EFFECT OF WHEEL CONFIGURATIONS ON THE STRUCTURAL DESIGN OF FLEXIBLE PAVEMENTS

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ABSTRACT

The aim of this research paper is to study the effect of wheel configurations on the structural design of flexible pavements. The study indicated that the wheel configurations should have significant influence on the structural design of the pavement thickness. New design formulas are presented for determination of pavement thickness taking into consideration this effect in addition to other important factors related to traffic and pavement material characteristics.

1. INTRODUCTION

In a previous study the author [1] investigated different factors affecting pavement thickness regarding traffic and pavement materials, such as dynamic and static modulus of deformation, Poisson's ratio of subgrade and base courses, wheel load and number of load repetitions. The wheel load has been considered in this study as a single wheel or single tire only.

In this current study the effect of different wheel configurations on the pavement thickness is studied. This is extremely important since most of the commercial vehicles have dual and dual tandem rear wheels.

2. STRUCTURAL APPROACH

The pavement is considered as a two-layers system, which is composed of a subgrade and a base course only. The wearing surface and subbase are not considered, since the main object of the surface course is to provide a smooth wearing resisting surface, whereas the main object of subbase is to provide non-frost layer, in frost susceptible regions. The two layers system represents the unpaved or mechanically-stabilized earth roads. According to previous study on two layers-system the author [1] has presented the following equation:

$$\frac{0.006\,E_d}{1+0.7\log N}=\frac{W}{3\sqrt{3}\,H^2}\left(6\frac{1-\upsilon_1^2}{E_1}\cdot\frac{E_2}{1-\upsilon_2^2}\right)^{2/3} \quad (1)$$

where

E_d = dynamic modulus of elasticity of the subgrade

N = number of load repetitions
W = Wheel load
H = the thickness of first layer [Base Course]
υ_1 = poisson's ratio of the first layer
υ_2 = poisson's ratio of the second layer [subgrade]
E_1 = modulus of deformation of the first layer
E_2 = modulus of deformation of the second layer

The above equation can be used for the design of flexible pavement thickness and is valid for the single wheel (single tire) only.

It is aimed to consider the effect of wheel configurations, such as dual and dual tandem wheels, since these can have a considerable effect on the stress distribution within and below the highway pavements.

The forecited equation must therefore be modified to take into consideration the effect of dual and dual tandem assembly.

2.1 *Case of Dual wheels Assembly*

Based on flexible pavement theories [2,3,4], the equivalent single wheel load can be obtained analytically as:

$$\log Q=\log P+\frac{\log 2P-\log P}{\log 2S-\log d/2}(\log Z-\log d/2) \quad (2)$$

where

Q = equivalent single wheel load

P = Tire load
S = distance between the centers of the individual tires
d = clear distance between tire edges
Z = The distance under the road surface, at which Q is to be determined, $(\frac{d}{2} \leq Z \leq 2S)$

Equation (2) can be written in the following forms:

$$\log Q = \log P + \frac{\log 2}{\log \frac{4S}{d}} \log (\frac{2Z}{d})$$

or

$$\log Q = \log P + \frac{0.301}{\log \frac{4S}{d}} \log (\frac{2Z}{d})$$

$$\log Q = \log P + \log \left[(\frac{2Z}{d})^{\frac{0.301}{\log \frac{4S}{d}}} \right]$$

$$\log Q = \log \left[P.(\frac{2Z}{d})^{\frac{0.301}{\log \frac{4S}{d}}} \right] \quad (3)$$

By eliminating the logarithm from equation (3) it can be written as follows:

$$Q = P\,(\frac{2Z}{d})^{\frac{0.301}{\log \frac{4S}{d}}} \quad (4)$$

By substituting the value of Q from equation (4) in equation (1) instead of W, we obtain the following equation:

$$\frac{0.0312\, E_d H^2}{1 + 0.7 \log N} = \left[P.(\frac{2Z}{d})^{\frac{0.301}{\log \frac{4S}{d}}} \right] \left[6 \frac{1-\upsilon_1^2}{E_1} . \frac{E_2}{1-\upsilon_2^2} \right]^{2/3} \quad (5)$$

By assuming $\upsilon_1 = \upsilon_2$, since the effect of these factors is not significant [1], Equation (5) takes the following from:

$$\frac{0.0312\, E_d H^2}{1 + 0.7 \log N} = \left[P. \left(\frac{2Z}{d}\right)^{0.301/\log\left(\frac{4S}{d}\right)} \right] \left[6 \frac{E_2}{E_1} \right]^{2/3} \quad (6)$$

