sults were in good agreement. Calibration was then carried out on the basis of U.S. Army Corps of Engineers testing, which covers a wider variety of configurations, and, again, the results provided justification for the model.

Finally, an industry-oriented approach is presented for the analysis of equivalent loads, the criterion being transportation of a given tonnage and similar reduction of the serviceability index of the road. According to this approach, the equivalent allowable load on tandem- and triple-axle assemblies in relation to design single-axle load can be determined.

The model is a useful tool for determining allowable loads for different wheel-assembly configurations and for slightly unconventional conditions, such as excessive pavement thickness. Further improvement, as well as adaptation to specific local conditions, can be achieved through field performance studies.

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Evaluation of Full-Depth Asphalt Pavements

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A research investigation begun in 1971 by the Minnesota Department of Transportation to learn more about the behavior of full-depth asphalt pavements is reported. The project has 26 test sections, each 365.8 m (1200 ft) long, of a variety of thicknesses, and on a variety of soils. The major portion of the research consisted of Benkelman beam measurements at 15.2-m (50-ft) intervals, taken weekly during the spring, biweekly in the summer, and monthly in the fall. The temperature of the upper 3.8 cm (1.5 in) of the mat was measured each time the Benkelman beam deflections were measured. These data were then used to determine the effect of temperature and season on deflections and to create a set of correction factors to apply to the measured deflections so as to adjust them to a 26.7°C (80°F) peak season deflection. This peak season deflection was then taken to be the standard deflection for each test section. These standard deflections were compared with the deflections of aggregate-base pavements, and a relation was developed between the full-depth thickness and the granular equivalency of an aggregate-base pavement with an equal deflection. That relation was used to develop a design chart for full-depth bituminous pavement, which is the deflection equivalent of the flexible-pavement design chart currently used by the Minnesota Department of Transportation.

The purpose of pavement design is to provide a structure of adequate thickness and strength to carry expected traffic loads. Various designs that are considered to be adequate are then examined for construction and maintenance costs so that the engineer can choose the most economical pavement design.

Before 1969, the Minnesota Department of Highways had to choose between rigid pavement or flexible pavement with an aggregate base. In June 1969, "full-depth" asphalt was approved and included as a design alternative, adding a third choice for pavement selection. The alternate allowed 2.5 cm (1 in) of bituminous base to replace 5.1 cm (2 in) of aggregate base. But, although full-depth pavement was approved, very little was known about its structural response to axle loads or its performance under traffic.

The Physical Research Unit of the Minnesota Department of Highways began evaluation of full-depth pavements in 1971 with the prime objective of determining a unit granular equivalent (GE) value for hot-plant-mix bituminous base. The Minnesota project consists of 26 test sections that cover a range of soil types and full-depth thicknesses (see Table 1). To include new test sections on new construction projects, four test sections were designed and constructed: one flexible pavement section with an aggregate base that represents the typical section from the project plans, one full-depth section with an equal GE, and two additional full-depth test sections, one of which had a 5.1-cm (2-in) reduction in full-depth thickness and the other a 10.2-cm (4-in) reduction in full-depth thickness. The reduced sections were included to reduce the time required to make performance

Table 1. Test sections.

Test Section	Highway	Year Built	Surface Thickness (cm)	Base Thickness (cm)	Subgrade	R-Value	Approximate Location
201	MN-23	1970	9	30.5	A-6	8.5	Marshall
202	MN-23	1970	7.5	25.5	A-6	10	Marshall
203	MN-23	1970	7.5	10	A-3	72	Marshall
204	US-212	1971	7.5	12.5 30.5*	A-4	23	Madison
205	US-212	1971	7.5	25.5	A-4	21	Madison
206	US-212	1971	7.5	23	A-4	17	Madison
207	US-212	1971	7.5	15	A-6	20	Madison
208	MN-13	1972	5	15	A-6	19.7	Prior Lake
209	MN-13	1972	5	10	A-6	18.7	Prior Lake
210	MN-13	1972	5	20	A-6	21.5	Prior Lake
211	US-169	1974	4	8.5	A-4	58	Princeton
212	US-169	1974	4	16	A-4	59	Princeton
213	US-169	1974	4	23	A-4	52	Princeton
CS 212	US-169	1974	4	8.5 15*	A-4	59	Princeton
CS 213	US-169	1974	4	3 46*	A-4	60	Princeton
214	US-10	1976	11.5	16.5	A-2-4	12	New York Mills
215	US-10	1976	11.5	16.5	A-6	21	New York Mills
216	US-10	1976	7.5	16.5	A-2-4	65	New York Mills
217	US-10	1976	7.5	14	A-2-4	70	New York Mills
218	US-10	1976	7.5	21.5	A-2-4	57	New York Mills
219	US-10	1976	11.5	16.5	A-6	10	New York Mills
220	US-10	1976	6.5	35.5	A-2-4	18	New York Mills
1	Kandiyohi County Road 1	1970	13.5		A-6	26	Willmar
2	Kandiyohi County Road 1	1970	18		A-4	26	Sunberg
3	Kandiyohi County Road 20	1970	10.5		A-7-6	21	Willmar
4	Kandiyohi County Road 4	1970	14.5		A-6	18	Lake Lillian
102	MN-109	1963	5	21.5 5*	A-4	17	Wells

Note: 1 cm = 0.39 in.
*Aggregate.

evaluations and to provide more thickness variables for purposes of analysis.

