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MODELING THE EFFECT OF TRUCK SPEED ON PERMANENT DEFORMATION OF ASPHALT CONCRETE MIXES

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ABSTRACT

The Portuguese Road Administration is considering the development of a performance based mix design procedure. As part of these efforts, the effect of truck speed on the accumulation of permanent deformation needs to be considered. Measurements of the development of actual rut depths as a function of truck speed (which decreased as the trucks climbed a steep hill) were made for five sites in Portugal. The SHRP A-698 permanent deformation methodology to predict the accumulation of rut depth in asphalt concrete mixes was used and adapted, yielding the selection of adequate loading times, eventually to be used in the Repetitive Simple Shear Test at Constant Height for the prediction of rut depth.

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

INTRODUCTION

The Portuguese Road Administration has been sponsoring research towards the development of a methodology to execute mix designs on asphalt concrete mixes using performance based testing systems. Among several methods considered, this research has been focused on a methodology developed during the Strategic Highway Research Program (SHRP). The SHRP A-698 methodology [1] to predict permanent deformation in asphalt concrete surface layers was proposed, using as a basis the results of the repetitive Simple Shear Test at Constant Height (RSST-CH). Beyond the initial correlations developed based on the General Pavement Studies (GPS) data, this methodology has been used with relatively good success in other studies [2, 3, 4 and 5]. However, no validation of these concepts was presented for speeds other than normal highway speeds. In fact, the proposed loading time for the RSST-CH was a 0.1 second (haversine) loading followed by a 0.6 second rest period was selected based on a relatively small data set. The originally proposed methodology also referred to the possibility of applying other loading times if they relate to traffic at other speeds, but no specifics were presented.

To validate these concepts at different truck speeds, three 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 where long stretches of highway are on inclines where trucks frequently slow down to about 20 km/hr. Some of these sections exhibited increased rutting as the truck speed decreased. A diagram of this problem is presented in Figure 1.

With reference to Figure 1, at cross section CS1, the speed is higher than at cross section CS2, etc. It was observed that at cross-section CS2 the rut depth was higher than at cross section CS1, and so on up the grade the rut depth increased significantly with decreasing truck speeds.

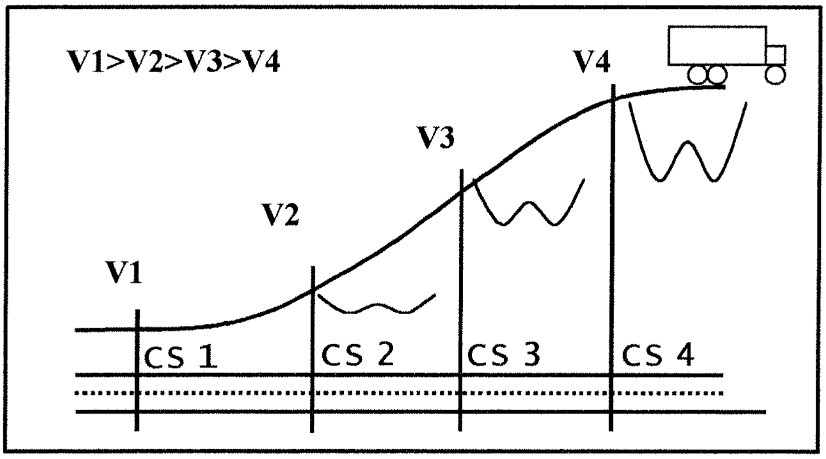

Figure 1 **– Schematic presentation of location of the pavement cross sections as a function of the location along the grade**

Three sites were selected for this validation effort: Site ST64, Site ST84 and Site ST132, starting respectively at km post 64, 84 and 132. For each of these sites, RSST-CH testes were executed from cores obtained from the four up-hill cross sections (CS1, CS2, CS3 and CS4). The assumption is that the mix may not be exactly identical in all sections. These sites were selected along in the same roadway, where the traffic was exactly the same in all test sections. The traffic was estimated to be an equivalent 8 million 80kN ESALs total passes at the time the cores were extracted.

The speed of the trucks at each of the sites was measured by driving behind them as they climbed the slope. For each site, 5 random trucks were followed and the average speeds for these five sample trucks are reported in Table 1. 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/hr, it is possible that other trucks may have lower speeds given the 8% grade found at that point. This assumption is corroborated by the fact that a 22 mm rut depth is found at that place. However, material variability or higher air void contents may also justify this unexpected rut depth at the time of compaction.