2.2 *Case of Dual-Tandem Wheel Assembly*

By the same manner the equivalent single wheel load Q in case of dual-tandem wheels assembly can be obtained as follows:

$$\log Q = \log P + \frac{\log 4P - \log P}{\log 2D - \log \frac{d}{2}} (\log Z - \log \frac{d}{2}) \quad (7)$$

where

D = diagonal distance between the centers of the front and rear tires in dual-tandem wheels assembly.
Z = the distance under the road surface, at which Q is to be calculated $(\frac{d}{2} \leq Z \leq 2D)$

Equation (7) can be written also in the following form:

$$Q = P.(\frac{2Z}{d})^{\frac{0.602}{\log \frac{4D}{d}}} \quad (8)$$

By substituting the value of Q from equation (8) in equation (1) instead of W, and by putting $\upsilon_1 = \upsilon_2$, we obtain the following equation:

$$\frac{0.0312\, E_d H^2}{1 + 0.7 \log N} = \left[P(\frac{2Z}{d})^{\frac{0.602}{\log \frac{4D}{d}}} \right] \left[(6 \frac{E_2}{E_1}) \right]^{2/3} \quad (9)$$

3. DISCUSSION OF THE RESULTS

Equations (1,6) and (9) have been solved by putting Z = H and by assuming d = 20 cm, S = 50 cm and D = 145 cm, Since these values are the common dimensions for dual and dual tandem wheels assembly [5]. Based on previous experiences reasonable values of E_2/E_1, N and E_d have been chosen, which meet the properties of Highway pavement materials [6].

The graphical representations for the solution of equations 1,6 and 9 are shown in Figures (1) to (6).

3.1 *Effect of Wheel Configurations on Pavement Thickness:*

Figure (1) shows the relationship between the thickness of the pavement and the logarithm of the layers strength ratio (E_1/E_2) at different wheel configurations and 50kN tire load.

From Figure (1), it is clear that, the pavement thickness required for dual-tandem assembly is greater than the thickness required for single as well as for dual wheels assembly, and the difference decreases with the increase of the strength ratio of the layers (E_1/E_2). At $E_1/E_2 = 2$, the thickness required for dual-tandem is about 1.62 and 1.15 times the value required for single and dual wheels respectively, whereas the required thickness at $E_1/E_2 = 10$, is 1.38 and 1.1 times only.

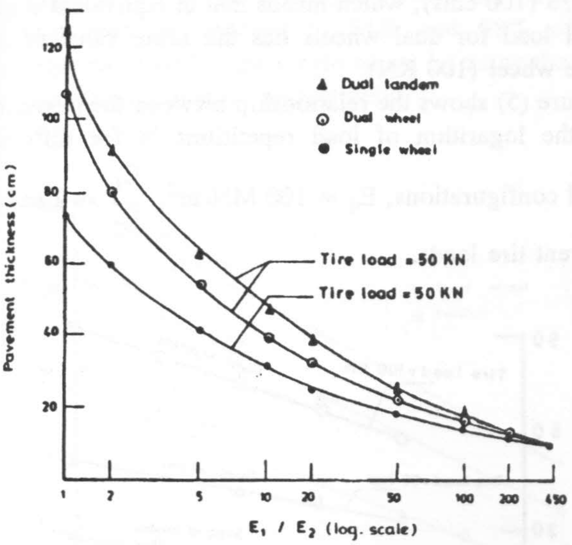

Figure 1. Relation between the pavement thickness and log. E_1/E_2 at E_d = 50 MN/m^2, N = 10^6, tire load = 50 kN, for different wheel configurations.

At values of E_1/E_2 equal to 450 or more, the different wheel configurations have the same effect, since the required pavement thickness is equal to or less than half of the clear distance between the tire edges ($\frac{d}{2}$), which means that, there is no stresses overlap, since the equivalent single wheel load equals to the tire load in this case.

Figure (2) represents the relationship between the pavement thickness and the logarithm of load repetitions N at E_1/E_2 = 1, E_d= 100 kN/m^2 and 50 kN tire load. It can be seen that the required pavement thickness for dual-tandem is greater than the thickness required for single and dual wheels assembly, and the difference increases as the number of load repetition increases. For example, the thickness required for dual-tandem at N=100 is 1.4 and 1.26 times the thickness required for single and dual wheels assembly respectively, whereas the thickness required for dual-tandem is 1.54 and 1.34 times the thickness required for single and dual wheels respectively at N = 10^6.

