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BEARING CAPACITY OF ROADS AND AIRFIELDS

VALIDATION OF SHRP A-698 PERMANENT DEFORMATION CONCEPTS FOR DIFFERENT TRUCK SPEEDS

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ABSTRACT

The effect of loading rate on the accumulation of permanent deformation is evaluated. Measurements of actual rut depth function of truck speed (which decreases as they climb a steep hill) were made for two sites in Portugal. The SHRP A-698 permanent deformation methodology to predict accumulation of rut depth was used and adapted, to yield conclusion towards the selection of adequate loading times, to be used in the Repetitive Simple Shear Test at Constant Height, in rut depth predictions.

Key words: Simple Shear Test, Rut Depth, Permanent Deformation, Rate of Loading

INTRODUCTION

During the Strategic Highway Research Program, a methodology to predict permanent deformation in asphalt concrete surface layers was proposed (Sousa et al 1994). However, no validation of those concepts were presented for speeds other than normal highway speeds. The proposed loading time for the RSST-CH was 0.1 sec haversine loading and 0.6 sec rest period. However, the methodology proposed referred to the possibility of applying other loading times if they relate to traffic at other speeds but no specifics were presented.

To validate those concepts at different truck speeds two sites were selected on Highway IP5 in Portugal. The traffic is well known and measured by weigh in motion scales. The road passes through rather hilly terrain and long stretch of highway are on inclines were trucks do slow down to about 20 km/h. In some of these sections increased rutting is found as the truck speed reduces. A diagram of this problem is presented in Figure 1.

At cross section CS1 the speed is higher than at cross section CS2. It was observed that at cross sections CS2 the rut depths is higher than at cross section CS1. For cross sections higher in the mountain the rut depth increases.

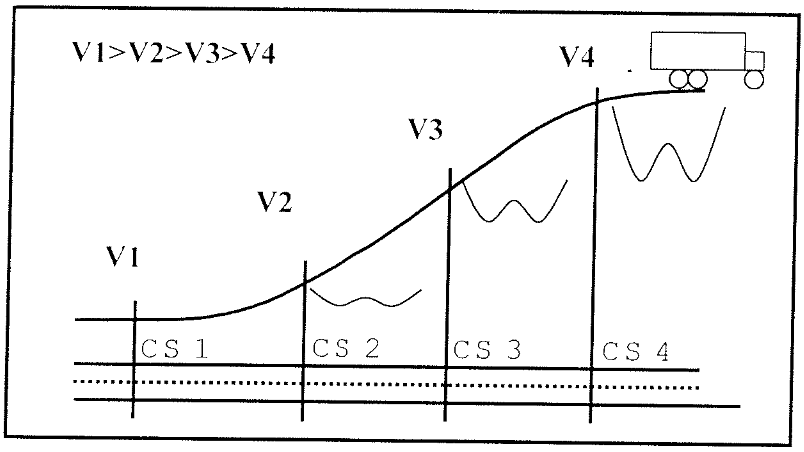

Figure 1 – Schematic presentation of location of the cross sections function of the location on the slope.

Three sites were selected for this validation effort; site ST64, site ST84 and site ST132 starting respectively at km post 64 , 84 and 132. At this time only the data for sites 64 and 132 is partially completed. For each of this sites testes were only executed from cores obtained from the second cross section (CS2). The assumption is that the mix is identical in all other sections. However in a future publication data from tests obtained from each of the cross sections will be presented.

The speed of the trucks at each of the sites was measured by driving behind them as they would go climbing the slope. For each site 5 trucks were followed and the average speed reported in Tables 1 and 2. The rut depth and longitudinal slope at each cross section was also measured.

Although the speed at cross section CS2 of site ST64 was 40 km/h, it is possible that other trucks may have lower speeds given the 8% grade found at that point. This assumptions is corroborated by the fact that a 22 mm rut depth is found at that place. However, this unexpected rut depth may also be justified by material variability, or higher air void contents at the time of compaction.