Materials sampled for the investigation consisted of core samples and subgrade samples. Tests conducted on the test sections consisted of periodic Benkelman beam deflection measurements and corresponding measurements of pavement temperature, annual measurements of rut depth, roughometer index measurements, Mays road meter measurements, and surface condition ratings.

Laboratory work consisted of measurements of bituminous layer thickness from the cores, densities, extractions, gradation, penetration, and air voids. The subgrade samples were examined for Hveem stabilometer R-value, AASHO T-99 moisture density relations, gradations, and Atterberg limits.

The analytic work on this project had two objectives: (a) to determine the temperature and seasonal effects on deflections and (b) to determine how many centimeters of aggregate base it takes to reduce the Benkelman beam deflection to the same amount as that of bituminous base. The objectives were ranked in this order because the second was not possible without the first.

The loss in serviceability is too small at this time to determine the performance of full-depth pavements on all but two sections. Evidence is available, however, from the Brampton Test Road and the San Diego County Experimental Base Project, that the performance of full-depth pavement is at least as good as that of aggregate-base flexible pavement if the two have equal deflection values. This investigation will be continued until the test sections yield sufficient data to determine the performance capabilities of full-depth pavement.

CURRENT DESIGN OF FLEXIBLE PAVEMENT

A brief description of the basis for the current design of flexible pavement is included here to provide a better understanding of the basis of the research on full-depth pavement. Current flexible-pavement design is a product of Minnesota Investigation 183 (1). It combines the relation between deflection and 80-kN (18 000-lbf) standard axle loads (see Figure 1) derived from the AASHO Road Test (2, p. 110) with the relation between deflections, pavement GE, and embankment R-value (see Figure 2) derived from Minnesota test sections in Investigation 183 (1, p. 50). These two relations were algebraically combined, and the deflection terms were canceled. The resulting equation was then solved for GE. The following equation results:

$$GE = -69.6 + 35.8 \log(\Sigma N18) - 60.5 \log R \qquad (1)$$

where

GE = granular equivalent (cm),
ΣN18 = sum of the 80-kN axle loads carried to a present serviceability index (PSI) of 2.5, and
R = Hveem stabilometer value at 1.65 MPa (240 lbf/in²).

This equation is the basis of the Minnesota flexible-pavement design chart. Since the Minnesota relations used to develop the design equation were based on conventional aggregate-base flexible pavements, there was a concern for extending the design chart to include full-depth pavements.

Figure 1. AASHO Road Test relation between peak average spring deflections and standard equivalent 80-kN axle loads at PSI of 2.5.

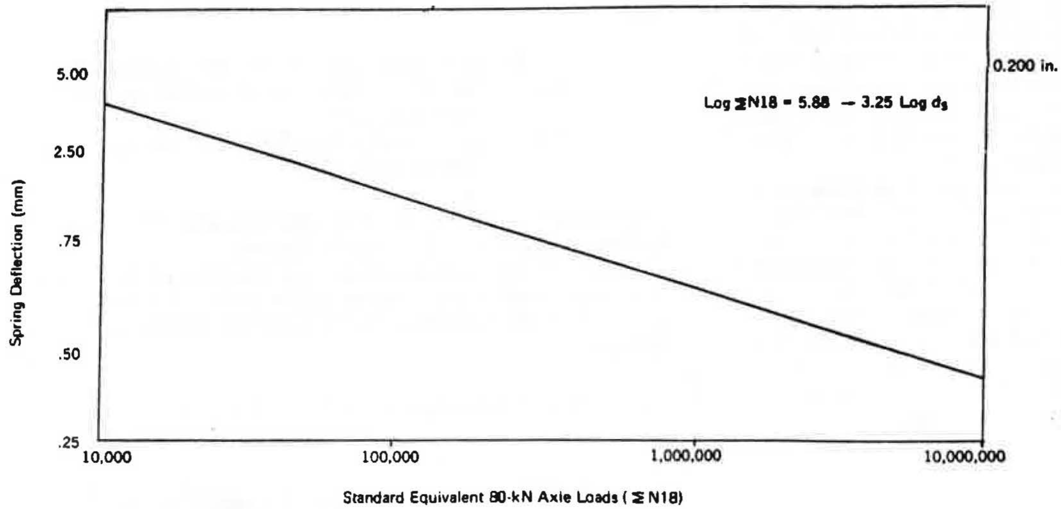
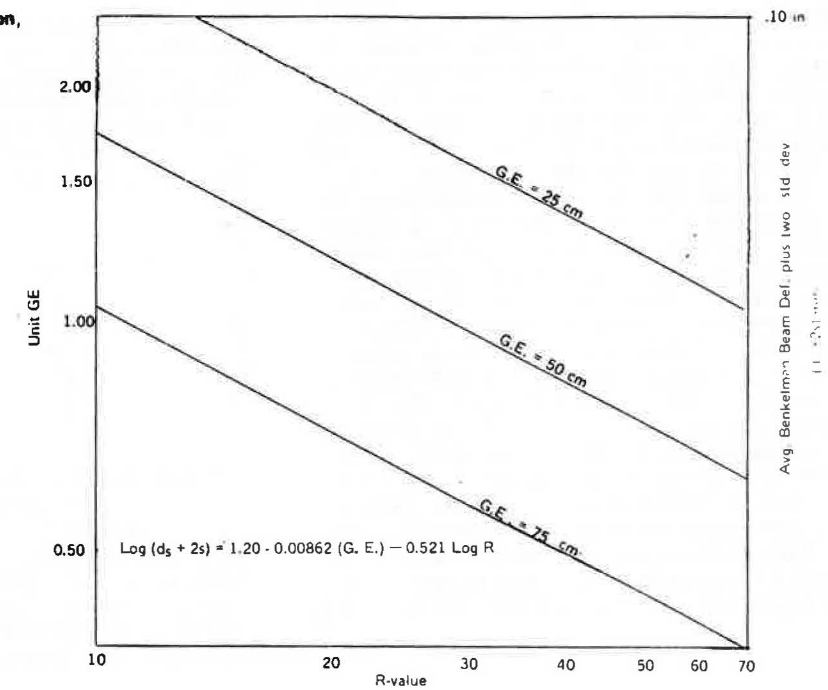


