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CONCRETE PAVEMENT TRUCK EQUIVALENCE FACTORS FOR UPGRADES

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ABSTRACT

Presented in this paper are the upgrade truck equivalence factors for single unit trucks of type, 1.2 and 1.22 which are not covered by AASHTO. The equivalency factors for front and rear axles of single unit trucks were developed using AASHO Road Test equation after considering the decrease in front axle load and the increase in rear axle load due to the axle load redistribution on upgrades. The axle loads on upgrades are function of position of center of gravity of the truck, wheel base, upgrade magnitude and truck weight. The truck equivalence factors are obtained by summing up the equivalency factors of front and the corresponding rear axles. For upgrade truck equivalence factors the new term H / B representing the ratio of the height of the center of gravity H to the base length of single unit truck is of great importance. The upgrade truck equivalence factors were developed taking into consideration the following three values for upgrade namely; 0%, 8% and 12%, four values of slab thickness namely; 6, 8, 10 and 12 inches (15.24, 20.32, 25.40 and 30.48 cm) and two extreme ratios of H / B of 0.2 and 1.0. Three values for terminal levels of serviceability of 2, 2.5 and 3 were considered.

The paper reveals that the upgrade truck equivalence factors increase as the upgrade slopes as well as slabs thickness increase. The increase in the equivalence factors is of significance at the higher values of H / B than at the lower ones.

INTRODUCTION

In most countries there is a tendency for operators of heavy vehicles to exceed legal axle load and gross vehicle weight limits, as the unit cost of freight movement decreases with increasing vehicle load and size. Following Van Wijk and Lovell [1] and Van Wijk et. al. [2], the pumping process under concrete pavement increases by increasing the number of repetitions of equivalent single axle loads during the design life of pavement. As excessive axle loads cause a serious increase in the total equivalent single axle load (ESAL) applications, the expected pavement damage will increase too. The cost of the resultant damage caused to bridges and to pavements is born by the highway authority and the increased costs of accidents and environmental pollution have to be met by the community.

Pavement failure may be caused by several factors. The most important factors in the Middle East include excessive loads, high repetitions of loads and high tire pressures [3,4,5,6]. Razouki and Abu-Shaecr [7] reported that the serious pumping under concrete pavements in Iraq is due to excessive axle loads. Such type of excessive axle loads becomes more damaging on upgrades than on horizontal highways due to axle load redistribution as discussed below.

AASHTO LOAD EQUIVALENCE FACTORS

One of the most widely used forms of equivalency factors for highway analysis are those developed from the AASHO Road Test equation. The AASHTO equivalency factors [8] for rigid pavements depend on pavement rigidity, load characteristics and the terminal level of serviceability selected as the pavement failure point. For rigid pavements, the rigidity is expressed by the thickness of pavement slab and the AASHTO equivalency factor is given by the following formula [3]:

$$Fj = \frac{(L1 + L2)^{a} \; 10^{G/\beta}}{(18 + 1)^{a} \; 10^{G/\beta i} \; (L2)^{b}} \tag{1}$$

where

Fj = Equivalence factor for a given axle group and pavement type.
L1 = The axle load being considered (kips).
L2 = Designation of axle type (i.e. L2=1,2 and 3 for single, tandem and triple axles respectively).
a & b = Constants, where (a = 4.62, b = 3.28 for rigid pavements).

$$G = \log_{10} \left(\frac{Co - pt}{Co - 1.5} \right) \quad (2a)$$

Co = Initial serviceability = 4.5 for rigid pavements.
Pt = Terminal level of serviceability (2 for minor highways and 2.5 or 3 for major highways).

$$\beta = 1 + 3.63 * (18 + 1)^{5.2} / (D + 1)^{8.46} (L2)^{3.52} \quad (2b)$$

D = Thickness of rigid pavement slab (inches).

$$\beta l = 1 + 3.63 * (L1 + L2)^{5.2} / (D + 1)^{8.46} (L2)^{3.52} \quad (2c)$$

The AASHTO [8] summarizes in tables the results of equation (1) for rigid pavements for various axle loads of single, tandem and triple axles. These values were determined for terminal levels of serviceability of 2, 2.5 and 3.