The permanent shear strain assumed for each cross sections was determined based on the relationship proposed in the SHRP A-698 methodology were:

$$\text{Rut depth (mm)} = 294 * \text{Permanent Shear Strain}$$

Table 1 – Values measured at site ST64

Cross Section Number	Rut Depth (mm)	ESALS (80kN)	Permanent Shear Strain (%)	Average Measured Truck Speed. (km/h)	Slope (%)	Distance from First Cross Section. (m)
1	10	8.00E+06	3.58	60	2	0
2	22	8.00E+06	7.89	40	8	130
3	10	8.00E+06	3.58	30	7	300
4	20	8.00E+06	7.17	25	5	520

Table 2 – Values measured at site ST103

Cross Section Number	Rut Depth (mm)	ESALS (80kN)	Permanent Shear Strain (%)	Average Measured Truck Speed. (km/h)	Slope (%)	Distance from First Cross Section. (m)
1	5	8.00E+06	1.79	85	1	0
2	15	8.00E+06	5.38	70	4	950
3	18	8.00E+06	6.45	50	6	1080
4	30	8.00E+06	10.75	45	6	1510

The objective of this paper was to establish if the effect of truck speed over the pavement, translated into rate of loading of the asphalt concrete mix could be capture by varying the loading rate in the RSST-CH test.

RUTTING CONCEPTS

The approach followed in this paper is illustrated in Figure 2. This diagram follows the concepts previously presented in Sousa et al (1994). The Quadrant identified as "Design Requirements" identifies the case were we have three rut depth levels caused by the same traffic. The rut depth is converted into permanent shear strain in Quadrant "Transfer Function". Cores from the field are tested at the Maximum Seven Day pavement temperature at 50 mm depth at different loading times (T1, T2 and T3).

If the loading times are adequately chosen (and if a correlation exists with the truck rate of loading and the rate of loading of the RSST-CH test) than the relationship previously determined and presented in Quadrant "Shif Factors" would be able to predict the number of ESALS actually travelled over the sections.

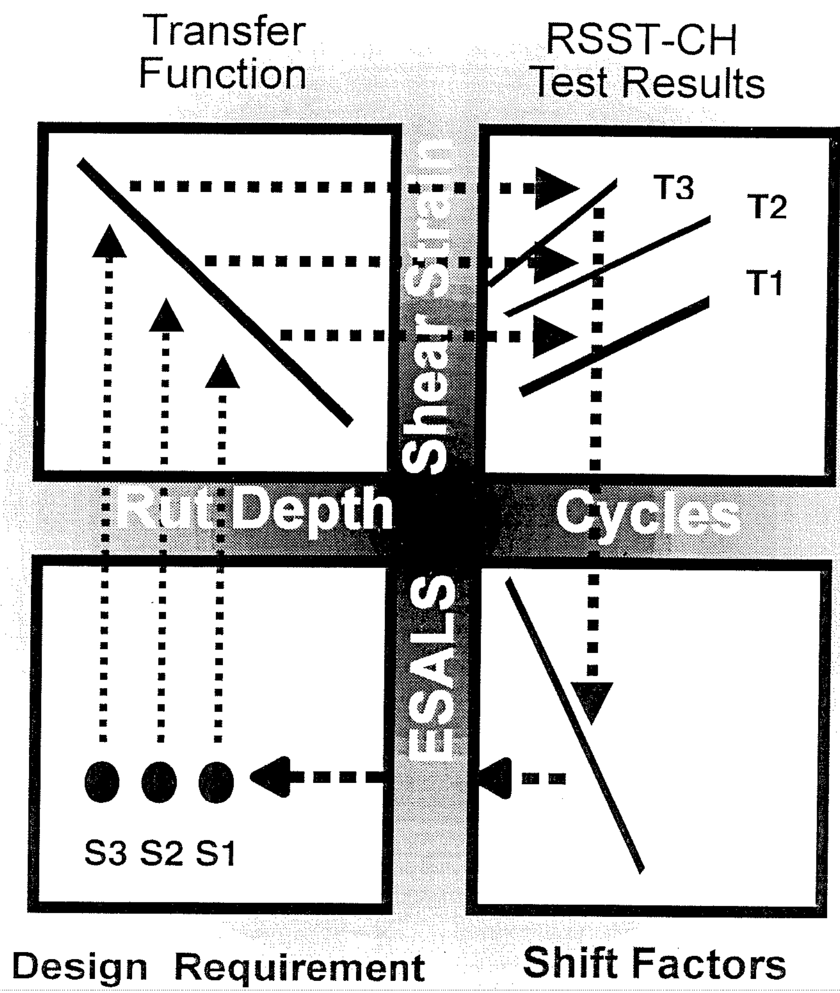

Figure 2 – Schematic representation of the permanent deformation validation concept