Table 1 **– Values measured at the various test sections**

Section Test (number)	Cross Section (number)	Rut Depth (mm)	Average Truck Speed (km/h)	Slope (%)	Distance From the First Cross Section (m)
64	1	10	60	2	0
	2	22	40	8	130
	3	10	30	7	300
	4	20	25	5	520
81	1	5	65	2	0
	2	10	50	5	250
	3	20	40	4	350
	4	30	35	4	445
103	1	5	85	1	0
	2	15	70	4	950
	3	18	50	6	1080
	4	30	45	6	1510

The objective of this rut depth study was to establish whether the effect of truck speed across the test section (translated into rate of loading of the asphalt concrete mix) could be captured by varying the loading rate in the RSST-CH test.

RUTTING CONCEPTS

The approach followed in this study is illustrated in Figure 2. This diagram follows the concept previously presented by Sousa et.al. in 1994 [2]. The quadrant identified as "Design Requirements" identifies a case were there were three rut depth levels caused by the same traffic. Rut depth is converted into permanent shear strain in quadrant "Transfer Function". Cores from the field were 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 truck rate of loading and the rate of loading of the RSST-CH test), then the relationship previously determined and presented in the quadrant "Shift Factors" should be able to predict the number of ESALs actually travelled over the test sections.

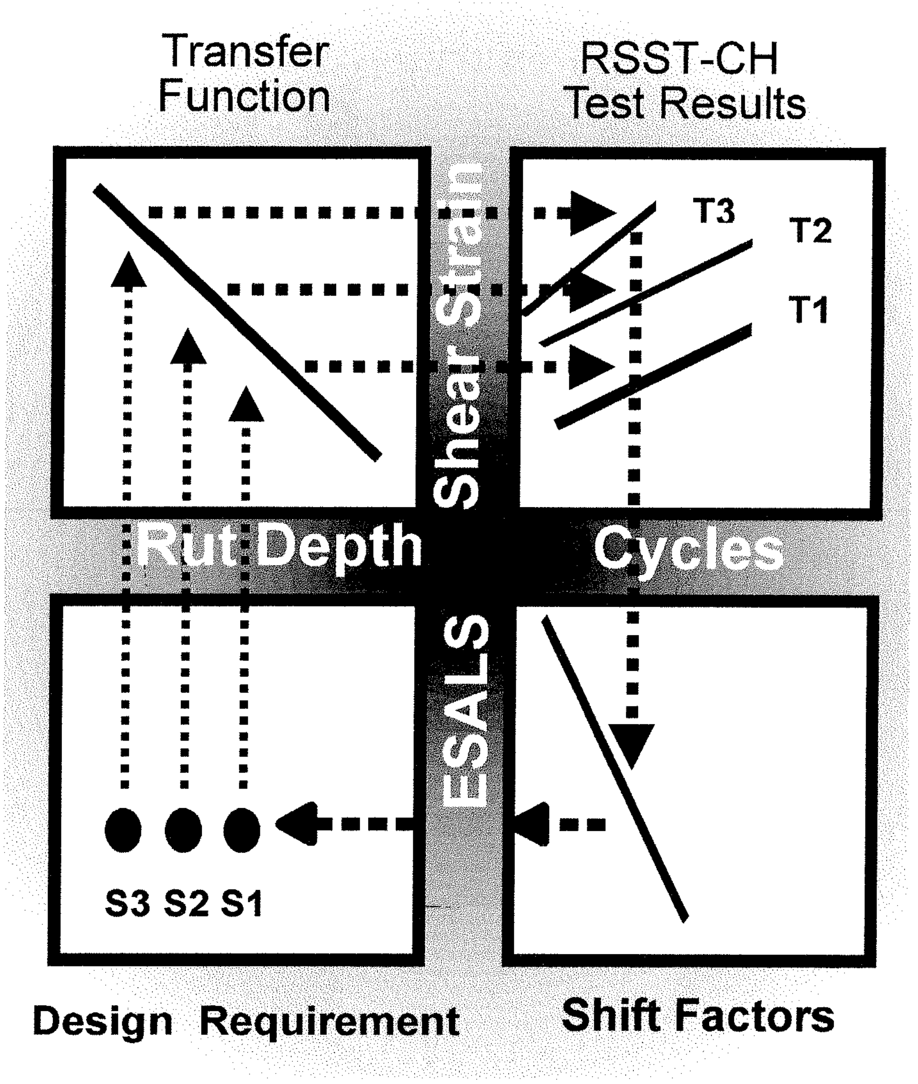

Figure 2 – **Schematic representation of the permanent deformation validation concept**