It is important to note here, that these values were calculated for level highways. Thus, the purpose of this work is to determine the equivalency factors for single and tandem axle loads of single unit trucks on upgrades for rigid pavements and for various terminal levels of serviceability.

CHARACTERISTICS OF SINGLE UNIT TRUCKS

Axle loads of commercial vehicles play a vital part in both design and maintenance of road pavements. Due to the great importance of commercial traffic, commercial vehicles are classified into their major groups namely, single unit vehicles (trucks), semi-trailers (articulated trailers) and trailers. Fig.1 shows the two types of single unit trucks and their code numbers considered in this work. As shown in this figure, type 1.2 truck refers to a single unit truck with a single tired front single axle

Fig. 1. Single unit trucks characteristic and code numbers.

and dual tired rear single axle while type 1.22 refers to a single unit truck with a conventional front single axle and dual tired tandem axle.

REDISTRIBUTION OF AXLE LOADS ON UPGRADES

The distribution of axle loads of vehicles on an upgrade is different from that on a level surface. For a vehicle on an upgrade, there will be a redistribution of axle loads due to the moment introduced by the component of the weight parallel to the road surface. This moment increases as the height of the center of gravity above the road surface increases. The rear axle load (non-steering axle load) perpendicular to the pavement increases by a value equal to ΔP, while the front axle load (steering axle load) decreases by the same amount. Therefore, the rear axle load increases with increasing upgrade, while the front axle load decreases with increasing upgrade. Following Fig.2, the analysis of the forces and moments yields the following axle loads on upgrades:

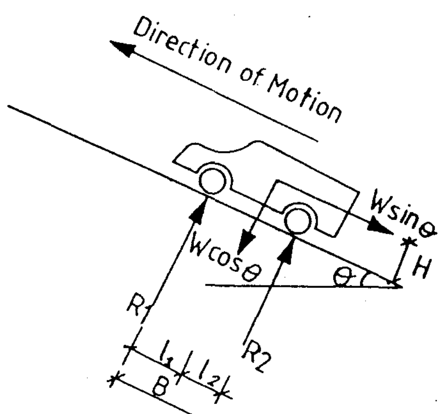

Fig. 2. Axle loads on upgrades

Concrete Pavement Truck Equivalence Factors for Upgrades

$$R1 = W\cos\theta\ l_2/B - W\sin\theta\ H/B \qquad (3a)$$

$$= R1^* - \Delta P$$

$$R2 = W\cos\theta\ l_1/B + W\sin\theta\ H/B \qquad (3b)$$

$$= R2^* + \Delta P$$

$$\Delta P = W\sin\theta\ H/B = (Ro + Fo)\sin\theta\ H/B = Ro(1+\alpha)\sin\theta\ H/B \qquad (3c)$$

$$R1^* = W\cos\theta\ l_2/B, \qquad R2^* = W\cos\theta\ l_1/B$$

where

R1 = Front axle load on upgrade.
R2 = Rear axle load on upgrade.
W = Total weight of a truck.
θ = Angle of slope, $\tan\theta$ = grade .
H = Height of the center of gravity of the truck (perpendicular to the pavement)

above the pavement.

B = Wheel base length of single unit trucks.
l_1, l_2 = Distances from center of gravity of truck to front and rear axles respectively

Ro = Original rear axle load (on a level surface).
Fo = Original front axle load (on a level surface).
α = Ratio of steering to non-steering axle load.

