THE CRITICAL AND AVERAGE STATIC CONTACT STRESS

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RINGKASAN

Dalam perencanaan perkerasan menggunakan metoda analitis, salah satu parameter yang digunakan adalah tegangan kontak antara permukaan jalan dengan ban kendaraan. Pada umumnya metoda analitis mengasumsikan bahwa tegangan kontak adalah seragam sepanjang luas kontak dan besarnya sama dengan beban dibagi dengan luas kontak. Tegangan kontak kritis adalah tegangan yang terjadi apabila hanya ada satu chipping didalam luas kontak, sedangkan tegangan kontak rata-rata merupakan tegangan kontak yang terjadi pada pusat luas kontak dimana didalam luas kontak terdapat beberapa chipping. Percobaan dilakukan untuk mengukur tegangan kontak kritis dan tegangan kontak rata-rata dengan berbagai variasi beban, tekanan ban, dan tinggi chipping. Didapat bahwa tegangan kontak kritis jauh lebih besar dari tegangan kontak rata-rata. Selain itu sumbangan tekanan ban juga sangat signifikan terhadap tegangan kontak dibandingkan dengan beban. Tulisan ini menerangkan secara detail mengenai tegangan kontak kritis dan tegangan kontak rata-rata yang diukur secara statis.

SUMMARY

In analytical pavement design the contact stress is one parameter needed as input. The common analytical pavement design assumes uniform along the contact area where its value equals to load applied divided by the contact area. The critical contact stress means the stress where there is only one single chipping on the contact area, while the average contact stress is the stress occurs in the centre of it with full chippings. Experiment has been done to determine the critical and the average contact stress in several variations of contact characteristics such as tyre inflation pressure, load and height of chipping. It was found that the critical contact stress is much higher than that of average contact stress. The other finding is that the contribution of tyre inflation pressure is more significant than that of load. This paper describes in details the critical and average contact stress which were measured by static approach.

I. INTRODUCTION

The contact stress and the contact area are the significant factors in pavement design especially in analytical pavement design method besides some other factors such as pavement system, traffic and environment. The contact stress is the stress generated on the interfacial layer between tyre and road surface during the contact process.

The existence of contact stress on the surface results the stress / strain in any point on the pavement structure. This can be explained through the knowledge of engineering mechanics particularly on the topic of load on the uniform elastic foundation. The repetition of horizontal tensile strain on the bottom of asphalt layer causes cracks which propagate to the top and well known as fatigue cracks. While the repetition of vertical compressive stress on the top of sub grade layer causes the permanent deformation of the whole asphalt structure. These two types of failure are the main consideration factors in designing pavement based on analytical approach.

Globally there are two types of contact stress namely dynamic and static contact stress. The dynamic contact stress is obtained through the dynamic experiment where the contact stress is recorded during a vehicle passing the experiment

tools in certain speed. On contrary the static contact stress is observed in the static basis and usually has a special load frame connected to load cell and a hydraulic jack which has ability to simulate loads. The special axle is designed to use with car and lorry tyre.

In the present research the experiment is carried out in the static basis. To measure the contact stress it is needed a transducer which has the shape of beam with a cantilever. The strain gauges are used to record the magnitude and direction of contact stress generated. It is required 6 strain gauges because one direction needs two of them. However in this test due to the static basis it is only z direction considered. During the test the transducer is put underneath the tyre which is covered by a transducer cap with a hole for transducer cantilever that can be set to simulate the height of chipping.

The term of 'critical' means that it is a critical condition which probably happens on the asphalt surface due to single chipping on the contact area. This condition can be simulated by putting only one chipping (hence one transducer) during experiment. While the term of 'average' is obtained when the transducer located in the center of contact area where some dummy chipping beyond it. This is intended to simulate the real condition of asphalt surface.

In this test there are two types of tyre investigated i.e. car and lorry tyres. A variation of tyre inflation pressure, loads and height of chipping are applied. The readings of contact pressure taken by strain gauge are in voltage format. A short program written in Quick Basic and run in Lab Windows environment is required to convert it into binary data. To correlate those values to the real contact stress it is also needed a calibration process.

2. METHOD OF EXPERIMENT

2.1 The load frame, the load cell and the hydraulic jack

The load frame is about 2.5 meter high and fixed to the ground. It is connected to load cell and hydraulic jack which has ability to simulate load up to 100 kN. The special axle is needed to use it with car and lorry tyre.

2.2 The transducer, the transducer cap and the dummy chippings

The transducer is a beam with cantilever as schematically seen in Figure 1. The value of vertical contact stress is indicated by the deflection happens in the main bar. While the direction and value of radial stress is shown by the deflections of cantilever. Due to static basis in this test it is only vertical contact stress observed.

During the experiment the transducer is located underneath the tyre and covered by transducer cap which has hole for the space of cantilever. This transducer cap can be set to simulate the height of chipping.