TEST PROGRAM

Cores from each cross section were obtained from between the wheel paths. RSST-CH test specimens were obtained from the top 50 mm of each core. The maximum particle size in the cores was found to be 12 mm. This corresponds to the materials used in typical surface courses applied to most high-volume pavements in Portugal.

RSST-CH testing was undertaken with different loading times, namely 0.1, 0.2, and 0.3 seconds haversine loading, plus (in all cases) 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 three loading times. The magnitude of the loading pulse was set at 70 kPa. The test temperature was chosen to be representative of the maximum average seven day temperature at 5 cm depth.

TEST RESULTS

Figure 3 shows the typical effect of loading rate observed in all cross sections. With increased loading time, an increase in the rate of accumulation of permanent deformation can be observed in the RSST-CH shear test results.

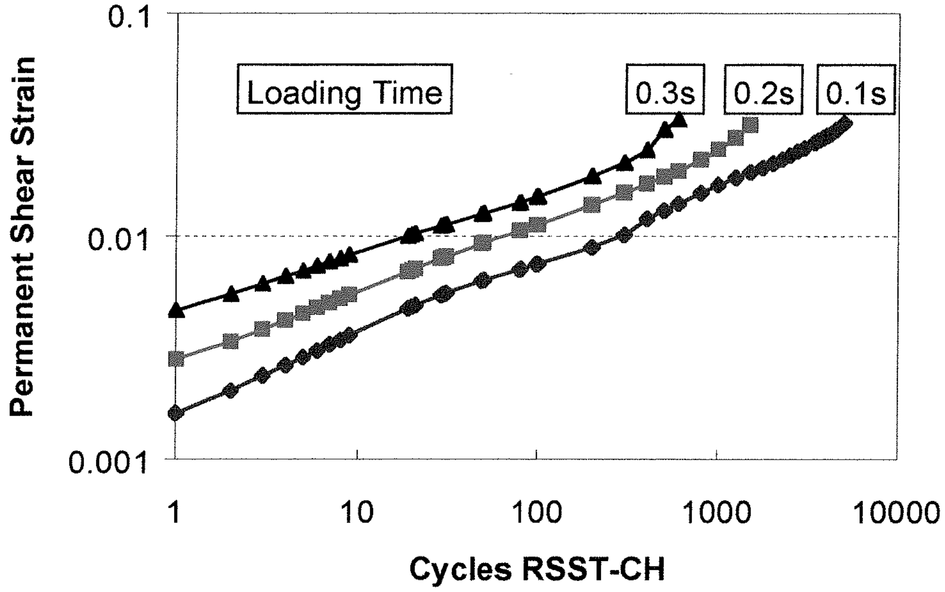

Figure 3 **– The effect of loading time on the accumulation of permanent deformation in the RSST-CH test at 50°C**

Figure 4 is a plot of the field data shown in Table 1, with least-squares linear regression lines superimposed. Clearly, a reduction of truck speed corresponds to a significant increase in rut depth. It must be noted that there may exist a combined effect of decreasing truck speed and increasing torque on the rear wheels as the truck climbs up the hill. In this study, the effect of the higher shear forces imposed on the pavement by the added torque was not considered. This effect can be masked by the increase in duration of the pulse time in the shear test.

