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Damage Equivalent of the flexible pavement Variation with Load Applied

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Abstract. Previous research revealed that influence function is strongly influenced the appropriateness of pavement damage prediction and are demanding to be concern in order for better prediction of long term pavement performance. In order to identify the impact of traffic loading condition on the influence function of the pavement toward failure, further stucdy was done to determine the exponential value in the Damage Equivalent Law for varies loading condition and also vehicle speeds. To achieve the aims, the simple quarter truck model was efficiently used with personal computers to predict pavement loading. Towards reality of traffic loading condition will contain a distribution of axles load between unladen and fully laden, the study was further taking into account realistic axle load variation. Results are presented from a study to evaluate the relative influence of truck speed and axle load variation on the stiffness of the asphaltic layer and thus the primary response of the pavement. In conclusion, the exponential value in the Equivalent Damage Law is clearly sensitive to both factor.

Pavement damage model

In fatigue cracking failure criterion, the allowable number of load repetitions (N_f) that caused fatigue cracking is related to the tensile strain (ε_t) at the bottom of the asphaltic layer as:

$$N_f = k_1 (\varepsilon_t)^{k2} \tag{1}$$

The major factors that affect the constants $k_1$and k_2 are the volumetric proportion of binder and its initial Softening Point. The fatigue constants k_1 and k_2 for typical were determined from the equation given in [1].

Damage equivalent law

Pavement failure occurs when a certain limiting value of a specific type of distress or combination of distresses is exceeds. Generally assessing pavement damage due to heavy vehicles a distinction must be made between surface and structural distress. Structural distress is caused by loads affecting the pavement course due to inadequate structural strength and environmental conditions. The notation of equivalent between loads in term of the damage is expressed in the form of a law:

$$\frac{D_i}{D_j} = \left(\frac{P_i}{P_j}\right)^n \tag{2}$$

Where D_i is the road damage due to applied force P_i and D_j is damage due to applied force by standard load, P_j, $D=1/N_f$. N_f is the number of cycles to failure. The exponential, n is representing the type of road damage being considered. For flexible pavements, a value of n=4 is suitable for fatigue damage [2].

Method of predicting pavement loading

The simple quarter truck model (Figure 1) can be efficiently used with personal computers to predict pavement loading [3-5]. Some of the pass studies in dynamic loading, quarter truck models are used, such as one-degree of freedom and two-degree of freedom models, the tyre of the vehicle is always simplified as a spring. The disadvantage of such a simplification is clear for it ignores the damping function of the tyre. Reviewing available literature on this topic, ultimately, in this study, the two-degree of freedom quarter truck model in which the damping of the tyre is considered. Meanwhile because the international Roughness Index (IRI), a unified standard that is widely used in many states for evaluating pavement roughness and can be compared easily for different pavements, is computed using the quarter–truck model, the selection of the quarter truck model then link dynamic loads and the IRI to one another. It is usual to limit the degree of freedom as a lot of time steps have to be calculated numerically and corresponding long calculation time. On the other hand the modelling of complex structures is restricted, although this is necessary when measured records of real structures have to be explained. The Q-truck model parameters are given in Table 1 the road profile as illustrates in Figure 1 (refer [6] for further detail).

Pavement Structure

The pavement structure consists of three layers with different materials. The thickness of the asphalt surface asphaltic anad granular subbase layer are 0.2m and at the most bottom is semi-infinite soil layer. Poisson's ratio was taken to be 0.35 for the asphaltic layer and 0.4 for the unbound layers. Bituminous material is characterized by viscoelastic behavior. The loads acting vertically on the surface are assumed to be uniformly distributed over one circular area. The radius of the contact area is 0.15m and bitumen Penetration and its percentage are 40 and 8% respectively.