TEST PROGRAM

Cores from each cross section were obtained from between the wheel path. Specimens were obtained from the top 5 cm of each core. RSST-CH testing was undertaken with different loading times, namely 0.1, 0.2, 0.3 and 0.4 s haversine loading and in all cases with a rest period of 0.6 seconds. For each test condition 3 replicates were tested at 50 °C. For each cross section tests were conducted at all these loading times. The magnitude of the loading pulse was 70 KPa. Data presented this far is only based on test results from cores from the second cross section.

TEST RESULTS

It can be observed in Figure 3 the typical effect of loading rate observed in all cross sections. With an increase in loading times, an increase in the rate of accumulation of permanent deformation is observed.

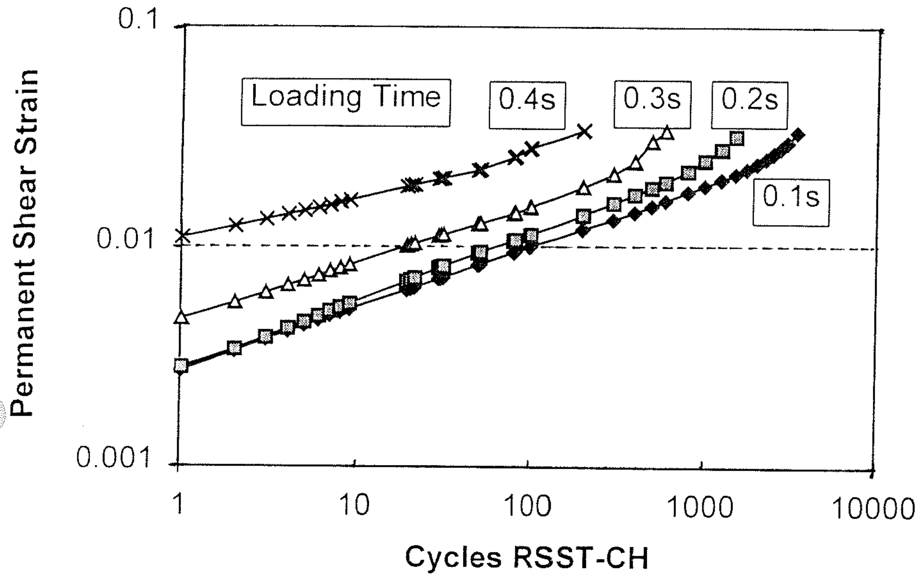

Figure 3 – Effect of loading time on the accumulation of permanent deformation in the RSST-CH test at 50 °C Temperature.

Tables 3 and 4 present a summary of the results obtained for each cross section. It must be noted, that the number of cycles RSST-CH cycles presented in these tables are the number of cycles required to reach the permanent shear strain obtained from the field, at the corresponding cross section. The conversion to ESALs was obtained based on the following relationship:

$$\log(\mathbf{Cycles}) = -4.36 + 1.24 \log(\mathbf{ESAL})$$

Figures 4 and 5 show the predicted ESALs to measured rut depth as function of load time.

Two approaches were followed to validate the effect of loading time; A and B.
In Approach A, for a given cross section the loading time that corresponds to the expected number of ESALs was obtained using a logarithmic interpolation between consecutive load times, that are above and below of the target value. In this case, it would be assumed that the relationship ESAL-RSST-CH cycles was valid, and it would vary the loading time to obtain the loading time that would yield the best relationship. The loading time was searched to reach the measured rut depth.
In section test number 103, for cross section number 2, 3 and 4, the load time was obtained by the load time that is closer of the expected number of ESALs, respectively, 0.1, 0.1 and 0.3 seconds.