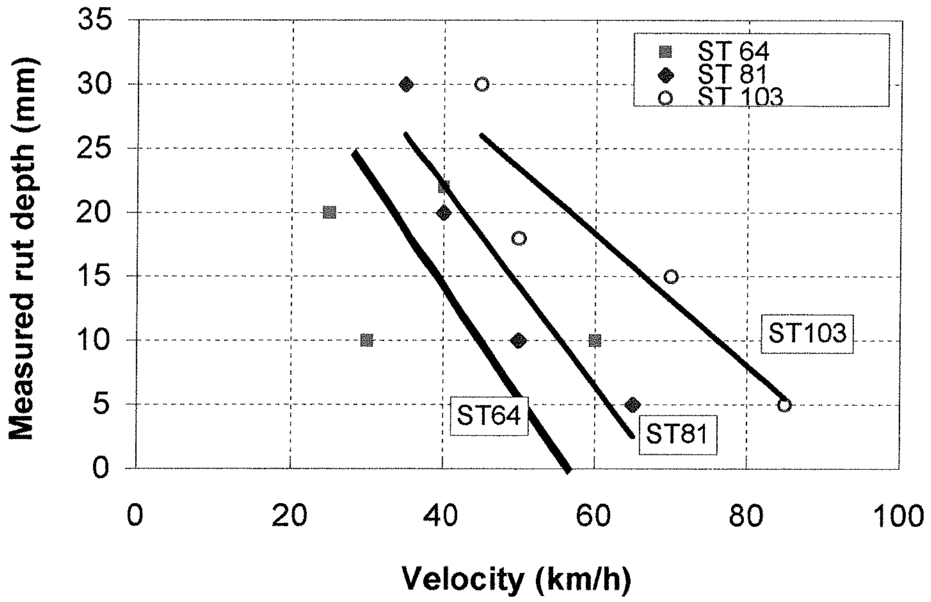

Figure 4 – **Effect of truck speed on rut depth**

Figures 5, 6 and 7 present a summary of the results obtained for each test section. These values are presented to show the relative effect of pulse load on the predicted rut depth caused by the estimated 8 million 80kN ESALs of accumulated traffic. This rut depth was predicted directly using the concepts introduced in (1), assuming that the relationship between ESALs and RSST-CH number of cycles is still valid for different loading times.

The conversion between ESALs and RSST-CH cycles used was obtained based on the following relationship:

$$\log(\#\ \text{of cycles}) = -4.36 + 1.24 \log(\#\ \text{of ESALs})$$

and by:

$$\text{Rut depth (mm)} = 279 * \text{Permanent Shear Strain}$$

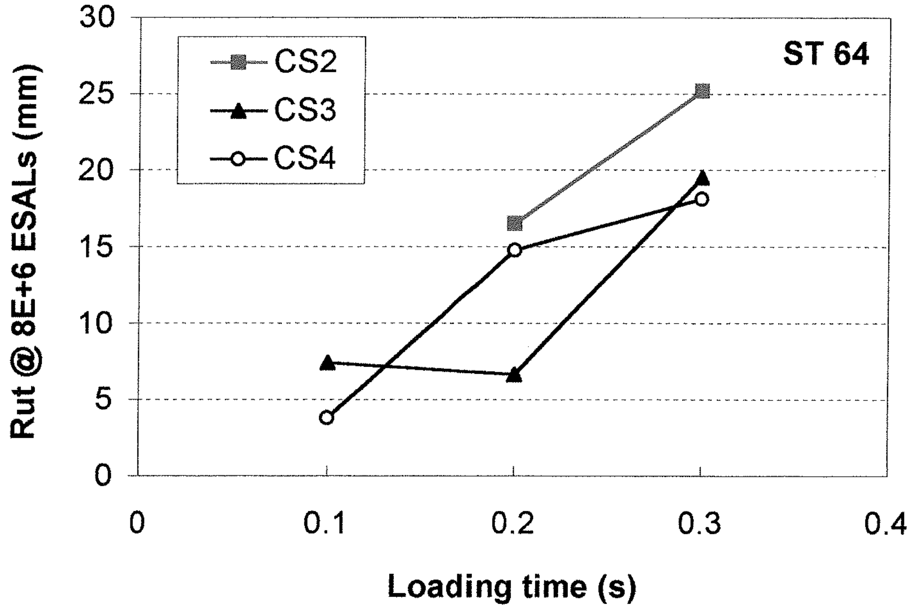

Figure 5 **– The effect of loading time in RSST-CH tests on rut prediction obtained by an 8m equivalent 80kN traffic level on cores obtained in test section ST64**