Figure 2. Relation between pavement deflection, GE, and R-value.



DATA ACQUISITION

Materials samples of all of the pavement materials and subgrade were obtained from the test sections. The bituminous samples were obtained by taking 15.2-cm (6-in) diameter cores from the test sections. A minimum of three bituminous samples (consisting of three cores) were generally taken from each section. The individual thickness of each layer was measured from the cores. Other tests, such as aggregate gradation, asphalt content, and density, were run to verify that the mix was within specifications.

Subgrade samples were also obtained from the test sections and sent to the central office laboratory, where they were analyzed for gradation, Atterberg limits, American Association of State Highway and Transportation Officials (AASHTO) soil classification, and Hveem stabilometer R-values (3) at a 1.65-MPa (240-lbf/in^2) exudation pressure. (The subgrade R-value has been found to have a good correlation with the maximum spring deflections for aggregate-base flexible pavements and is used in this investigation to characterize soil strength.)

Deflection measurements were made at 15.24-m (50-ft) intervals throughout the test section; this produced 25 deflection measurements in 365.76 m (1200 ft). The average of the 25 deflections is then the representative deflection for that test section, uncorrected for temperature and season.

To determine the seasonal deflection response of the test sections, deflections were taken as follows: weekly from mid-March to the end of May, biweekly from June through August, and monthly in September and October.

To find the effect of temperature on the test section deflections, pavement temperature was measured each time the deflections were measured. Pavement temperature was measured by driving a hole in the pavement 3.8 cm (1.5 in) deep, filling it with light machine oil, and placing a thermometer in the hole. The temperature was allowed to come to equilibrium while the deflections were taken and then read. It should be noted that this is not a surface temperature but an average temperature of the upper 3.8 cm of the mat. This method of measurement was found to be adequate for correlating pavement deflection with pavement temperature.

Ride, rut depth, cracking, and patching were also measured on each test section each year. Ride was measured by using two devices: the PCA road meter and the BPR roughometer. Rut depths were measured in the outer wheel path at 15.24-m (50-ft) intervals by use of an A-frame. These measurements were then averaged to produce one representative rut depth per test section. The survey of surface condition conducted in this investigation was very limited. Basically, it included only multiple cracking and patching.

ANALYSIS

Adjusting Deflections for Temperature

When the data analysis began, the first task was to characterize each test section by a Benkelman beam deflection value. This initially caused concern because of the variance in deflection values on the test sections throughout the year. Figure 3 shows the typical deflection response exhibited by a section from March through October. Since it was felt that the deflections of full-depth pavements were quite temperature dependent, the first task was to find a way to correct for temperature.

Since most of the data spanned a period from early March to mid-October and a 50° C (90° F) temperature range, there were no direct methods available to determine a temperature-deflection relation that was independent of date. Statistical regression techniques were then used to determine the effect of temperature and date. The first attempt was a three-variable regression of the average deflection of the test sections versus mat temperature and date. The results were surprising in that, for most of the sections, the date was not a significant factor in the regression and the mat temperature explained nearly all of the deflection variance. The sections were then rerun in a two-variable regression of deflection versus temperature. From each regression, a set of factors were developed, as follows:

$$\text{MTCF} = \text{def } 26.7°\text{C}/\text{def (T)} \quad (2)$$

where

MTCF = mat-temperature correction factor,
def 26.7°C = 26.7°C (80°F) deflection predicted by regression, and
def (T) = deflection predicted by regression at temperature T.

The factors for the individual sections and years used in the analysis are shown in Figure 4.

A two-variable regression was then run to relate the mat-temperature correction factor to the mat temperature. The best correlation resulted in the following relation:

$$\overline{\text{MTCF}} = 111.791\,81\,[(9/5)\text{C} + 32]^{-1.075\,31} \quad R = 0.95$$
$$\text{SE} = 0.05(\log) = 1.75 \text{ percent} \quad (3)$$

where $\overline{\text{MTCF}}$ = the average mat-temperature correction factor and C = mat temperature of the upper 3.8 cm (1.5 in) (°C).

The correlation is good, and the standard error is small enough to suggest that there is little difference in the correction factors from one test section to another. The above expression can thus be used to generate a set of MTCFs for mean deflections at mat temperatures other than 26.7°C (80°F). MTCFs are plotted in Figure 5 and given in the table below [t°C = (t°F - 32)/1.8]:

Mat Temperature (°C)	$\overline{\text{MTCF}}$	Mat Temperature (°C)	$\overline{\text{MTCF}}$
5	2.06	30	0.93
10	1.67	35	0.84
15	1.39	40	0.76
20	1.20	45	0.69
25	1.05	50	0.64
26.7	1.00		

It is interesting to note that the factors increase quite rapidly at mat temperatures below 26.7°C, which indicates significant increases in pavement strength at those lower temperatures. Above 26.7°C, the pavement continues to become weaker as indicated by the fractional correction factors above that temperature. This is in contrast to the conventional aggregate-base flexible pavements that have thinner bituminous layers; in these

Figure 3. Deflections for test section 207 in 1972.