Thus, on upgrades the rear axle load becomes:

$$R2 = R2^* + \Delta P = Ro\cos\theta + \Delta P = (Ro + W\tan\theta\ H/B)\cos\theta \qquad (4a)$$

while the front axle load becomes:

$$R1 = R1^* - \Delta P = Fo\cos\theta - \Delta P = (Fo - W\tan\theta\ H/B)\cos\theta \qquad (4b)$$

It is quite obvious from equations (4a and 4b) that the axle loads on upgrades are functions of height of center of gravity, wheel base and the magnitude of the upgrade. The steering axle loads on a level highway are lower than the corresponding non-steering axle loads. On upgrades, the steering axle load decreases while the heavier corresponding non-steering axle load increases by the same amount. Although the increase in the non-steering axle load is the same as the decrease in the steering axle load, the increase in damaging effect of non-steering axle load is much greater than the decrease in the damaging effect of the steering axle load. This is due to the fact that the damaging effect is a highly non-linear function of axle load magnitude. Following the AASHTO [9], the maximum allowable grade ranging from 7 to 12 percent with an average value of 8 percent depending on topography. If more important highways are considered, the maximum grade of 7 to 8 percent are representative for 30mph design speed of trucks. For low volume highways, grades may be 2 percent steeper. The corresponding maximum grade in mountainous areas is 16 percent. According to these values of maximum grades, the following three values namely 0%, 8% and 12% for the slope (tan θ) were selected in this work. The ratio H/B of the height of center of gravity of the truck (H) to the wheel base (B) is another important term affecting the equivalency factors. Following Timothy [10] and Lenker [11], the ratio of H/B is in the range of 0.2 to 1.0 for unloaded and loaded trucks. Thus, these two extreme values of 0.2 and 1.0 were adopted in this work for determining the equivalency factors on upgrades. Regarding the wheel base for single unit trucks, a survey was carried out in Baghdad by the authors. This survey revealed the following range of (3.70m to 5.67m) for wheel base of single unit trucks. The types of single unit trucks covered in the survey are listed in Table 1. To arrive at the proper combination of front and rear axle loads for single unit trucks, use was made of the axle load survey carried out by Alshefi [12] together with the junior author. Tables 2 and 3 show the front and the corresponding rear axle loads for single unit trucks of type 1.2 and 1.22 respectively. In addition, the maximum value of front single axle load of 9.50 tonne was combined with the maximum rear single axle load of 30 tonne for the case of 1.2 trucks as given by Razouki and Razouki [6]. Similarly, the maximum front single axle load of 11 tonne was combined with the maximum rear tandem axle load of 49 tonne as reported by Razouki and Razouki [6].

Table 1. Wheel base for single unit trucks type 1.2 and 1.22 in common use in Iraq as obtained form axle load survey.

SINGLE UNIT TRUCK 1.2	WHEEL BASE (mm)
RC – Hino bus	
RC 301 PE	5200
RC 401 P	5200
RC 321 PE	5670
RC 421 P	5670
Ky – Hino truck	
Ky 200	4700
TE – Hino truck	
TE 220 E	4400
KB – Hino diesel truck	
KB 302 E	3700
KB 402	3700
KB 322 E	5050
KB 422	5050
KB 342 E	5550
KB 442	5550
Schwing concrete pump Mercedes N 1033	4520
SINGLE UNIT TRUCK 1.22	**WHEEL BASE (mm)**
Volvo type AM6SH	4905
Mercedes	4320

Table 2. Axle loads for single unit trucks of type 1.2 weighed in the axle load survey.

NO.	F.A.L.	R.A.L.	NO.	F.A.L.	R.A.L.
1	4	7	31	8.20	18.10
2	6	14.40	32	6.70	15.80
3	8.60	19.20	33	4.40	14.20
4	7.50	16.30	34	6.00	14.50
5	8.40	18.90	35	7.10	16.20
6	8.20	19.30	36	7.70	19.20
7	6.90	18.30	37	8.20	19.70
8	7.13	19.20	38	8.50	22.40
9	6.20	17.50	39	9.50	20.32
10	5.20	10.40	40	8.30	20.40
11	7.350	20.65	41	7.30	19.30
12	6.50	13.50	42	4.80	9.80
13	8.20	19.30	43	6.00	12.00
14	6.30	15.40	44	5.80	10.50
15	8.60	19.10	45	5.30	9.50
16	6.90	18.50	46	5.50	12.00
17	7.50	18.30	47	6.30	10.20
18	9.50	19.50	48	8.20	22.50
19	8.70	17.40	49	8.70	19.70
20	5.60	14.80	50	6.80	19.90
21	7.70	19.20	51	9.00	23.20
22	7.90	19.90	52	7.30	20.30
23	8.20	20.50	53	5.30	19.20
24	8.20	22.60	54	4.50	11.50
25	7.50	20.40	55	2.00	2.00
26	8.20	21.30	56	3.20	5.30
27	8.90	20.50	57	4.20	6.00
28	8.90	21.30	58	4.40	5.20
29	9.30	22.40	59	3.10	4.20
30	7.60	21.40	60	3.40	4.20