Table 3 – Summary of test results and corresponding analysis for site ST64

Section Number	Loading Time	Field Permanent Shear Strain	Average of Number of RSST-CH Cycles to Reach the Field Permanent Shear Strain	ESALs required to reach the measured rut depth
1	0.1	3.58		
2	0.1	7.89	887	782 504
2	0.2	7.89	41 151	17 274 351
2	0.3	7.89	4 144	2 712 708
2	0.4	7.89		
3	0.1	3.58	24 240	11 273 076
3	0.2	3.58	214 670	65 455 242
3	0.3	3.58	745	679 931
3	0.4	3.58		
4	0.1	7.17	735	672 436
4	0.2	7.17	30 244	13 475 662
4	0.3	7.17	3 130	2 163 298
4	0.4	7.17		

Table 4 - Summary of test results and corresponding analysis for site ST103

Section Number	Loading Time	Field Permanent Shear Strain	Average Number of RSST-CH Cycles to Reach the Field Permanent Shear Strain	ESALs Required to Reach the Measured Rut Depth
1	0.1	1.79	5 835	3 574 780
2	0.1	5.38	7 681	4 462 005
2	0.2	5.38	4 479	2 888 151
2	0.3	5.38	4 186	2 735 031
2	0.4	5.38	4 222	2 753 959
3	0.1	6.45	13 503	7 032 556
3	0.2	6.45	7 456	4 356 361
3	0.3	6.45	6 830	4 059 089
3	0.4	6.45	7 403	4 331 281
4	0.1	10.75	65 648	25 175 781
4	0.2	10.75	31 121	13 789 733
4	0.3	10.75	26 936	12 273 842
4	0.4	10.75	35 730	15 414 583

