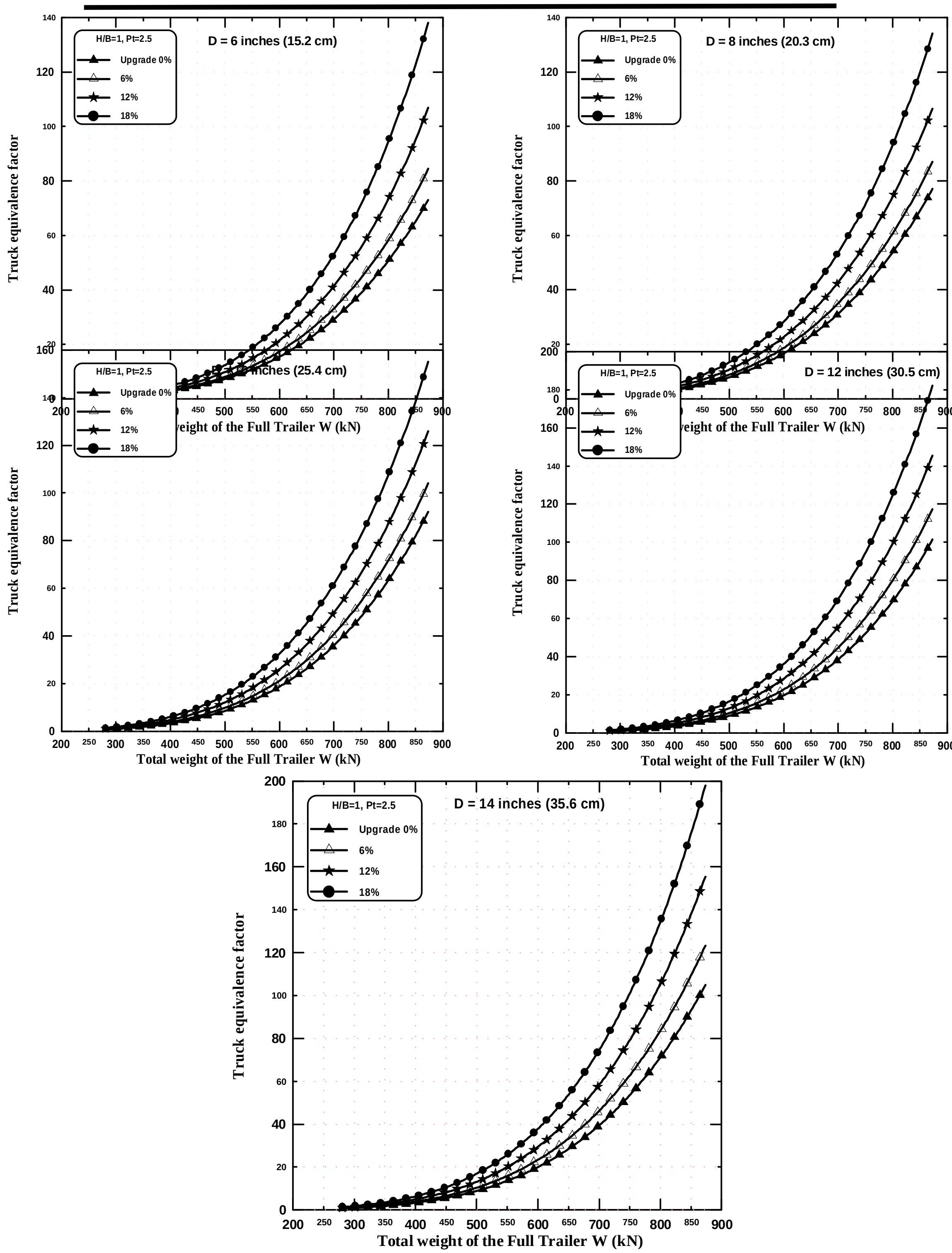

Figure (11) Equivalence factors for Full Trailers of type 1.22+2.22 on upgrades, for H/B =1.0, p_t=2.5, and D=6, 8, 10, 12, and 14 inches (15.2, 20.3, 25.4, 30.5 and 35.6 cm).