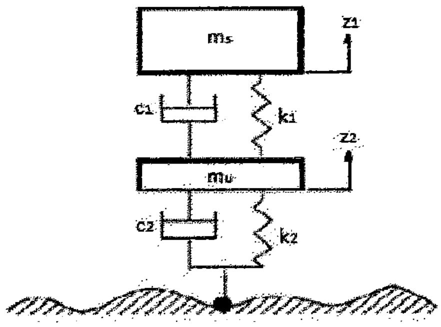


Figure 1 Quarter truck model

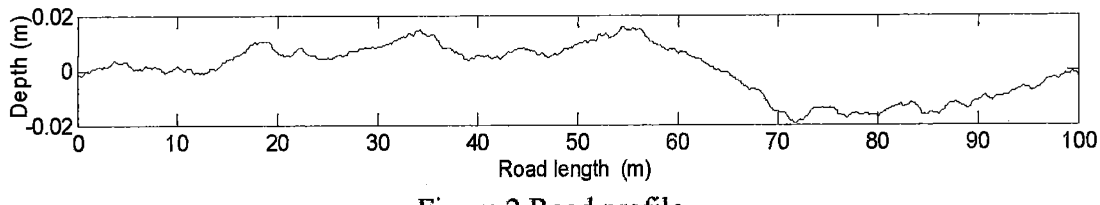


Figure 2 Road profile

Table 1: Q-truck Axle model [6]

	Suspension type		
Parameters	Steer axle	Single axle – steel suspension	Single axle – air suspension
Body mass , *ms* (kg)	X	X	X
Wheel mass, *mu* (kg)	400	600	600
Suspension damping, c_1 (Ns/m)	1.5E+03	6.5E+03	1.3E+04
Wheel damping, c_2 (Ns/m)	1.0E+03	2.0E+03	2.0E+03
Suspension stiffness, k_1 (N/m)	2.3E+05	8.6E+05	5.0E+05
Wheel stiffness, k_2 (N/m)	1.0E+06	2.0E+06	2.0E+06

*** X = 1/3, 2/3, fully lading or overloading from maximum gross weight

Results and Discussion

The compressive and tensile strain along the road for fully laden truck with steel suspension travelling at speed 10m/s and 20m/s are shown in Figure 3. It illustrates that at some locations there were increased in tensile and compressive strains rather than decrease. For both tensile and compressive strain the magnitude of the peak strains increasing with increasing speed.

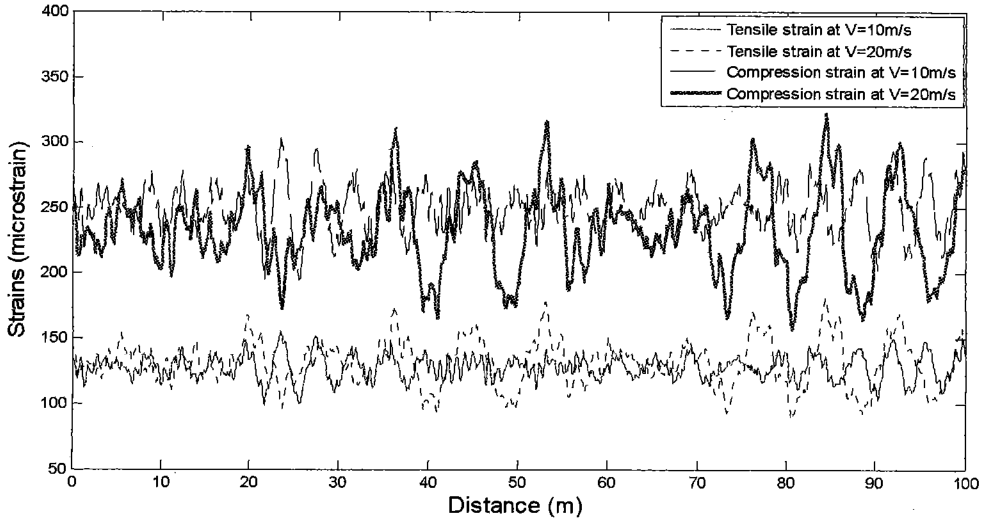


Figure 3: Radial and Vertical strains

The peak tensile strain at 20 m/s is higher with approximately 17% more than the tensile strain for truck travelling at 10m/s. The same result also found for compressive strain but with a smaller difference which is about 7%. From the result, it is clear that the increase in dynamic wheel forces with speed is reflected in the shape of the curve and strongly affected the primary response of the pavement.Logarithm plotting of tensile strain and number of allowable cycle to fatigue failure for varies vehicle speed gives a linear relationship (Figure 4). Decreasing tensile strain at base of the asphaltic layer clearly increase the life of the pavement for truck travelling at 10m/s to 30m/s. It follows from the previous section that value of elastic modulus is dependent on the loading time that is due to special nature of the bitumen. Similarly, the stiffness modulus also depends on temperature and it is necessary to consider both temperature and time of loading in pavement performance analysis.