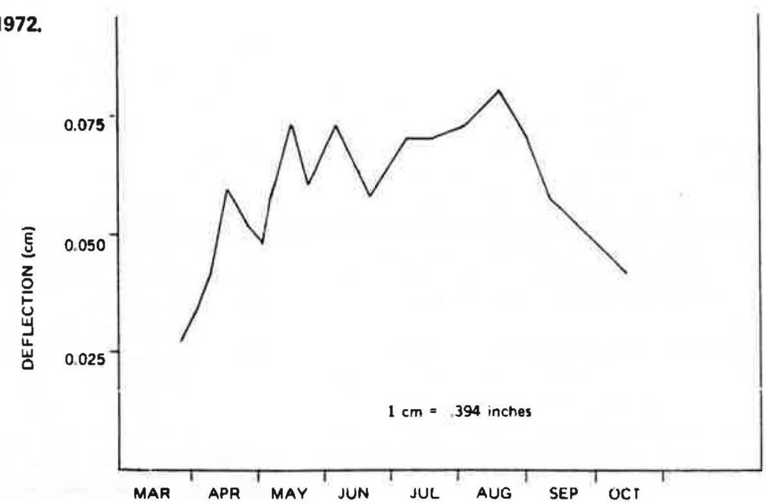


Figure 4. Correction factors for correcting full-depth 26.7°C deflections to deflections at any temperature.

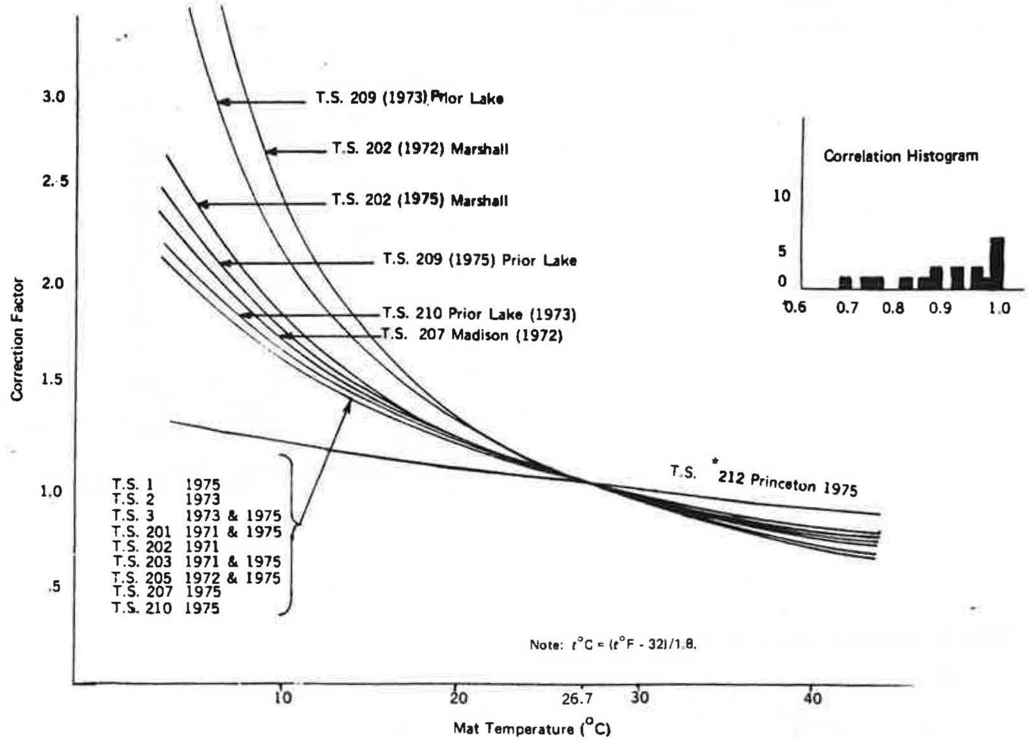
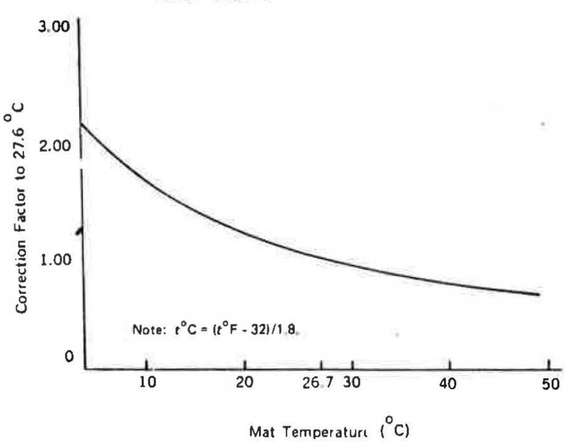


Figure 5. Temperature adjustment factors for Benkelman beam deflections on full-depth pavement.



pavements, the mat temperature does not appreciably affect pavement strength above 26.7°C. The shape of the curve in Figure 5 for factor versus temperature is similar to a curve recommended by the Asphalt Institute.