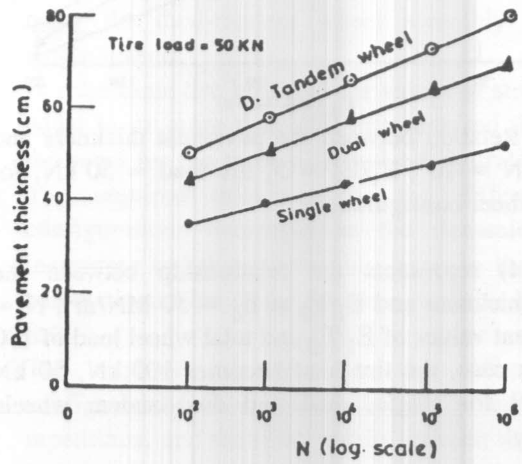

Figure 2. Relation between the pavement thickness and log. N at E_d = 100, E_1/E_2 =1, tire load = 50 kN, for different wheel configurations.

Figure (3) shows the relationship between the pavement thickness H and the logarithm of the dynamic modulus of elasticity, E_d, at N = 10^5, E_1/E_2 = 5 and 50 kN. tire load.

It may be noticed from Figure (3) that the required pavement thickness for dual-tandem is greater than the thickness required for single and dual wheels assembly, and the difference decreases as the dynamic modulus, E_d increases. The pavement thickness required for dual-tandem at E_d = 50 MN/m^2 is 1.45 and 1.3 times the thickness required for single and dual-wheels respectively, whereas the thickness required for dual-tandem is 1.2 and 1.05 times only for single and dual wheels respectively at E_d = 200 MN/m^2.

Figure (3) indicates a linear relationship between the pavement thickness H and log E_d for different wheel configurations, and it can be expressed as:

$$H = A - \beta \log E_d$$

where A and β are constants.

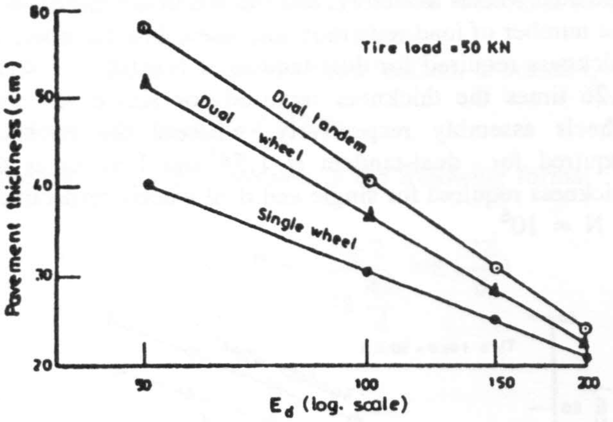

Figure 3. Relation between the pavement thickness and log. E_d at $N = 10^5$, $E_1/E_2 = 5$, tire load = 50 kN, for different wheel configurations.

Figure (4) represents the relationship between the pavement thickness and E_1/E_2 at $E_d = 50$ MN/m^2, $N = 10^6$, different values of E_1/E_2 and total wheel load of 100 kN. In this case, the tire load becomes 100 kN, 50 kN and 25 kN for single, dual and dual-tandem wheels respectively.

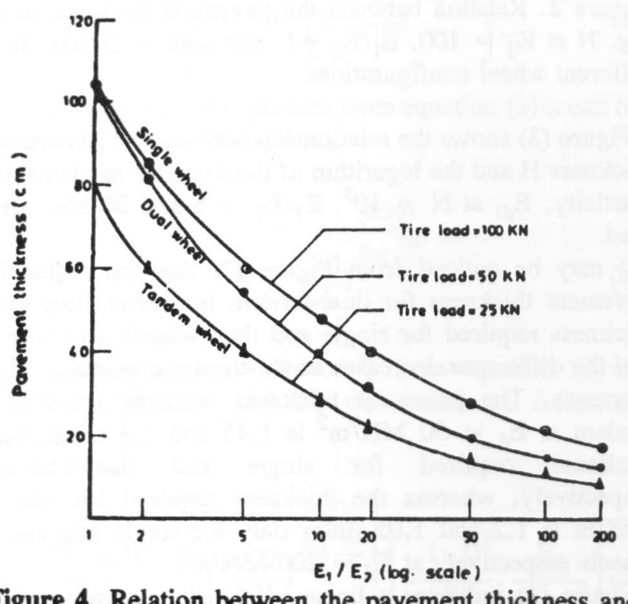

Figure 4. Relation between the pavement thickness and log. E_1/E_2 at $E_d = 50$ MN/m^2, $N = 10^6$, for different wheel configurations.

It can be seen from Figure (4) that for E_1/E_2 values of more than one, the required thickness for single wheel is greater than the thickness required for dual and dual-tandem wheels, and the difference increases with the increase of the strength ratio E_1/E_2. For example, the thickness required for single wheel at $E_1/E_2 = 10$ is 1.14 and 1.58 times the thickness required for dual and dual-tandem wheels respectively, whereas the thickness required for single wheel at $E_1/E_2 = 100$ is 1.29 and 1.92 times the thickness required for dual and dual-tandem wheels respectively. Therefore and for the same total wheel load, the required thickness can be reduced to 63% or 52% by using dual-tandem wheels and $\frac{E_1}{E_2} = 10$ or 100 respectively.