The dummy chippings are made from the piece of steel with size of 0.5 x 0. 5 cm^2 area and different height such as 1 mm, 3 mm and 5 mm. These dummy chippings are glued using epoxy mastic resin to the transducer cap in order to simulate the real condition of pavement surface.

2.3 The critical and average contact stresses

To obtain the critical value of contact stress a single transducer (hence assumed as single chipping) is put in the center of contact area. Refer to the actual permanent surface it can be assumed as the critical condition which possibly exists on the real pavement surface where there is only one single chipping on the whole contact area.

The centre contact stress is simulated by putting the transducer (hence assumed as a chipping) in the center of contact area where it is believed as the position of maximum contact stress as observed by some researchers [1,2] and it is accompanied by some dummy chippings beyond it. These dummy chippings are glued to the transducer cap using the epoxy mastic resin. The choice of dummy chipping height depends on which type of test being carried out.

III. THE CALIBRATION OF STRAIN GAUGE

The calibration is needed to see the relationship between strain gauge reading and the load being applied. The calibration is done only for the vertical contact stress. There are 8 loads applied as follows :

load (kg)	Reading.
0	-1.37951
0.25	-1.37358
0.75	-1.37185
1.25	-1.35655
2.25	-1.33819
4.25	-1.30802
7.25	-1.19933
10.25	-1.15424
13.25	-1.10472

The relationship for this calibration is :

load = -45.11541 Reading + 62.4706

$r^2 = 0.9869$

It is noted that during experiment, it is needed to record zero reading, because in the mechanism of strain gauge the assumpation taken is that the changes of resistance due to the load follows the linear relationship.

IV. VARIATION OF CRITICAL CONTACT STRESS WITH HEIGHT OF CHIPPING

The experiment is carried out for both car and lorry tyres. The heights of chipping chosen are 0 mm, 1 mm, 3 mm and 5 mm. For the car tyre the load is varied from 1.5 kN, 2.0 kN, 2.5 kN, 3.0 kN, 3.5 kN and 4.0 kN and the tyre inflation pressures of 103.5 kPa, 138 kPa, 172.5 kPa and 207 kPa. For the lorry tyre the load applied is 10 kN, 12 kN, 14 kN, 16 kN, 18 kN and 20 kN and the tyre inflation pressures of 276 kPa, 345 kPa, 414 kPa, 483 kPa, 552 kPa and 621 kPa. The summary of results can be seen in Table 1 and Table 2 below.

It is clearly seen that the critical vertical contact stress increases sharply with the increase in the height of chipping. The influence of loads seems not too significant as indicated by the range of critical contact stress value at the same tyre inflation pressure and height of chipping but different loads. Another thing that can be drawn is that the tyre inflation pressure is a moderately significant factor in affecting the critical contact stress.

V. VARIATION OF AVERAGE CONTACT STRESS WITH THE HEIGHT OF CHIPPING

This test is also done for both car and lorry tyres. The height of chipping is varied from 1 mm, 3 mm and 5 mm. The loads and tyre inflation pressures are taken as same as point 4 earlier for car and lorry tyres.

The transducer is put in the center of contact area and some dummy chippings are glued beyond it. The distance of dummy chipping is about 2 mm between each other. Even though the position of actual chipping on the pavement surface is random, but this configuration is hoped can express the real condition of pavement surface. The results of experiment are shown in Table 3 and Table 4 below.

Based on the results above (Tables 3 and 4) it can be said that the variation of average contact stress is quite strong with the changes of load as shown by the range of its value at the constant tyre inflation pressure and the height of chipping.

The average contact stress is also much lower when comparing it to the critical ones. It is easily understood because in the case of maximum contact stress there are so many chippings that transfer load from the tyre. In other word the load from tyre spreads out to some chipping in maximum condition other than one single chipping in the critical case.

VI. THE MATHEMATICAL FORMULA

It is tried to create some mathematical formulations between contact stress and its influencing factors such as tyre inflation pressure, load and the height of chipping. This is done for both car and lorry tyres.

For car tyre on the critical condition there are 96 data configurations which consist of 4 types of tyre inflation pressure, 6 types of load and 4 types of chipping height. Using the SPSS package program it is obtained a simple equation as follows :

$$\sigma_v = 7.0143\ p_i + 6.7025\ p + 200.6660\ h - 1138.0647$$
$$r^2 = 0.7624$$

Where :
σ_v = vertical contact stress (kPa)
p_i = tyre inflation pressure (kPa)
p = load (kN)
h = height of chipping (mm)

There are 144 data configurations for lorry tyre in the critical condition which consist of 6 types of tyre inflation pressure, 6 types of load and 4 types of chipping height. The equation as follows :

$$\sigma_v = 3.2664\ p_i + 35.5143\ p + 1433.3531h - 533.6377$$
$$r^2 = 0.9821$$

In average condition the car tyre has 72 data configurations i.e. 4 types of tyre inflation pressure, 6 types of load and 3 types of chipping heights. It gives the following equation :

$$\sigma_v = 4.1966\ p_i + 96.0635\ p + 178.1667\ h - 1114.8497$$
$$r^2 = 0.8978$$

And average are 108 data configurations for lorry tyre in this condition i.e. 6 types of tyre inflation pressure, 6 types of load and 3 types of chipping height. The equation is as follows :

$$\sigma_v = 2.8043\ p_i + 43.6429\ p + 105.5833\ h - 430.8790$$
$$r^2 = 0.8568$$

It can be said that the regression equations give good relation between σ_v and the other factors (p_i, p and h) as indicated by their coefficient correlations (r^2).