Once the approximate mat-temperature effect on the mean spring recovery deflections had been determined, the spring recovery deflections for each test section were corrected to a mat temperature of 26.7°C by using the temperature correction factors. An analysis of the temperature-corrected deflections showed a definite relation between deflection and date. A suitable relationship between the corrected deflections and the date at which they were recorded was then determined. The relation took the following form:

$$\ln\overline{BB}_{26.7} = \ln a_0 + a_1 \ln D + a_2 D \quad (4)$$

where

$\overline{BB}_{26.7}$ = average mat-temperature-corrected spring recovery deflection,

D = day of the year, and

a_0, a_1, and a_2 = regression coefficients.

In all instances, time significantly affected the the average mat-temperature-corrected defle...

To aid in comparing the effect of time on th... recovery deflection of each test section, the m... $\overline{BB}_{26.7}$ predicted by the relation and the avera... which it occurred were calculated. The result... given in Table 2. The data show that the maxi... spring 26.7°C deflection occurs between about ... of May and the middle of June.

To determine the average time effect, spring ... covery correction factors were generated for ea... section in Table 2 by determining the ratio betw... deflections calculated for other times in the yea... the calculated maximum 26.7°C deflection. Th... were then compared with the corresponding dat... a correlation. The result of the analysis was ...

$$\overline{SRCF} = 24.281\,82\,(D)^{-0.808\,75}\,e^{0.005\,788\,(D)}$$

$R = 0.86 \quad SE = 0.05$ on $\ln \overline{SRCF}$

where $\overline{SRCF}$ = average spring recovery correcti... and D = number of days into the year (April 26 is 11...

The correlation is good, and the standard error ... small enough to suggest that there is little differen... the correction factors from one test section to anoth... The above expression can thus be used to generate a... average set of spring recovery factors for the mean m... temperature-corrected deflection. The spring recover... correction factors are given below:

Date	Factor	Date	Factor
March 1	1.25	June 29	1.03
March 16	1.14	July 24	1.06
March 31	1.07	July 29	1.08
April 15	1.03	August 13	1.12
April 30	1.01	August 28	1.16
May 15	1.00	September 12	1.20
May 30	1.01	September 18	1.25
June 14	1.02	October 12	1.31

Table 2. Date of peak-temperature-corrected deflection by test section and year.

Test Section	Year	Predicted Peak $\overline{BB}_{26.7}$[a] (mm)	Day into Year of Maximum Deflections	Pavement Thickness (cm)	Embankment	
					Subgrade	R-Value
102	1973	0.85	117	25.4	A-4	17
102	1974	0.86	131	25.4	A-4	17
102	1975	0.76	142	25.4	A-4	17
201	1971	0.38	137	39.4	A-6	8.5
201	1975	0.39	128	39.4	A-6	8.5
202	1971	0.46	138	33.0	A-6	10
202	1975	0.47	145	33.0	A-6	10
203	1971	0.36	136	17.8	A-3	72
203	1972	0.32	132	17.8	A-3	72
203	1975	0.25	162	17.8	A-3	72
207	1972	0.57	148	22.9	A-6	20
208	1975	1.63	150	20.3	A-6	20[b]
209	1975	1.88	141	15.2	A-6	19[b,c]
210	1975	0.81	167	25.4	A-6	22[b]
212	1975	0.85	128	19.7	A-4	59

Note: 1 mm = 0.039 in; 1 cm = 0.39 in; $t^\circ C = (t^\circ F - 32)/1.8$.
[a] The maximum deflection value as determined from $\overline{BB}_{26.7} = a_1 (D)^{a} 1e^{a} 2_D$, not the maximum observed deflection corrected to 26.7°C.
[b] R-value given is that obtained prior to paving.
[c] Subgrade samples taken from the subgrade in the northbound lane, during later maintenance repair, resulted in R values between 8 and 10.

Figure 6. Benkelman beam deflection response to season.