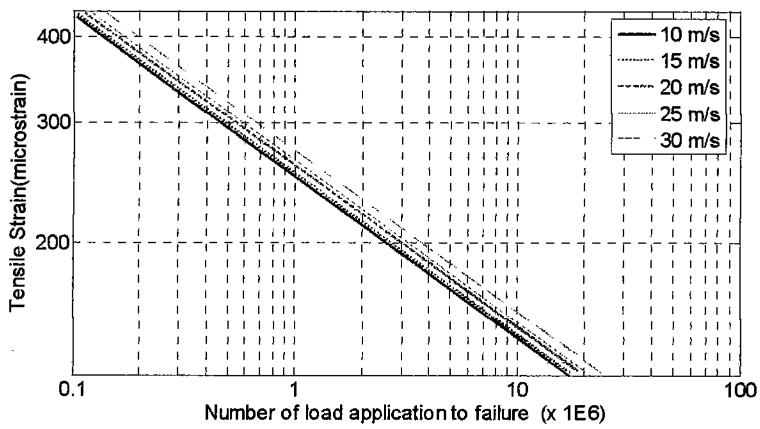
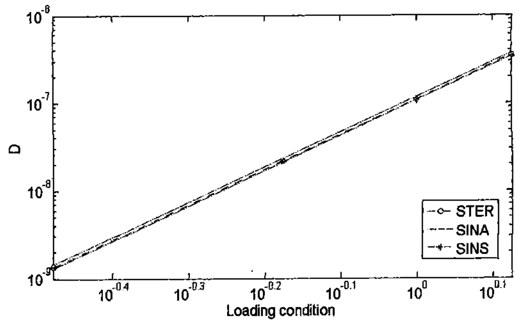


Figure 4: Tensile strain and N_f plotting for varies truck speed:

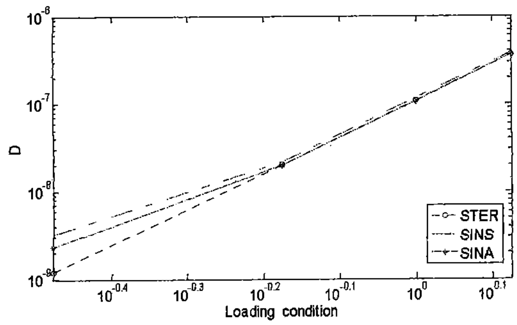
Applying Equation (2) to the result of damage calculated give the comparison of the exponent *n* value of different type of truck suspension with varies vehicle loading driven at speed 20 m/s as seen in Table 2. The result shows that the exponent *n* value is depends on the type of truck axle and loading condition and varies between 3.3 to 4.2 with the mean value is n=4. It clearly observed that, for axle with air and steel suspension, there is a lower of exponent *n* value for truck with 1/3 of fully loading, indicating that with loading approximately 1/3 of fully lading condition or lesser, the *n* value will be decreasing. The comparison of damage calculated using n=4 and *n* varies are clearly observed in Figure 5. It shows that, pavement damage is linear when using n=4 (Figure 5(a)), while, the pavement damage from 1/3 of fully laden of steel and air suspension is higher than the damage assumed by using n= 4 (Figure 5b). It should be noted that the *n* value is strongly dependent on the dynamic loading generated by the reaction of truck and road profile. The damage shows about similarity for steer axle in each loading condition.