F.A.L. : Front Axle Load (Tonne)
R.A.L. : Rear Axle Load (Tonne)

Table 3. Axle loads for single unit trucks of type 1.22 weighed in the axle load survey.

NO.	F.A.L.	R.A.L.	NO.	F.A.L.	R.A.L.
1	7.90	26.96	31	10.20	30.00
2	8.02	26.98	32	6.00	18.10
3	6.14	14.46	33	9.00	24.40
4	8.44	24.36	34	7.40	17.40
5	9.40	28.00	35	8.80	26.60
6	6.13	26.50	36	8.90	30.87
7	7.00	23.50	37	9.20	29.30
8	7.30	36.30	38	10.00	30.20
9	6.30	26.40	39	9.80	32.00
10	11.0	26.70	40	7.50	28.00
11	8.40	24.30	41	7.00	25.50
12	9.20	25.00	42	6.30	23.50
13	7.30	30.40	43	5.60	20.70
14	9.70	31.00	44	6.30	14.70
15	9.20	26.30	45	5.80	13.60
16	9.80	25.00	46	4.90	12.80
17	9.70	27.20	47	5.50	12.50
18	7.90	26.70	48	6.00	13.20
19	8.00	26.80	49	5.50	19.80
20	6.10	24.40	50	6.00	20.20
21	8.40	24.30	51	8.50	24.20
22	9.30	28.00	52	7.80	28.20
23	9.20	25.00	53	7.30	29.50
24	5.40	12.40	54	6.70	27.40
25	6.00	13.70	55	9.50	27.60
26	6.20	13.50	56	8.30	19.50
27	6.50	18.20	57	8.70	20.30
28	5.60	17.30	58	9.10	21.30
29	7.30	17.70	59	7.90	23.00
30	6.70	15.40	60	6.00	9.50

F.A.L. : Front Axle Load (Tonne)
R.A.L. : Rear Axle Load (Tonne)

Since for heavy loaded trucks the H/B ratio is close to unity, the increase ΔP in the non-steering axle load can thus be obtained from Eq. (3c) as follows:

$$\frac{\Delta P}{Ro} = (1 + \alpha) * \sin\theta$$

For small θ, the grade ($\tan\theta$) can replace $\sin\theta$, and the relative increase in non-steering axle load can thus be written as follows:

$$\frac{\Delta P}{Ro} = (1 + \alpha) * \text{grade} \qquad (5)$$

A thorough study of the variation of α with Ro for all trucks surveyed showed a good average α value of 0.44 for type 1.2 and of 0.34 for type 1.22 trucks. The substitution of these average α values into equations 5 yields:

$$\frac{\Delta P}{Ro} = 1.44 * \text{grade} \qquad \text{for 1.2 trucks}$$

$$\frac{\Delta P}{Ro} = 1.34 * \text{grade} \qquad \text{for 1.22 trucks}$$

Accordingly, for rapid estimation of ΔP, it is recommended to adopt an increase in non-steering axle load of about 10% to 15% to take into account the effect of significant upgrade on the increased damage of rear axles.

AASHTO EQUIVALENCY FACTORS FOR SINGLE UNIT TRUCKS ON UPGRADES

Now making use of the values for the various parameters discussed in the preceding section together with the slab thicknesses of 6, 8, 10 and 12 inches (15.24, 20.32, 25.4 and 30.48 cm) a computer program was written in FORTRAN 77 to calculate the equivalency factors for single unit trucks of type 1.2 and 1.22 on upgrades using equations (1) and (2). The truck equivalence factors on upgrade was obtained by summing up the equivalency factors for the front axle load on upgrade together with the corresponding rear axle load on upgrade. Note that the reduction in equivalency factor of the front axle on upgrade (as compared to level highways) is much less than the increase in the equivalency factor of the rear axle load on upgrade.