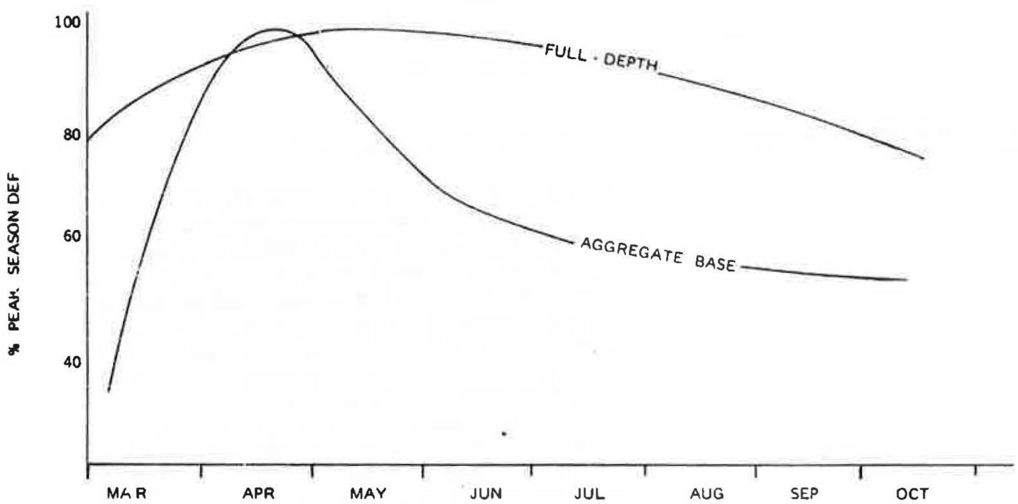
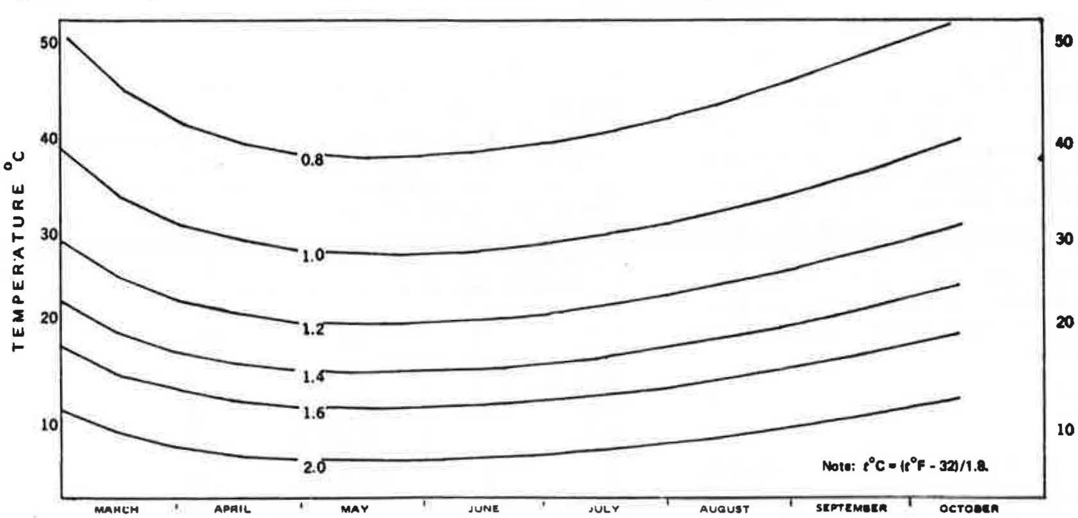


Figure 7. Full-depth correction factors to correct deflections for season and temperature.



It can be seen that the peak seasonal deflection can be expected from the middle of April through the end of June. In addition, the correction factors are small in comparison with the seasonal correction factors developed for flexible pavements that have aggregate bases (4), as shown in Figure 6.

The factors obtained in this investigation represent mostly plastic soil subgrades, which are found exclusively in the southern half of the state. Early- and late-season factors given above may be low when they are used to adjust the deflection of a full-depth pavement in the northern part of the state because of the later spring thaw and earlier freeze.

Correction Factor for Date and Temperature

To quicken the process of correcting deflections for temperature and date, the above two relations were combined and put into graph form, as shown in Figure 7. To use this graph, the Benkelman beam operator enters the graph on the right or left side at the measured mat temperature and goes horizontally into the graph to the date on which the deflection was taken. The factor is then interpolated by its position between the factor contour lines. For example, a 15.6°C (60°F) mat temperature on April 15 has a correction factor of 1.42; or a 43.3°C (110°F) mat temperature on August 15 has a correction factor of 0.80. It should be noted that the mat temperature for which Figure 7 was developed is the average temperature of the upper 3.8 cm (1.5 in) of the pavement surface. For the greatest possible accuracy, low mat temperatures or early- or late-season deflection measurements should be avoided if possible.

Deflection Behavior in Full-Depth Pavements

The following observations can be made concerning deflection behavior in full-depth pavements:

1. Full-depth pavement deflections, when corrected for temperature, generally peak in mid-May, whereas conventional pavements generally peak in mid-April. The actual uncorrected deflection peak for full-depth pavement occurs from mid-June to mid-July because of the high pavement temperatures.
2. Mat temperature has a marked moderating effect on the spring recovery in full-depth pavement. Deflections will peak in late spring and will not drop off significantly until late summer or early fall.
3. The thinner the pavement becomes, the larger the spring recovery correction factors tend to be. Deflection for full-depth pavements that are less than 14 cm (5.5 in) thick should not be corrected by use of the spring recovery factors given in this paper.
4. The spring recovery factors given in the table above are typical of full-depth thicknesses of ≥14 cm on weak soils such as plastic A-4 and A-6 soils in the Stabilometer R-value range of 5-25. Although there have been indications that the factors apply to other soils (test section 203 on an A-3 soil), there are not enough data at this time for valid conclusions.
5. Because of the small spring recovery factors, a weak period for full-depth pavement cannot be sharply defined. For that reason, it would be very risky to build a thin full-depth pavement with the intention of restricting axle loads in the spring. To protect a full-depth pavement by means of axle-load restrictions during its peak deflection period, the restrictions would have to remain in effect until fall.

Full-Depth Granular Equivalency

Now, with the ability to assign a standardized deflection value to a full-depth pavement, structural analysis can be done. Several methods were used and are briefly described here.

The first method described involved computing a GE for each full-depth test section from the temperatures, seasonally corrected deflections, and subgrade R-values of the sections. The equation used for this computation relates the average peak spring deflection of a flexible pavement with an aggregate base to its GE and subgrade R-value. The computed GE was then correlated with the thickness of the full-depth test sections to produce a GE-thickness relation (see Figure 8). This relation is used to develop the full-depth design chart shown in Figure 9. Minimum thickness designs, based on the R-values included in the full-depth design chart, are based on the full-depth thickness, which is equivalent [illegible] GE required to limit the average deflection plus two [illegible] deviations to 1.9 mm (0.075 in). It should be [illegible] this method does not result in a single fixed G[illegible] full-depth pavement.