Table 2: Fitted Exponent *n* Value

	n			
Axle Group model	1/3	2/3	1	4/3
STEER axle, (STER)	4.1	4.2	4	4.1
Single axle- steel suspension (SINS)	3.3	4.2		4.1
Single axle- air suspension (SINA)	3.5	4.2		4.2



(a)



(b)

Figure 5: Comparison of damage calculated using (a) Exponnetial value n=4 and (b) Exponential value, *n* varies for each loading condition

In addition, Figure 6 shows the variation in the power *n* value as a function of truck speed by varies axle type and loading conditions. Increasing truck speed travelling on the road surface even with the same roughness will increasing the potential of dynamic loading exerted to the pavement compare with their static loads, and it getting worst for the light weight truck. These factor effects clearly observed from Figure 6. It can be shown that *n* values are relatively insensitive to the speed for loading condition of 2/3 of fully laden, fully laden and overloading. It can be seen from the figure, the general trend is for the predicted *n* to increase as the speed is increase. Besides, as expected, the exponential value much decreasing with increasing truck speed for truck with loading 1/3 of fully laden for air and steel suspension. The reason for this is once again due to the body bounce modes affected by the road surface roughness. To be more clear, Table 3 given the exponential, *n* value for each vehicle speed and loading condition.

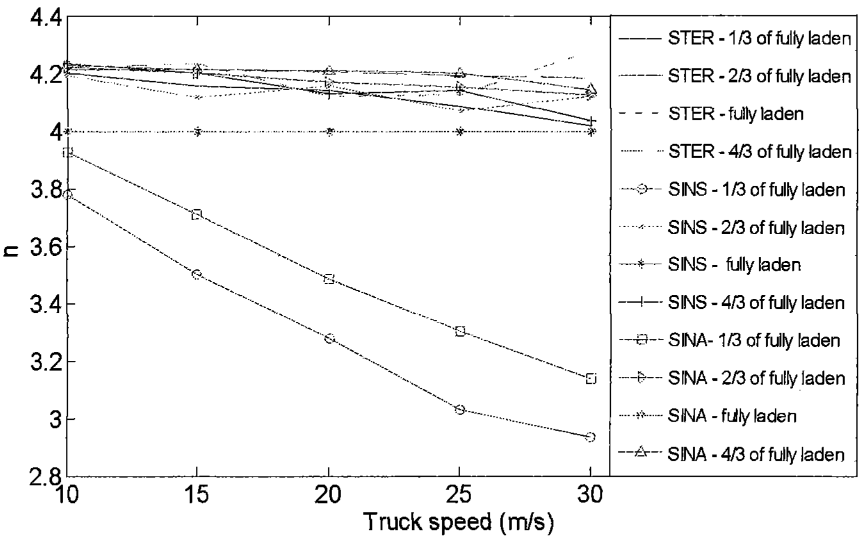


Figure 6: Exponential, *n* value for different truck speed

Table 3: Exponential value

Type of Axle	Loading Condition	Exponential value				
		10m/s	15m/s	20m/s	25m/s	30m/s
STER	1 /3	4	4	4	4	4
	2/3	4.20	4.20	4.19	4.17	4.15
	1	4.24	4.23	4.20	4.22	4.21
	4/3	4.25	4.23	4.23	4.22	4.18
SINS	1/3	4.00	4.00	4.00	4.00	4.00
	2/3	4.19	4.16	4.14	4.1	4.07
	1	4.22	4.21	4.17	4.13	4.05
	4/3	4.22	4.21	4.18	4.12	4.05
SINA	1/3	4.00	4.00	4.00	4.00	4.00
	2/3	4.20	4.19	4.18	4.17	4.16
	1	4.24	4.23	4.22	4.2	4.20
	4/3	4.24	4.23	4.22	4.2	4.20

Summary and Conclusions

- The form of the load equivalence law from the point of view of pavement damaging power is generally valid, but the power *n* will vary from 3.3 to 4.2 according to type of axle and their loading condition.
- Axle load applied at lower speed can cause higher pavement damage than higher speed, although, the increase in dynamic load with speed can increase theoretical road damage significantly. However, at high speed, road damage may decrease somewhat because of the reduction in road strain response with speed.
- Pavement long term performance with including varies truck axle and different loading condition should be fully considered to predict long term pavement performance.
- It is important to verify the specific value of the power *n* value due to the possibly to increase or decrease and the value is dependent on several factors including vehicle speed, axle type, load configuration and damage mechanism.

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