Lowell Test Road: Helping Improve Road Surfacing Design

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The primary objective of this study was to determine the effects of tire pressure, aggregate thickness, and aggregate quality on surfacing performance in the context of verifying the Surfacing Thickness Program (STP). STP is a new aggregate thickness design model that has been adapted from previous U.S. Army Corps of Engineers research. Secondary objectives were to determine the relationship between surface and subgrade rutting and the implications for road maintenance, as well as to evaluate the use of the dynamic cone penetrometer (DCP) as a tool for evaluating material strengths. The study was accomplished by constructing, testing, and monitoring 18 test sections in western Oregon in 1992 and 1993. Tests were conducted from January through April to obtain the effect on log haul during normal wet weather periods. Surface and subgrade rutting was measured using a pressure transducer, which gave digital elevation results. The test sites were subjected to unloaded and loaded log trucks that were varied as to high and low tire pressures. The major conclusion of the study is that the STP accurately predicts aggregate surfacing rutting. Additional findings include the following: (*a*) surface rutting is primarily due to densification and aggregate shear, and only a small portion of the rut is observed in the subgrade; (*b*) the DCP is a useful tool for rapidly evaluating material strength properties; and (*c*) central tire inflation (CTI) showed less rutting than highway tire pressure.

The USDA Forest Service road network consists of 594 000 km (369,000 mi), approximately 65 percent of which is unsurfaced, 30 percent is aggregate surfaced, and 5 percent is paved (D. Badger, unpublished data). Annual road construction consists of 1930 km (1,200 mi) per year.

Road use, especially during periods of wet weather, causes accelerated surface deterioration (rutting) and may result in surfacing erosion and sedimentation. The Forest Service has attempted to reduce road maintenance costs and surfacing sedimentation (*1–3*; Copstead, unpublished data; Ashmore, unpublished data; Foltz unpublished data). The Lowell Road Test is a part of this effort to evaluate design, operational, and maintenance effects on surfacing requirements and sedimentation.

Objectives

The objectives of this study include the following:

1. Determining the effects of tire pressure, aggregate thickness, and aggregate quality on surfacing performance in the context of verifying the Surfacing Thickness Program (STP), a new aggregate thickness design model (*1*);

2. Determining the relationship between surface and subgrade rutting and its implications for road maintenance; and

3. Evaluating the use of the dynamic cone penetrometer (DCP) as a tool for evaluating material strengths.

Scope

This study was accomplished by constructing and monitoring the performance of 18 test sections on Road Number 1821190 in the Lowell Ranger District of the Willamette National Forest in Oregon. A plan view of the test section layout is shown in Figure 1.

The test sites were subjected to unloaded and loaded log trucks traveling uphill and downhill, respectively. Specific sites were subjected to either high or low tire pressures with specially equipped central tire inflation (CTI) trucks.

Field testing consisted of in situ California bearing ratio (CBR), DCP, and moisture and density tests. Site monitoring consisted of periodically measuring surface and subgrade rutting, records of traffic, and maintenance records.

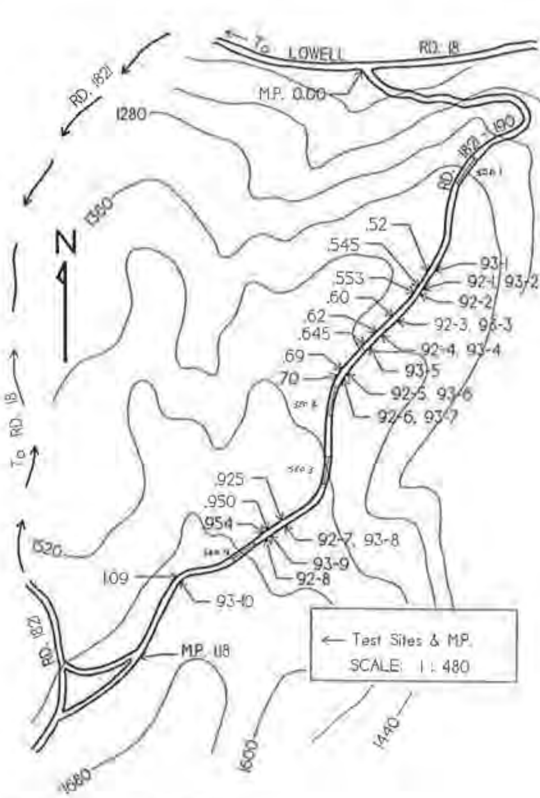

FIGURE 1 Site map.