Another GE analysis compared the deflectio[illegible] full-depth test sections with the adjacent contr[illegible]

A determination of the GE of bituminous ba[illegible] of the aggregate-base control sections yields [illegible] of 2.57 for test sections 205 and 206 in compar[illegible] test section 204. A unit GE of 2.32 is obtained [illegible] sections 208, 209, and 210 in comparison with [illegible] flection behavior of the aggregate-base test se[illegible] the adjoining project. Comparison of test sect[illegible] and 213 with control sections 212 and 213 yields [illegible] GE of 1.81 and 2.51, respectively.

Test sections 214-216 and 218 and 219 provi[illegible] unique opportunity to evaluate bituminous base [illegible] test sections are all in the outside lanes of a fo[illegible]r roadway and can be compared with aggregate-[illegible] sections adjacent to them in the inside lanes. [illegible] test-section pairs are used to directly compare [illegible] flection resistance capabilities (GE) of bituminous [illegible] and aggregate base. Because these sections oc[illegible] same embankment side by side, all other factors [illegible] be about as close to equal as can be expected in [illegible] A deflection analysis of these sections yields an [illegible] unit GE of 2.78. This result is based on only one [illegible] deflection measurements that were obtained late [illegible] fall of a drought year. Additional deflection m[illegible]ments are needed to substantiate these results.

Edge Effect on Deflections

A special deflection study was run to determine [illegible] flection behavior of a full-depth pavement near [illegible] There were two objectives in this study: (a) to deter[illegible] mine the design thickness of full-depth widenings [illegible] to a portland cement concrete pavement and (b) to de[illegible] termine the distance the bituminous base should ext[illegible] beyond the outer wheel track of a full-depth pavement.

The deflections that have been discussed so far are slab deflections that were taken about 1.5 m (5 ft) from the edge of the bituminous base. These deflections are fairly representative of the interior portion of a uniformly supported slab. Full-depth widenings, however, are narrow and thus approach the behavior of a strip foundation rather than that of a slab.

A special deflection study was conducted on test sections 201 and 203 to quantify this difference in deflection. To ensure equal field conditions, deflections were first measured at 0.3-m (1-ft) intervals from 2.74 to 3.66 m (9-12 ft) from the centerline, at 0.15-m (0.5-ft) intervals to the edge of the bituminous base 4.56 m (15 ft) from the centerline, and then at 0.3-m intervals to the edge of the shoulder at three locations per test section. No increase in deflections (attributable to the edge effect) was noted until beyond the 3.66-m (12-ft) edge stripe, which indicates that the standard 9.14-m (30-ft) width of bituminous base could be reduced to 8.53 m (28 ft) without excessive deflections in the outer wheel path. On four-lane roadways, the center of the base should be shifted 0.3 m to the right to provide the protection required for right-shoulder traffic encroachment.

After the first set of deflections was measured, the slab was sawed longitudinally 3.66 m (12 ft) from the centerline for 12.2 m (40 ft). Deflections were then taken at 2.44, 2.74, 3.05, 3.35, and 3.96 m (8, 9, 10, 11, and 13 ft) from the centerline. The deflection at 3.96 m is of particular interest here because it is the deflection of a strip footing rather than a slab. The deflection was found to increase by about 30 percent for the

Figure 8. Full-depth thickness versus GE.