Figure 3 shows the truck equivalence factors on upgrade for truck type 1.2, while Fig. 4 shows the same relation but for type 1.22 truck. Note that both figures are devoted to a relatively low center of gravity with H/B ratio of 0.2 as well as high one with H/B of 1.0, while the terminal level of serviceability was taken as pt = 2.5. These figures were developed for a slab thickness value of 8 inches (20.32cm). Similarly, figures 5 and 6 were developed for slab thickness of 12 inches (30.48cm). It is quite obvious from these figures that the truck equivalence factors increase with increasing upgrade as well as slab thickness.

It is also clear from these figures that the upgrade equivalence factors are significantly affected by the slope of the upgrade as well as the ratio of H / B more than the slab thickness. The effect is more pronounced for the higher values of upgrade and H / B ratio. This means that the cases of higher slope and H / B values cause serious damage and danger to truck and pavements. This effect is not significant for the low values of slopes and H / B ratio as shown in figures.

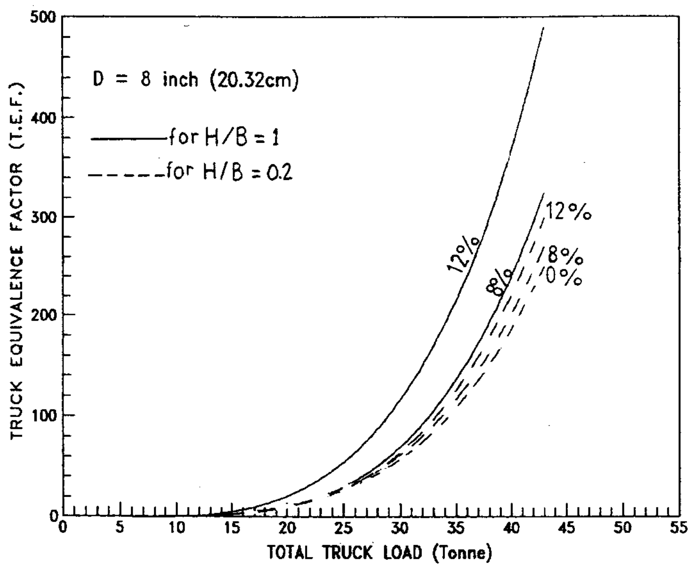

Fig. 3. Upgrade truck equivalence factor for single unit trucks type 1.2

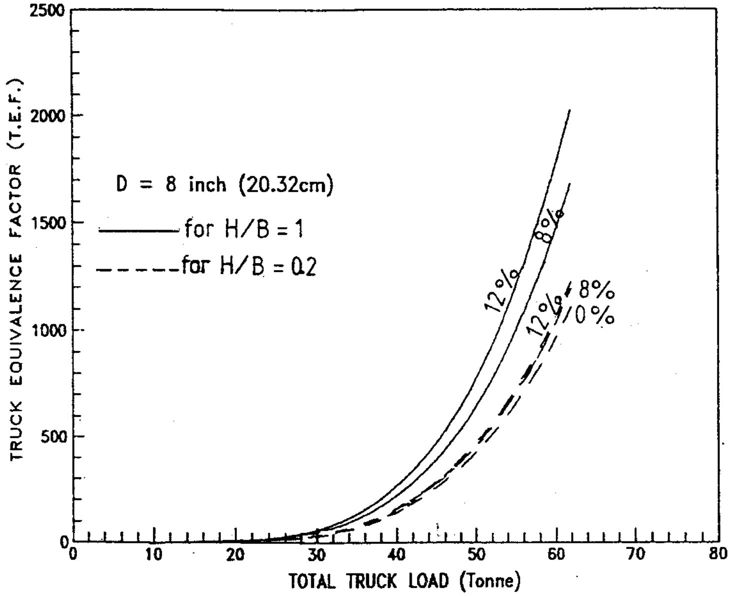

Fig. 4. Upgrade truck equivalence factors for single unit trucks type 1.22

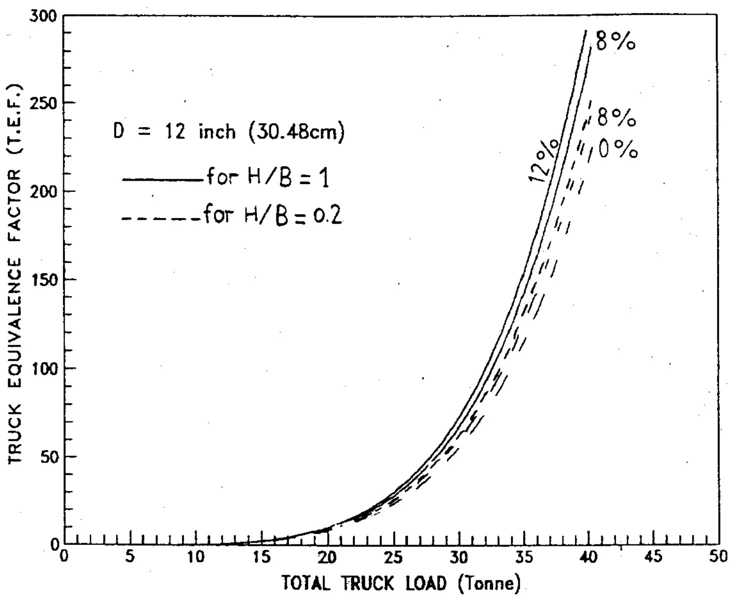

Fig. 5. Upgrade truck equivalence factors for single unit trucks type 1.2