Surfacing Thickness Program

STP is the Forest Service surfacing thickness design computer program for native- and aggregate-surfaced roads; it was first released in 1989. Whitcomb et al. (*1*) provided details on the selected model and incorporated a user's guide for STP. Yapp et al. (*4*) discuss the selection of the surfacing thickness design model for the computer from a variety of models used by the Forest Service before 1989.

Model

The Forest Service surfacing thickness design model is based on the U.S. Army Corps of Engineers 1978 Barber (*5*) equation. The model, shown below, assumes that the top layer has a higher strength than the bottom layer ($C_1 > C_2$):

$$RD = \frac{0.1741 P_k^{0.4704} t_p^{0.5695} R^{0.2476}}{(\log t)^{2.002} C_1^{0.9335} C_2^{0.2848}}$$

where

RD = rut depth (in.)
P_k = equivalent single-wheel load (ESWL) (kips),
t_p = tire pressure (psi),
t = thickness of top layer (in.),
R = repetitions of load or passes,
C_1 = in situ CBR of top layer, and
C_2 = in situ CBR of bottom layer.

This equation indicates the thickness necessary to limit the rut depth for known traffic conditions and layer strengths. This thickness applies to aggregate-surfaced roads designed by the Forest Service, on which the average rut depth is limited to 50 mm (2 in.). For native- (earth) surfaced roads, the model is used to determine the expected rut depth for known traffic conditions and layer strengths with an assumed top layer thickness of 152 mm (6 in.).

Initial STP

As developed in 1989, STP performs these calculations using interactive computer screens on an IBM-compatible personal computer. STP allows for the following:

1. Up to two periods (seasons) of layer strengths for each native-surfaced road and up to four seasons for each aggregate-surfaced road,

2. User-determined reliability based on work by Barber et al. (*5*), and

3. Economic analysis modules to determine the life-cycle cost of the proposed facility.

Current STP

From 1989 to 1993, STP was modified to include the following:

1. A module to determine the additional thickness for an existing aggregate-surfaced road and
2. A module to calculate the allowable ESWLs based on a known thickness of the top layer and the layer strengths for a given rut depth.

Future STP

Whitcomb et al. (*1*) emphasized the need for field studies to refine the design algorithm, mainly because of its need for field verification. This is one of the primary objectives of this study. At the Waterways Experiment Station (*3*) the U.S. Army Corps of Engineers has performed validation that has resulted in a slight modification to the coefficients in the rut-depth model.

The Forest Service is continuing to evaluate these validation studies and will modify the design model as necessary. The Forest Service is currently preparing a guide that will summarize this information entitled the *Surfacing Design Guide for Low Volume Roads*, which will serve as the latest user's guide for STP and provide comprehensive guidelines on surfacing selection, surfacing design, and use of STP as a maintenance tool for native- and aggregate-surfaced roads.

Test Section Design

Site Characteristics

The test site consisted of a 6.9-km (4.3-mi) loop of an existing Forest Service road with a gate to allow exclusive use for this test. The road grades varied from 7 to 14 percent, and the test sections were approximately 61 m (200 ft) long to allow for site instrumentation and provide a transition zone for different aggregate thicknesses. The test sections were situated on tangents to reduce the likelihood of vehicle braking or accelerating on the test site. Vehicle speeds were less than 48 km (30 mi) per hour.

The particular site variables selected for study included aggregate quality, strength and thickness, subgrade strength, and tire pressure. Table 1 shows how the above variables were included in the design for road tests of 1992 and 1993.

Aggregate Materials

Rut depths were measured on sections surfaced with good-quality and marginal-quality aggregates. Rutting is dependent upon material strength measured by CBR. For an aggregate material, the CBR is dependent on gradation and quality.

The good-quality aggregate met all of the requirements of the Forest Service Standard Specifications. These include sieve requirements for a dense, 25.4-mm (1-in.) minus gradation, Los Angles Abrasion (AASHTO T96) percent wear of 40 maximum, durability index (AASHTO T210) of 35 minimum, and a sand equivalent (AASHTO T176) of 35 minimum. The poor-quality aggregates had sand equivalent and durability (fines) values less than 35, with marginal test results in Oregon air degradation (OSHD TM 208-86).