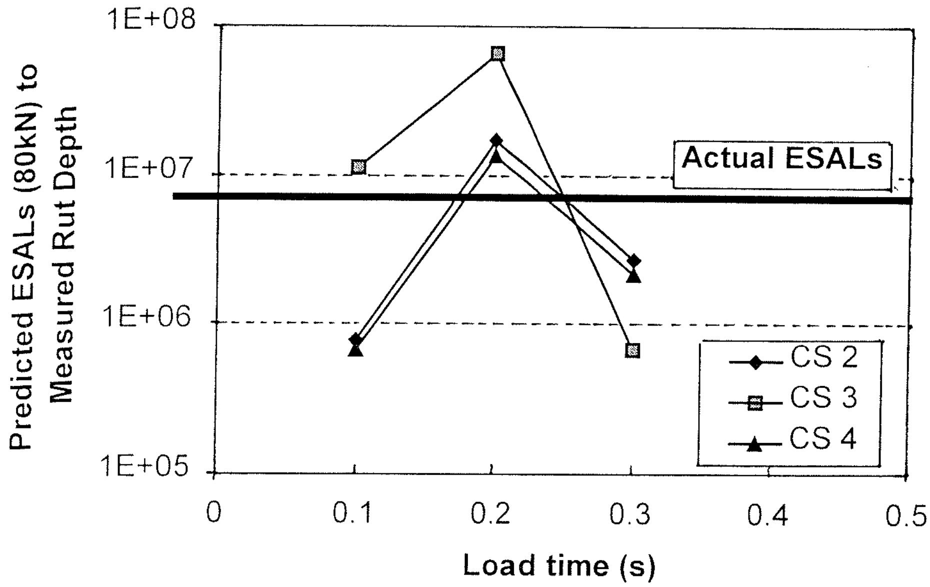

Figure 4 – Effect of loading time on the predictions made for each ST64

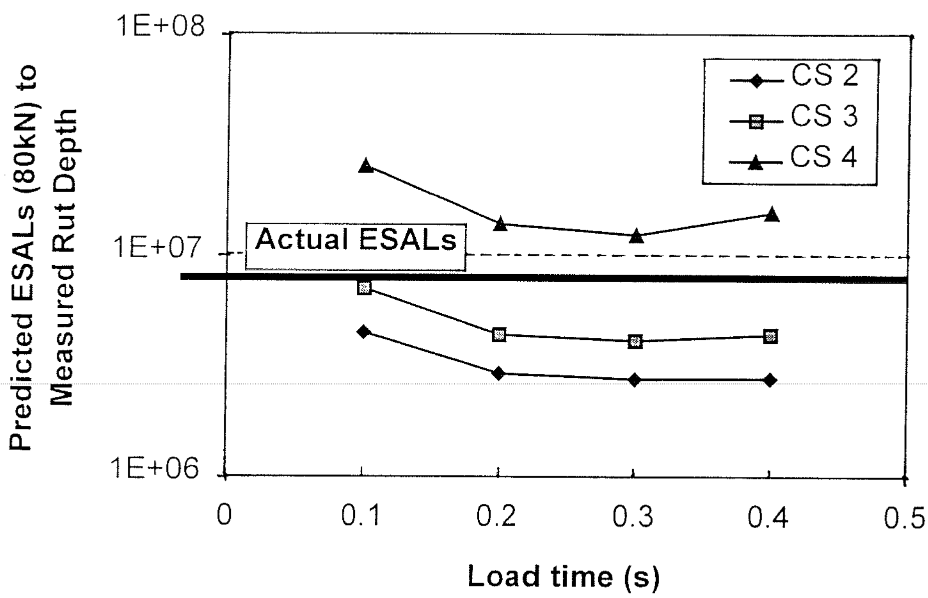

Figure 5 – Effect of loading time on the predictions made for each ST103

A different approach was evaluated in Approach B. The loading time for the standard test (0.1 s) was assumed to correspond to a truck speed of 80 km/h. In this case, for a given truck speed, the corresponding loading time should be:

$$\text{Load time (s)} = \frac{8}{\text{Velocity (km/h)}}$$

As the truck speed for each cross section is known, the corresponding load time can be calculated. Thus, the number of ESALs that produce the measured rut depth can be estimated, using a linear interpolation in values presented in Table 3 and 4.

Tables 5 and 6 present, respectively for ST64 and ST103, the results for approach A and B and the corresponding differences to loading time function of speed, to approach A, and 8E+06 ESALs, to approach B.
It can be observed that the differences for approach A, in both section tests, are very low, indicating that the RSST-CH also predict well the rut depth for sloped roads. In terms of approach B, although some discrepant values have been found, the overall approach appears to yield reasonable results.

Table 5 – Summary results of the analysis made to identify the effect of loading time for ST64

		Approach A		Approach B	
Cross Section Number	Loading Time F(vel)	Interpolated Time	Dif. to Loading Time F(vel) (%)	ESALs Assuming correct Loading Time f(vel)	Dif. to 8E6 ESALs (%)
1					
2	0.200	0.175	-12.44	17 274 351	115.93
3	0.267	0.246	-7.74	22 271 702	178.40
4	0.320	0.229	-28.59		

Table 6 – Summary results of the analysis made to identify the effect of loading time for ST103

		Approach A		Approach B	
Cross Section Number	Loading Time F(vel)	Interpolated Time	Dif. (%)	ESALs Assuming correct Loading Time f(vel)	Dif. to 8E6 (%)
1				3 574 780	-55.32
2	0.114	0.1	-12.50	4 237 169	-47.04
3	0.160	0.1	-37.50	5 426 836	-32.16
4	0.178	0.3	-68.75	16 319 966	104.00

It can be concluded that the loading time is an important factor in the correlations made. Small variations in loading time cause significant effects in the predictions made. On the other hand, it can be assumed that errors in measuring truck speed (or the effect caused by trucks going at lower speeds than expected) may be the cause of some dispersion in comparisons between observed and predicted data.

A representation of predicted ESALs to measured rut depth assuming correct loading time function of speed, approach B, is represented in Figure 6, where it can be observed that the results are mostly with half and order of magnitude of the actual number of ESALs. For site 103 the results have less dispersion than for site 64. It is to be expected high data scatter in site 64, because the variation of rut depth function of measured truck speed is not as expected (see Table 1). Material from cross section 2 may not be identical to that of other cross sections.