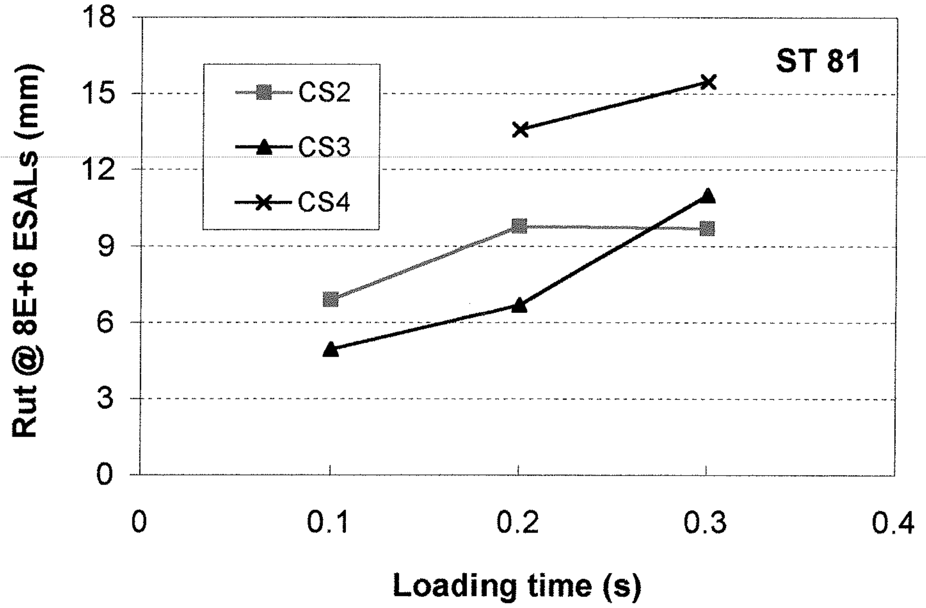

Figure 6 **– The effect of loading time in RSST-CH tests on rut prediction obtained by an 8m equivalent 80kN traffic level on cores obtained in test section ST81**

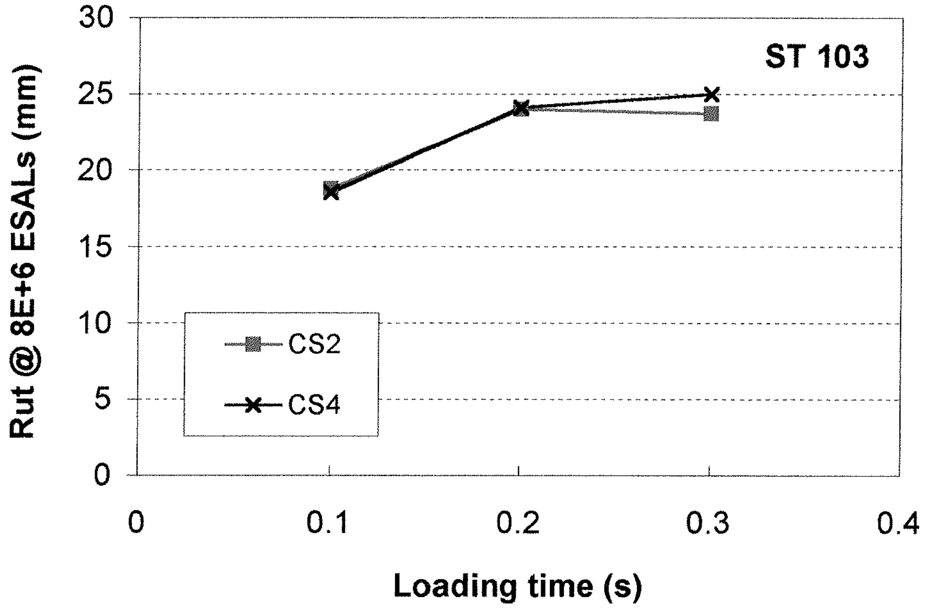

***Figure** 7* **– The effect of loading time in RSST-CH tests on rut prediction obtained by a 8m equivalent 80kN traffic level on cores obtained in test section ST103**

Each of the points marked in Figures 5 through 7 correspond to the average of three or four RSST-CH test results. The total number of tests executed was about 80. A few test results yielded an extremely high rut resistance. These were considered anomalous and were therefore disregarded.

It can be concluded from these results that time of loading (as used in the RSST-CH test) will significantly affect rut depth prediction. It is interesting to notice that, in Sections ST64 and ST81, this effect was essentially linear.