The specified good-quality aggregate that was placed on Sites 1, 2, 5, and 9 in 1993 had good durability properties but poor gradation characteristics. The aggregate was open-graded, which resulted in an inability to attain the desired compaction. The gradation was improved by blending sand-sized materials with the surfacing rock in the field with limited success, as shown by low CBR values obtained for a good-quality aggregate.

In 1992 the average field densities of the subgrade generally ranged from 95 to 100 percent of AASHTO T-99 density, except for Site 1992-8, where the density was about 85 percent.

Subgrade Testing

The subgrade soils generally had a Uniform Soil Classification System grade of MH or ML. Typical values of in situ dry density and moisture content were 1280 kg/m^3 (80 lb/ft^3) and 35 percent, respectively. Additional subgrade soil values were determined by laboratory CBR, field CBR, and DCP tests. Field testing occurred before any traffic and at later points in the program. The field CBRs were performed in excavations in the wheel tracks between the monitoring lines. The DCP testing was done nearby, in the wheel tracks, without excavating any material.

Construction and Operational Plan

Construction

In 1992 construction of the test sites was accomplished by first blading off the existing aggregate from selected sites on Road 1821190. The desired thickness of either good- or poor-quality aggregate was then placed on the subgrade. Once the aggregate was placed, a 0.6-m (2-ft) wide trench was excavated transverse to the roadway to the top of the subgrade for placement of the subgrade tube. Typical sites are shown in Figures 2 and 3.

TABLE 1 Test Site Characteristics and Results

1992								
Site	1	2	3	4	5	6	7	8
Aggregate Quality	Good	Good	Good	Good	Poor	Poor	Good	Good
Ini. Thickness	140	183	234	269	221	211	160	132
Surfacing CBR	50	50	21.5	37.5	45	32.5	58	23
Subgrade CBR	17	17	11	19.5	22.5	14	16	6
Tire Pressure	Std	Std	Std	Std	Std	Std	CTI	CTI
Surface Rut	120	25	20	10	28	20	46	110
Subgrade Rut	10	5.1	0.0	0.0	5.1	2.5	2.5	120
Thick. Change	-4.6	-5.1	-10	-13	-41	-48	-33	-74
R Squared	.938	.891	.203	.389	.800	.559	.965	.710

Note: R Squared between actual and predicted rut

1993										
Site	1	2	3	4	5	6	7	8	9	10
Aggregate Quality	Good	Good	Good	Good	Good	Poor	Poor	Good	Good	Poor
Ini. Thickness	150	142	211	234	221	206	188	147	165	175
Surfacing CBR	23.5	20.5	86	60	28	50	74	61	18	33.5
Subgrade CBR	6.5	8.5	17.7	19.5	8.5	13.5	16	20.5	15	8
Tire Pressure	Std	Std	Std	Std	Std	Std	Std	CTI	CTI	CTI
Surface Rut	81	99	5.1	10	41	12.7	25	23	135	132
Subgrade Rut	7.6	7.6	0.0	2.5	17.8	5.1	7.6	5.1	15.2	5.1
Thick. Change	27.9	-12.7	-10	7.6	-7.6	-7.6	-7.6	-5.1	-51	41

note 1) Surface and Subgrade ruts are maximum obtained and may occur at different traffic levels for different sites.
2) Positive thickness change occurred where additional aggregate had been added. 25.4 mm = 1 inch

In 1993 additional test sites were added in a similar manner with the following exceptions. The subgrade tubes were placed in a 38-mm (1 1/2-in.) deep notch excavated in the subgrade before aggregate placement. This notch was used to ensure that no movement of the tube occurred in the direction parallel to the traffic, as had occurred on some sites in the Weyerhauser test road (Copstead, unpublished data) and the Lowell 1992 test.