It is clear from figure (4) also that the dual and single wheels have the same effect at $\frac{E_1}{E_2} = 1$ (one layer system), since the required thickness (105 cms) is greater than 2S (100 cms), which means that th equivalent single wheel load for dual wheels has the same value of the single wheel (100 KN).

Figure (5) shows the relationship between the pavement and the logarithm of load repetitions N for different wheel configurations, $E_d = 100$ MN/m^2, $\frac{E_1}{E_2} = 2$ and at different tire loads.

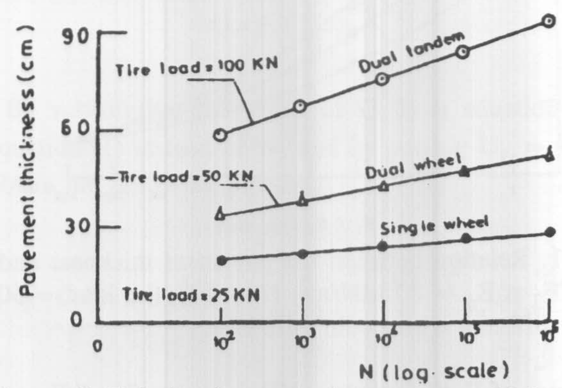

Figure 5. Relation between the pavement thickness and log. N at $E_d = 100$, $E_1/E_2 = 2$ for different wheel configurations.

It can be concluded from Figure (5) that the increase of the total load to 4 times increases the required thickness by 75% only by using dual-wheels assembly instead of single wheel, and the increase of the total load to 16 times increase the required thickness to 3.25 times only by using the dual-tandem assembly instead of single wheel.

The relationship between the pavement thickness (H) and log N is a straight line, and it can be expressed as:

$$H = A + \beta \log N$$

where A and β are constants.

Figure (6) represents the relationship between the pavement thickness and log E_d, for different wheel configurations, at $N = 10^5$, $\frac{E_1}{E_2} = 5$ and 100KN total wheel load.

It is clear from figure (6) that the required pavement thickness for single wheel is greater than the thickness required for dual and dual-tandem wheels, and the thickness required for dual wheels is greater than the thickness required for dual-tandem wheels assembly. Therefore and for the same total load, the pavement thickness can be reduced to 84% and 58% of the thickness required for the single wheel by using the dual and dual-tandem wheels respectively

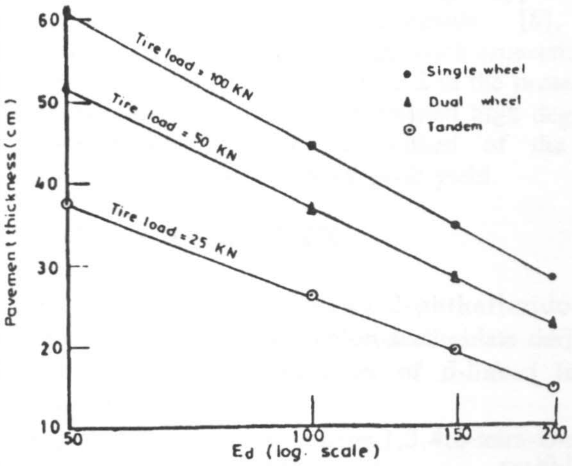

Figure 6. Relation between the pavement thickness and log. E_d at $N = 10^5$, $E_1/E_2 = 5$ for different wheel configurations.

4. CONCLUSIONS

In addition to introducing new design formulas and for specified conditions related to wheel configurations and pavement material characteristics, the main conclusion deduced from this investigation can be summarized as follows:

1. For the same total wheel load, the pavement thickness can be reduced to 84 and 58% of the thickness required for single wheel by using dual and dual-tandem wheels respectively.
2. The increase of the total wheel load to 4 times increases the required thickness by 75% only by using dual wheels assembly instead of single wheels.
3. The increase of the total wheel load to 16 times increases the required thickness to 3.25 times only by using the dual-tandem wheel assembly instead of single wheels.
4. For the same tire load and for values of strength ratio equal to or more than 450, the required thickness is the same for the three different configurations.
5. The required thickness for the different wheel configurations decreases as the dynamic modulus increases, and the relationship between the thickness and the logarithm of the dynamic modulus is a straight line.
6. The required thickness for the different wheel configurations increases with the increase of load repetitions, and the relationship between the thickness and the logarithm of load repetitions is linear.

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