Figure 4 presented a relationship between observed rut depth and truck speed. A relationship between pulse duration and predicted rut depth has been determined, based on RSST-CH tests and SHRP-A698 concepts. These relationships were presented in Figures 5 through 7. It is therefore possible to establish a direct relationship between truck speed and necessary pulse duration to yield rut-depth predictions equal to the in-situ (observed) rut depth. The values obtained through this analysis are presented in Figure 8.

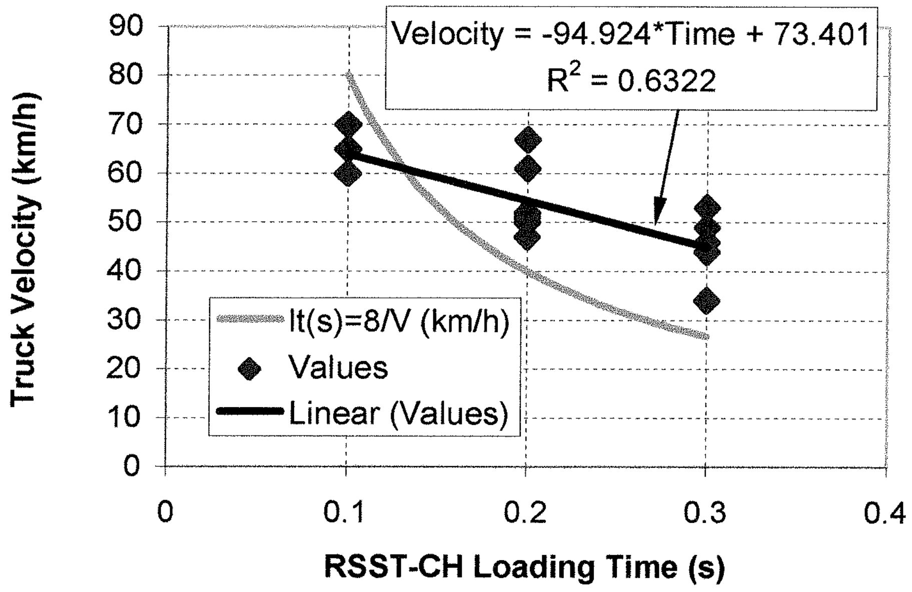

Figure 8 **– Relationship between RSST-CH loading time and truck speed necessary to yield equivalent rut depths values**

The best-fit linear regression line resulted in an R^2 equal to 0.63. The equation for this relationship is given by:

Velocity (km/hr) = -94.9 * Pulse duration (sec.) + 73.4

Figure 8 also depicts the relationship first proposed on preliminary data [6], and based on the assumption that a loading time for the standard test (0.1 sec.) corresponds to a truck speed of 80 km/hr. In this case, the authors proposed that, for a given truck speed, the corresponding loading time in the RSST-CH should be:

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

Since the new data does not support this initially proposed equation, a new relationship is proposed.

It can be concluded that 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 a given measured rut depth, assuming the correct loading time relationship as a function of speed is known, is represented in Figure 9. Here, it can be observed that the results are mostly within a half-order of magnitude of the actual number of ESALs. For Site 103, the resulting values show less scatter than for Sites 64 and (to some extent) 81. The large deviation for Cross Section 3 at Site 64 is to be expected because the variation of rut depth as a function of measured truck speed was not as expected (see Table 1).