Surface and Subgrade Deformations

The deformations of the top of the road surface and subgrade were monitored by means of a specially designed pressure probe, which is shown in Figure 4. The device consists of a 0- to 13.8-kPa (2-psi) pressure transducer sealed in a 13-mm-diameter by 76-mm (1/2-in.-diameter by 3-in.) section of conduit with silicon and epoxy. The conduit has two 6.3-mm (1/4-in.) diameter tubes (one vented to air and the other filled with an ethylene glycol solution), an electrical cable, and a wire line extending from one end. The conduit is fed into a 25.4-mm (1-in.) inside-diameter hydraulic hose that was buried in the top of the subgrade with the ends extending out of the ground into the ditch line. Additional information on this measuring device can be found in other sources (6).

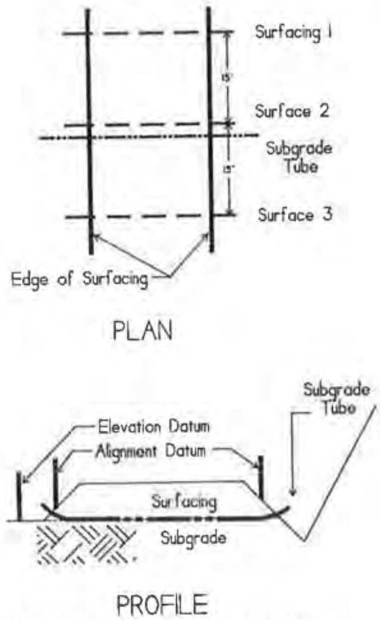

FIGURE 2 Typical site plan.

Elevation profiles of the subgrade were obtained by connecting the liquid-filled tube to an elevation datum, connecting the cable to a specially designed data logger, and pulling the probe through the hydraulic hose. The probe was stopped at 152-mm (6-in.) intervals to obtain elevation measurements. Surface profile data were obtained by simply stopping the probe at 152-mm (6-in.) increments in the line across the surfacing. The device reads to 0.01 in. and has been shown to be accurate to approximately 1.3 mm (0.05 in.). An example of subgrade and surface profile elevations taken at a typical site is shown in Figure 5.

Vehicles and Traffic

All vehicles used for traffic were equipped with CTI systems which allow the changing of the tire pressure for each wheel while en route. For the loaded trucks, CTI tire pressures were 482 kPa (70 psi) for the steering tires and 358 kPa (52 psi) for the driver and trailer wheels. For the unloaded logging truck and the dump truck (used to simulate an unloaded log truck), the tire pressures were 482 kPa (70 psi) for the steering and 207 kPa (30 psi) for the driver wheels. For sites where highway tire pressure was designated, all tires were set to 620 kPa (90 psi).

The loaded trucks traveled downhill, and the unloaded trucks traveled uphill. Specific sections were designated to have highway tire pressures, whereas others had only CTI low tire pressures. The total traffic in-

FIGURE 3 Typical site.

FIGURE 4 Pore pressure probe, two views.

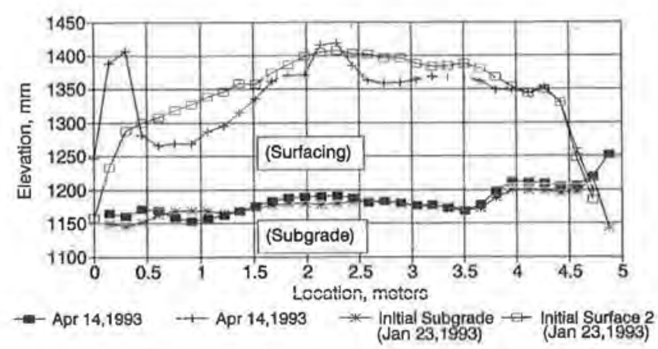

FIGURE 5 Typical subgrade and surface profiles, Site 1993-9.

cluded 1,025 loaded truck laps in 1992 and 787 laps in 1993, with an approximately equal number of unloaded truck laps.

Summary of Test Results

Surface Rutting

The progression of rutting for each site was plotted. Some of these sites are plotted as a function of date in Figures 6 and 7. Site 1992-7 is plotted in Figure 8 as a function of equivalent drive axle repetitions. Table 1 gives the maximum ruts for both surfacing and subgrade and the change in thickness from initial. As seen in Figures 6 and 7 and Table 1, Sites 1 and 8 had the least amount of surfacing thickness and the greatest amount of surface rutting in 1992. In 1993 Sites 1, 2, 9, and 10 had the greatest amount of surface rutting, again with the least aggregate thickness. All these sites had an initial thickness of less than 178 mm (7 in.).