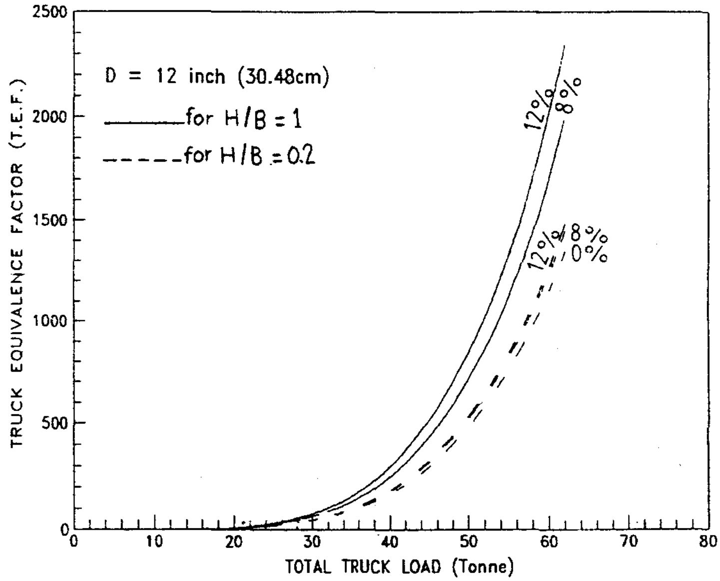

Fig. 6. Upgrade truck equivalence factor for single unit trucks type 1.22

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions can be drawn from this paper:

On upgrades, the magnitude of increase in the rear (non-steering) axle load perpendicular to the pavement is equal to the magnitude of decrease in the front (steering) axle load perpendicular to the pavement. The increase in damaging effect of rear axle loads on upgrade is much larger than the decrease in damaging in damaging effect of the front axle load.

The amount of increase in the rear axle load and of decrease in front axle load increases with the increase in slope and the ratio of height of center of gravity to wheel base of the truck.

On an upgrade the equivalency factor for the rear axle load increases faster than the decrease in equivalency factor for the front axle load.

The truck equivalency factor increases with increase in slope, H/B ratio and slab thickness. This increase is quite significant for the higher values of the slope, H/B ratio as well as the slab thickness.

For rapid estimation of increase in non-steering axle load for the case of significant upgrade, it is recommended to adopt an increase of 10% to 15% in damage effect to take into account the effect of upgrade on the increased damage of rear axles.

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