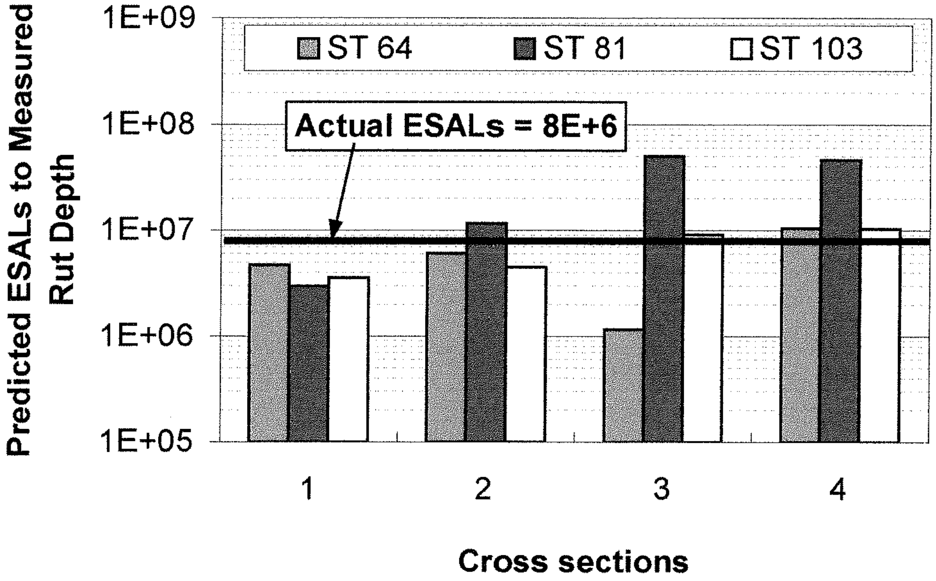

Figure 9 – **Predicted ESALs to measured rut depth, assuming RSST-CH test results were conducted at the correct loading time (as a function of speed)**

Because tests were executed only at 0.1, 0.2 and 0.3 seconds, interpolation of test results was needed when the conversion between truck speed and RSST-CH test pulse duration yielded values different from those at which the data were collected. When pulse durations where outside the 0.1-0.3 seconds range the dta obtained at the extreme values was used (i.e. if a truck speed called for test results at 0.35 seconds the data for 0.3 seconds was used rather then making extrapolations outside the range of values tested).

A comparison between predicted and measured rut depth, taking into account the proposed correction on RSST-CH loading times to account for truck speed, is presented in Figure 10. The R^2 of the resulting relationship was = 0.68.

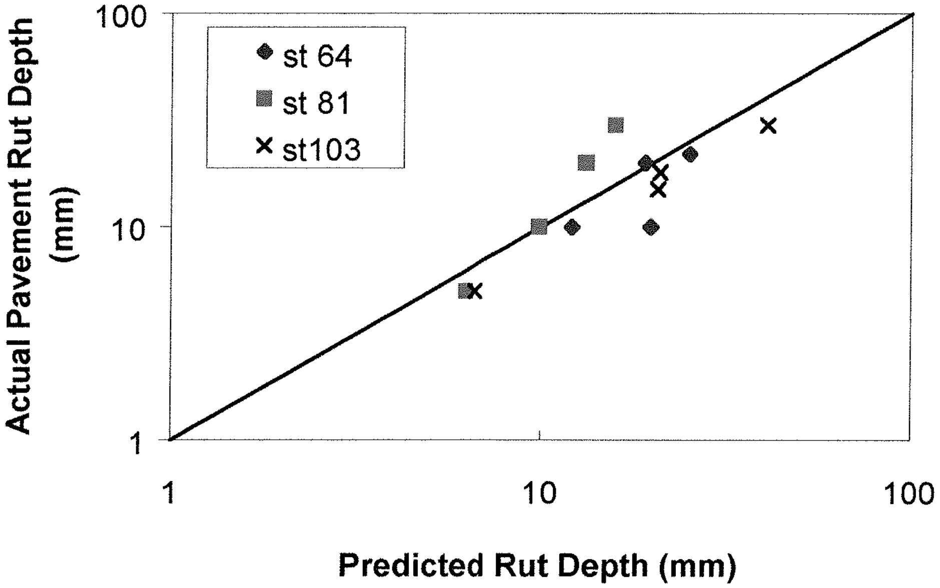

Figure 10 **– Predicted versus actual rut depth**

CONCLUSIONS

Loading rate strongly affects the rate of accumulation of permanent deformation. However, the shift factor between ESALs and RSST-CH cycles, as proposed by the SHRP-A698 procedure, appears to be capable of relating the accumulation of permanent shear strains in the test to those observed in the field. This seems to hold true for different truck speeds — as long as the rate of loading is taken into consideration.

The concepts presented (but not quantified) in the SHRP A-698 permanent deformation evaluation methodology appear to be able to generally capture the effect of truck speed. By varying the loading time in the RSST-CH test, the effect on the rate of accumulation of permanent deformation can be related to the effect truck speed has on the rate of development of rutting in the field. This paper proposes a new equation to convert truck speed to pulse duration in the RSST-CH test.

It is recognized that these values were obtained based on only one traffic level and 12 similar pavement sections. Further validation is needed before these concepts can be generally accepted. In this study, a constant recovery period of only 0.6 seconds between pulse loads was used. It may be worthwhile to investigate the effect of other rest periods, as well as other traffic levels and pavement sections.

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