Sites 1992-1 and 1992-8 and 1993-9 and 1993-10 experienced drainage problems during periods of heavy rainfall that were not typical of the other sites. Site 1993-9 is in the same location as Site 1992-8. These sites exhibited high surface rutting after these rainy periods, whereas only Site 1992-8 had any significant subgrade rutting.

As previously stated, Sites 1993-1, 2, 5, and 9 had an open-graded aggregate that was specified to be of good quality. These sites also exhibited the greatest amount of surface rutting in 1993, which can be attributed to the low surfacing CBRs caused by the gradation of this aggregate (the aggregate CBRs ranged from 18 to 28).

Subgrade Rutting

In this study, subgrade rutting, which is typically less than 7.6 mm (0.3 in.), was considered insignificant

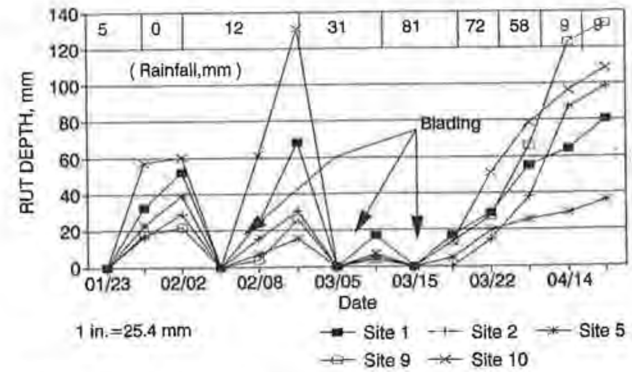

FIGURE 7 Surfacing ruts, 1993.

when compared with surface rutting. Because of drainage problems, low subgrade CBR, and low initial thickness, Site 1992-8 was the exception. Subgrade material pumped through the surfacing aggregate of this site. The surfacing thickness changed from an original 132 mm (5.2 in.) to 58 mm (2.3 in.) after traffic. When the surfacing thickness was reduced to a critical value, subgrade deformation accelerated.

Aggregate and Subgrade Strength Variations

CBR and DCP tests were measured before, during, and after traffic and tended to fluctuate with the weather and with density changes due to the traffic. The surfacing and subgrade field CBR values given in Table 1 were used along with values correlated to DCP testing.

In addition to the initial field CBRs, data analysis was performed using CBRs correlated from the DCP values. The DCP CBRs for 1992 were averaged from all DCP values obtained that year because there was relatively little rainfall in 1992, and rutting progressed

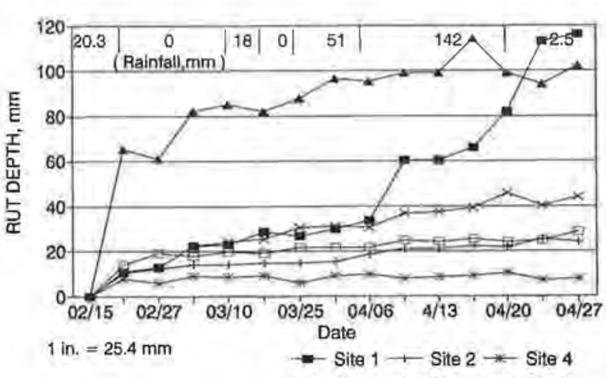

FIGURE 6 Surfacing ruts, 1992.

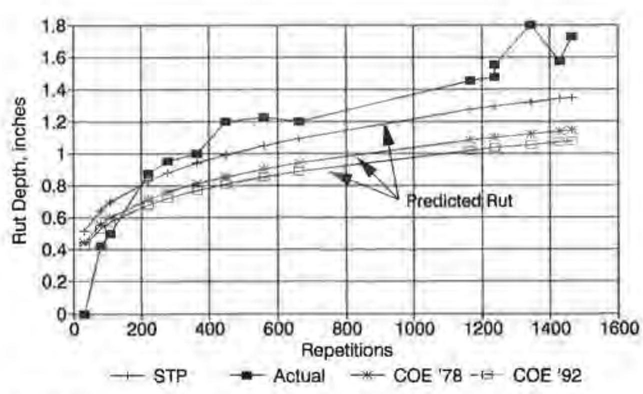

FIGURE 8 Site 1992-7: DCP CBRs C1 = 32.7, C2 = 6.4.