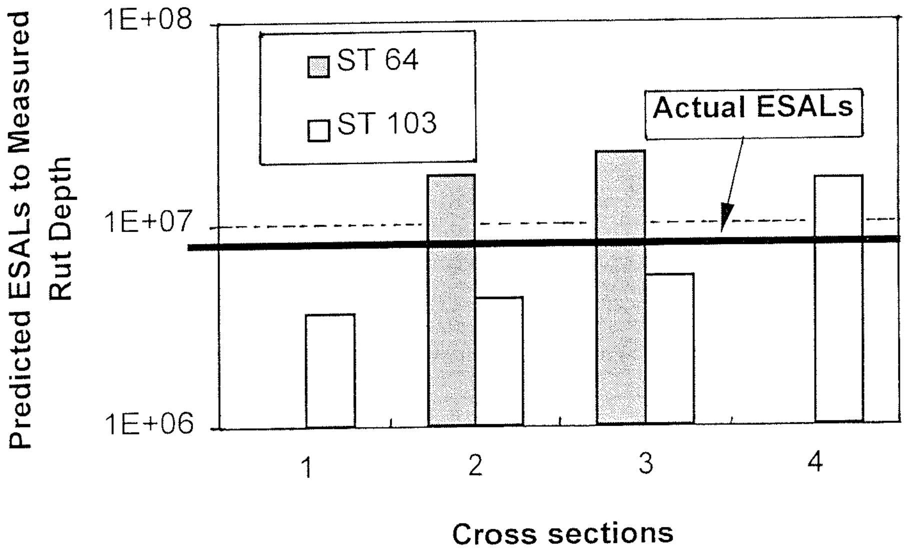

Figure 6 – Predicted ESALs to measured rut depth assuming correct loading time function of speed (Approach B).

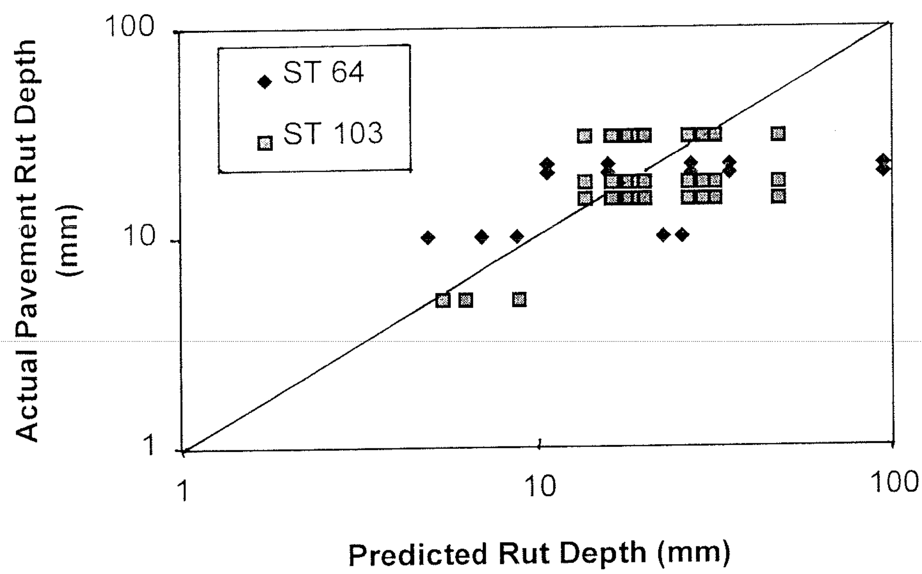

Figure 7 – Comparisons between predicted versus actual rut depth.

Figure 7 presents the comparison of predicted (using approach B) versus observed rut depth, based on the actual results for each of the tests. It can be observed that test results for site 103 generally are very good. This graph is presented to show the effect of test variability on actual rut depth predictions, when compared with observations. Normally, average all test results would be used for predictions. In this case the average of all the values would be just below the equality line, indicating that the concepts proposed are slightly conservative.

CONCLUSIONS

The concepts presented in the SHRP A-698 permanent deformation evaluation methodology appear to be able to capture the effect of truck speed. By varying the loading time in the RSST-CH, the effect in the rate of accumulation of permanent deformation can be related to the effect of speed has on the rate of development of ruts in the field.

The loading rate strongly affects the rate of accumulation of permanent deformation. However, the shift factor between ESALs and RSST-CH cycles, proposed by the SHRP-A698 procedure, appear to be able to relate the accumulation of permanent shear strains in the test, with those observed in the field for different truck speeds, if the rate of loading is taken into consideration. The data in this paper suggests that the rate of loading should be determined by the following equations:

Loading time in the test (sec) = 8/ Truck speed (km/h).

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