VII. DISCUSSION

As shown on the results the values of average contact stress are much lower than the critical ones because in the case of this condition there are so many chippings which transfer load from the tyre. This is the real condition of pavement surface.

However, the critical values is still needed to know for the upper limit input for design purposes and the values of average contact stress can be taken as the lower limit. In other words, the range of critical and centre values should be clearly understood. Some adjustment should be made in choosing the input value by considering other factors which possibly influence the real condition of pavement surface such as environment and condition of surface (wet and/or dusty) which are not covered during the experiment.

It is obvious that the changes in chipping height influence the contact stress significantly. From this point of view it can be suggested that care must be taken when designing the chipping height. It must be considered between the requirement of texture depth and the stress generated. The more depth texture which gives the good skid resistance the more stress generated which results the shorter life time of pavement structure.

From the results of both car and lorry tyres it seems that the contributions of tyre inflation pressure to contact stress is more significant than that of load. In implication, this gives a good idea for the researchers who are working in the heavy loaded traffic that the limitation of tyre inflation pressure is more important than that of load.
The equations created can be used directly as input for pavement analysis. For design purposes the lorry tyre equations should be chosen because the standard axle philosophy based on commercial vehicle tyre. The value of standard contact stress should be taken in the range of critical and average values by considering some factors which possibly influence the real condition of asphalt surface.

VIII. CONCLUSIONS

There are some points can be drawn such as :

a. The critical values of contact stress are much higher than that of centre values.
b. The changes in the height of chipping influence the contact stress in both critical and centre conditions significantly.
c. The contribution of tyre inflation pressure is more significant than that of load.
d. Some equations relating contact stress to tyre inflation pressure, load and the height of chipping have been created.

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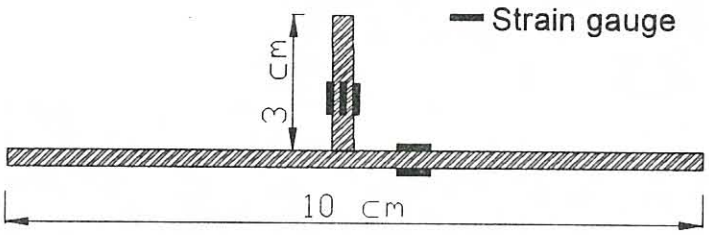

Figure 1. The schematic of transducer and location of strain gauges

Table 1.
Variation critical contact stress with height of chipping for car tyre

h(mm)	σ_v(kPa)			
	pi=103.5 kPa	pi=138kPa	pi=172.5kPa	pi=207kPa
0	164-221	190-258	238-261	245-279
1	220-251	302-347	402-421	410-413
3	291-298	376-393	477-526	703-662
5	609-613	738-747	1183-1208	1700-1746

Pi = tyre inflation pressure
σ_v = contact stress

Table 2.
Variation of critical contact stress with height of chipping for lorry tyre

h(mm)	σ_v(kPa)					
	pi=276kPa	pi=345kPa	pi=414kPa	pi=483kPa	pi=552kPa	pi=621kPa
0	1048-1629	1522-1995	1416-1668	1365-1902	1394-1940	1800-2461
1	1988-2351	2034-2389	2235-2564	2432-2734	2641-2862	2765-2910
3	5492-5616	5613-5792	5763-5900	6153-6194	6376-6663	6827-7149
5	7450-8321	7722-8397	8105-8565	8621-8816	8736-8967	9261-9811

Table 3.
Variation of centre contact stress with height of chipping for car tyre

h(mm)	σ_v(kPa)			
	pi=103.5 kPa	pi=138kPa	pi=172.5kPa	pi=207kPa
1	120-171	125-185	143-245	200-311
3	294-374	400-547	507-693	557-772
5	389-466	499-538	624-727	723-864

Table 4.
Variation of centre contact stress with height of chipping for lorry tyre

h(mm)	σ_v(kPa)					
	pi=276kPa	pi=345kPa	pi=414kPa	pi=483kPa	pi=552kPa	pi=621kPa
1	1276-1979	1313-2576	1736-3086	1955-3154	2235-3428	2483-3670
3	1386-1917	1465-2721	1818-3495	2019-3521	2445-3589	2715-3735
5	2158-2918	2374-2988	2982-3181	3170-3479	3234-3735	3740-3886