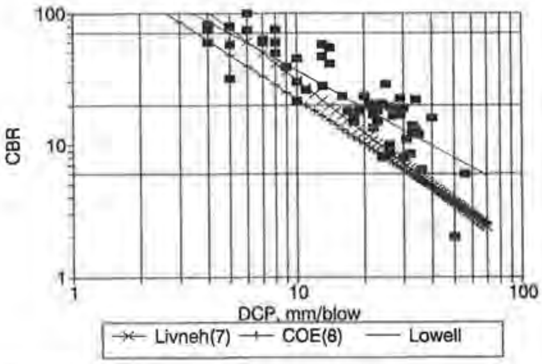

FIGURE 9 Field CBR versus DCP.

slowly. In 1993 the first set of DCP values obtained was used in further analysis. This year had considerably more rainfall, with significantly changing material properties.

Environmental Factors

Rainfall during the testing period ranged up to 52.6 mm (2.07 in.) per day, with one 12-day period accumulating 142 mm (5.6 in.) when traffic was being applied. The longest period involving traffic without rain was 9 days. Typically, because of low temperatures, tree canopy, and high humidity, the road materials stayed damp for a considerable period after a substantial rainfall.

Analysis of Test Results

Relationship Between CBR and DCP

For this project, 77 field CBRs and 115 DCP readings were taken. The tests of the DCP reading compared with field CBR that were taken at the same site at approximately the same time are plotted in Figure 9. Also plotted are two relationships for converting DCP readings to CBR values, those of Livneh (*7*) [$CBR = 646/(DCP)^{1.32}$] and the Corps of Engineers (*8*) [$CBR = 292/(DCP)^{1.12}$].

As seen in Figure 8, the data obtained from this study indicate a closer match between field CBRs and the Livneh correlation, which tends to give higher CBR values for the same penetration than does the Corps of Engineers equation.

For the Lowell test data, a regression analysis was done using the 77 field CBRs with the correlated DCP values. This resulted in the following relationship:

$$CBR = \frac{320}{DCP^{.943}} \qquad R^2 = .76$$

Surface Rutting, Aggregate Thickness, and Thickness Loss

The relationships between surface rutting, traffic (date), maintenance, and rainfall are shown in Figures 6 and 7. The most significant rutting occurred during periods of higher rainfall. At Site 1992-8, the largest increment of rutting, 66 mm (2.6 in.), occurred during the first two traffic periods when 20 mm (0.8 in.) of rain was recorded. Sites 1992-1, 7, and 8 developed rut increments of 48, 15, and 18 mm (1.9, 0.6, and 0.7 in.), respectively, during the traffic period of April 6 through April 20, when 142 mm (5.6 in.) of rain was recorded.

The surfacing thickness of each site was monitored from initial construction through the testing periods in the same manner as the rutting. The loss of thickness can be attributed to densification, local shear of aggregate, and aggregate loss.

After 1,025 or less loaded log truck had passed, the reduction in surfacing thickness at the sites during the testing ranged from 5 to 74 mm (0.2 to 2.9 in.), measured from the wheel path to the subgrade-surface interface. In 1992 the sites with good-quality aggregate and subgrade CBRs greater than 11 resulted in a thickness loss of less than 13 mm (0.5 in.). Sites 1992-1 and 8, with thicknesses of less than 140 mm (5.5 in.), experienced a maximum thickness loss of 74 mm (2.9 in.). These sites also had drainage deficiencies during periods of heavy rainfall.

Aggregate densification was monitored periodically by performing density tests. Densification ranged from 32 to 176 kg/m^3 (2 to 11 lb/ft^3), which accounted for approximately 7.6 mm (0.3 in.) of thickness loss. At several sites, aggregate thickness increases were measured outside the wheel path, indicating lateral displacement of the aggregate.

Typically, the loss of surface thickness was 50 percent or more of the surfacing rut value. Since the subgrade rut was typically less than 15 percent of the surfacing rut, the surfacing rut appears to be more directly affected by lateral movement of the surfacing, resulting in changes in surface thickness, than it is to subgrade rutting.

Subgrade Rutting

The total subgrade rut for any of the sites did not exceed 10 mm (0.4 in.) except at Site 1992-8 (designated Site 1993-9 the following year), and the scarified subgrade Site 1993-5. Fourteen of the 18 sites tested had total subgrade ruts of less than 7.6 mm (0.3 in.). When the sites with subgrade rutting greater than 7.6 mm (excluding Site 1992-8 due to drainage deficiencies) are considered, the subgrade rut was about 10 percent of the surface rut for Sites 1992-1 and 1993-9 and 40 percent for Site 1993-5. For the sites with less than 7.6 mm subgrade rutting, the subgrade rut averaged 14 percent of the surface rut.

Maintenance Implications

The only sites with significant subgrade rutting were sites that, because of drainage deficiencies from lack of side ditches, had a detrimental aggregate thickness loss. This thickness decreased to a critical value, which allowed the subgrade to become overstressed. At the other sites, the surface rutting was not primarily due to subgrade rutting and could be treated by blading maintenance.

As shown in Figure 7, the rut progression after maintenance could be equal to, greater than, or less than the initial rut progression. These sites had DCP values indicating CBR ranges of 10 to 27 for the surfacing and 5 to 8 for the subgrade. These are relatively low; however, the rut progression was generally less than or equal to the initial rut progression even though the aggregate surfacing was not compacted with a roller after blading.

Effect of Aggregate Quality and Moisture Conditions on Rutting

With the exception of Site 1993-10, the poor-quality aggregate sites (1992-5 and 6; 1993-6, 7, and 10) resulted in a very low amount of surfacing rutting, less than 28 mm (1.1 in.), and a minimal amount of subgrade rutting, less than 7.6 mm (0.3 in.). These sites typically had high surfacing CBRs (32.5 to 74), high subgrade CBRs (13.5 to 22.5) during dry conditions, good drainage, and an average of 203 mm (8 in.) of surfacing material. These factors, coupled with relatively dry conditions in 1992, account for the low rutting at these sites.

Higher rainfall levels in 1993 suggested that a difference in rutting between the good and poorer-quality aggregate sites would occur. However, the new sites that were specified for good-quality aggregate were low-strength (CBR) sites because of the poor aggregate gradations.

The 1993 aggregates with poor-quality tests and poor gradations were susceptible to strength decreases during rainfall extremes. The field and DCP CBR tests varied widely for these sites.

Effect of Tire Pressure on Rutting

In 1992 two of the eight sites (7 and 8) had CTI traffic; in 1993 three of the ten sites (8, 9, and 10) had CTI traffic. Sites 1992-8 and 1993-10 had drainage problems and are not good sites from which to draw conclusions. The CTI sites were constructed on weaker soils and less aggregate thickness in an effort to test CTI under extreme conditions. For these reasons, it is not possible to draw definitive conclusions regarding the performance of the CTI compared with highway tire pressures. However, some observations were noted:

1. During 1992 the highway tire pressure sites typically performed as predicted by STP or slightly better, as indicated by the R^2 values in Table 1 and additional analysis provided on the Lowell test road (9). The CTI site (1992-7 only) performed close to the STP predictions. This would support the STP method of addressing traffic and tire pressure, possibly being slightly optimistic toward CTI.
2. During 1993 the highway tire pressure sites typically performed better than had been predicted by STP. The CTI sites generally performed as predicted by STP; some sites performed better. This indicates that STP handles traffic and tire pressure acceptably and is slightly optimistic regarding CTI.
3. An analysis of the effect of tire pressure on individual sites showed a dramatic increase in rutting of the 1993 CTI sites 8 and 9 after the traffic was changed from CTI to highway tire pressure shortly after the March 26 measurement. This indicates large benefits for CTI over highway pressures, especially when sections are minimally designed.

In the Lowell rutting study, the lack of a large difference between highway and CTI rutting can be partially explained by the tire pressures used. For the standard highway situation, 620 kPa (90 psi) was used on all tires. For CTI, the steering tire pressure was reduced to 482 kPa (70 psi). In reducing the steering tires from 620 to 482 kPa (90 to 70 psi), the average tire contact pressure decreased from 469 kPa (68 psi) to 427 kPa (62 psi), as determined from a measured load and tire contact prints. In changing from 620 to 358 kPa (90 to 52 psi), the average contact pressure of the driver and trailer tires decreased from 365 to 303 kPa (53 to 44 psi), whereas the contact area radius increased only 11 mm from 128 mm (0.45 in. from 5.05 in.).

Comparison of Rutting with Design Model

Corps of Engineers

The 1978 Corps of Engineers design model (5) was used to predict the amount of rutting that would occur at each of the test sites for 1992 and 1993. The actual rutting that did occur was then compared with the predicted rutting by use of linear regression analysis. From this, the R^2-value and other statistics were used to compare different aspects of predicted versus actual rut development.

In 1992, 114 total data points were collected from the test sites. For 1993 the sites were graded before a number of data pairs were obtained. Because of this, only 21 data points were used for this analysis. For these data, the relationship between predicted (PR) and actual (RD) ruts for 135 data points using field CBRs in the prediction model is $PR = .21RD + .40$ with an $R^2 = .39$. In all conditions evaluated, as the actual rut depth increased, the predicted rut generally tended to approach a factor of from 0.2 to 0.7 of the RD value. In this analysis the field CBRs do not appear to contribute to significantly better correlation between predicted rut and actual rut than do the DCP CBRs.

In looking at the R^2-values for the individual 1992 sites, there is a high correlation (greater than 0.5) between predicted and actual ruts for all sites except 1992-3 and 1992-4. These two sites also had the greatest surfacing thicknesses, 234 and 269 mm (9.2 and 10.6 in.), and relatively high subgrade CBRs (11 and 19.5). At both of these sites, the rut prediction equations predicted a higher rut than actually occurred.

Surfacing Thickness Program (STP)

In preparing the STP program, to simplify use of the Corps of Engineers equation, a number of factors and input variables were standardized. This is explained in more detail by Whitcomb et al. (*1*). To analyze the effect this had on rut prediction, rut depth was predicted using both methods before any maintenance activities.

Considering the maximum rut predicted at each of these sites, the STP model predicted a higher rut than the Corps of Engineers equation did. The differences ranged from 1.5 to 16 mm (0.06 to 0.64 in.), or 11 percent to 44 percent, greater when compared with the Corps of Engineers prediction. The difference was typically around 20 percent. The sites with the greatest differences generally occurred where CTI tire pressures were used and the surfacing thicknesses were less than 175 mm (6.9 in.).

In comparing the predicted rut with the actual maximum rut exhibited, the STP model tended to underpredict the rut by an average of 16 percent, whereas the Corps of Engineers model tended to underpredict by an average of 29 percent.

Although the predicted ruts for each site both exceeded and fell short of actual ruts at different sites, the same general tendency for underprediction of ruts was verified by the linear regression analysis comparing actual and predicted ruts. In the equations generated relating predicted rut to actual rut, a coefficient typically less than .7 would need to be multiplied by the actual rut depth followed by the addition of a small constant for equality to be obtained.

Conclusions and Recommendations

Conclusions

The major conclusions and findings of this study are discussed in the following paragraphs.

The STP accurately predicts aggregate surfacing rutting. STP tended to underpredict rut by an average of 16 percent.

Surface rutting is primarily due to densification and lateral aggregate displacement; only a small portion of the rut (typically less than 20 percent) is observed in the subgrade. Subgrade rutting can be significant if aggregate thicknesses are at a minimum level to initiation of subgrade shearing.

The DCP is a useful tool for evaluating material strength properties. A good correlation exists between CBR and DCP—it is a rapid test that supports the ability to perform a large number of tests.

The CTI showed improved performance over highway tire pressure sites when used at the same sites later in the testing. The beneficial effect of CTI may not be as much as predicted by STP. However, this may be due to the lower difference between CTI and highway tire pressures used in this study than was used in previous efforts.

Not surprisingly, low compaction and poor drainage contribute to significantly more rutting than would normally be experienced.

Recommendations

For future studies of this type, it is recommended that a more significant difference between actual tire contact pressures for highway and off-highway conditions be obtained than was used for this study.

Additionally, the pressure probe used to measure elevations in this study worked very well by providing accurate measurements in a digital form that could easily be reduced and analyzed with a personal computer.

ACKNOWLEDGMENTS

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