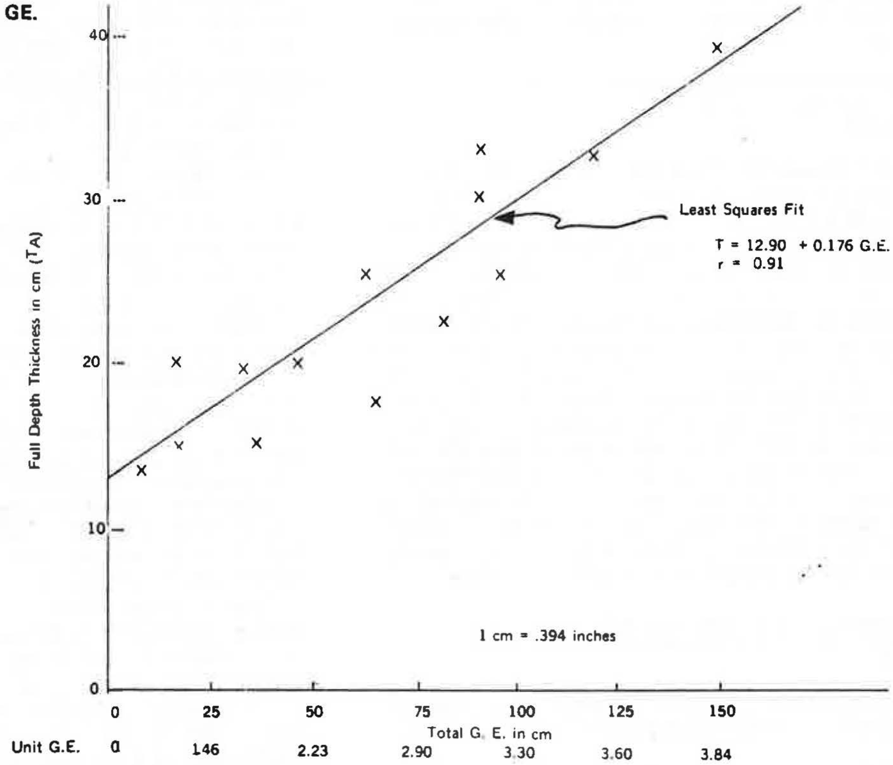
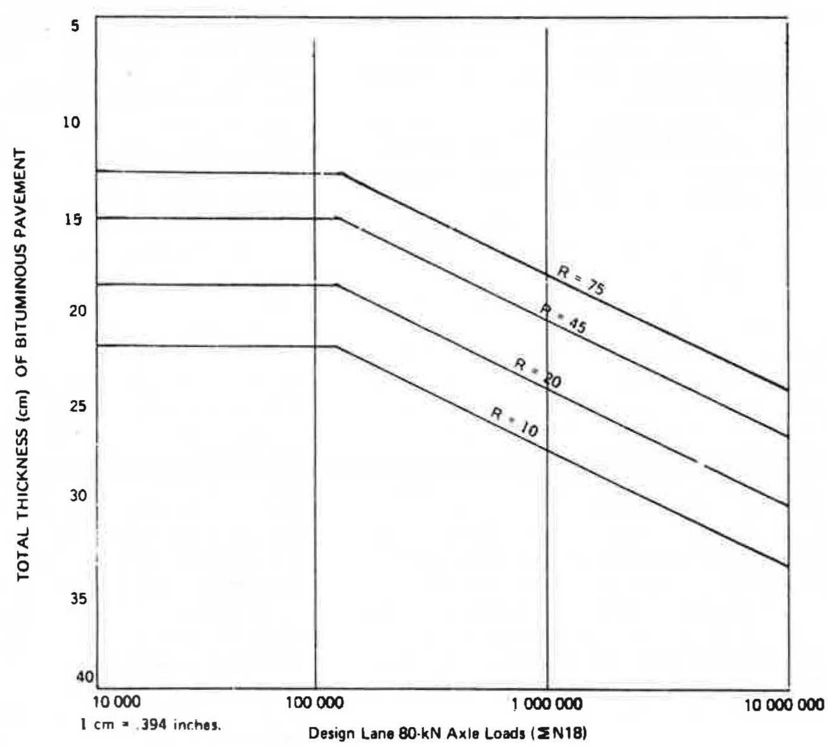


Figure 9. Design chart for full-depth bituminous pavement.



A-6 embankment (test section 201). No noticeable increase was found on the A-3 embankment (test section 203) after the longitudinal saw cut. Finally, transverse saw cuts across the shoulder were made at the ends of the longitudinal saw cut, and the deflection measurements were repeated; no increase in deflections was noted, however.

Based on the deflections obtained after the saw cut, if widening of an existing narrow, rigid pavement is based on the full-depth design, the thickness of the full-depth pavement should be increased by 20 percent. This additional thickness will result in approximately the same deflection intended in the design.

FINDINGS AND CONCLUSIONS

Full-depth pavements do not exhibit the same Benkelman beam deflection behavior as aggregate-base flexible pavements. The deflections are much more sensitive to the temperature of the bituminous. The deflections are, in fact, so dependent on temperature that this effect nearly masks the seasonal effect. The seasonal effect can only reduce the deflections by about 30 percent (at most) from the peak seasonal deflection and then only at the seasonal extremes, such as early March or October. Temperature, on the other hand, can vary the deflection by as much as 300 percent at any time of the year. For instance, a deflection of 0.25 mm (0.010 in) at a 4.4°C (40°F) mat temperature can increase to 0.76 mm (0.030 in) if the mat temperature increases to 43.3°C (110°F).

Analysis of the deflections, adjusted to peak season deflections at a 26.7°C (80°F) mat temperature, shows that the deflections are very sensitive to pavement thickness in the 12.7- to 22.9-cm (5- to 9-in) range. But, as pavement thickness increases beyond 30.5-33.0 cm (12-13 in), there is little decrease in measured deflections. This implies that assigning a single unit GE value to full-depth pavement is not appropriate. Our comparisons of the full-depth and aggregate-base flexible test sections on this project show that a 17.8-cm (7-in) full-depth pavement has the same deflection as a flexible pavement with 27.9 cm (11 in) of GE and that a 27.9-cm full-depth pavement has the same deflection as a flexible pavement with 85.1 cm (33.5 in) of GE. The unit GE of full-depth pavement varies with the pavement thickness; for example, it is 1.5 at a thickness of 17.5 cm (6.9 in) and 3.0 at a thickness of 27.4 cm (10.8 in).

In the special study of the edge effect, it was found that full-depth pavement on plastic soils deflects about 30 percent more at the edge of the pavement than it does 0.6 m (2 ft) from the edge. This same increase in deflections also occurs in full-depth widenings that are less than 1.22 m (4 ft) in width. To reduce the deflection of a widening to the deflection of a normal pavement, the full-depth thickness should be increased by 20 percent.

Early indications show that the performance of full-depth pavement is comparable to that of aggregate-base flexible pavement if both types have the same peak season 26.7°C (80°F) Benkelman beam deflection.

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Analysis of a Cracked Pavement Base Layer

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A study is reported whose objectives were to investigate the effect of the presence of a crack in a treated pavement layer on the stresses and strains induced in the layer by traffic loading and to formulate a procedure for including the effect of the crack during structural pavement design. Prismatic-solid finite-element analysis was used to calculate the stress next to a wide crack, and the ratio of this stress to the stress calculated in an uncracked pavement was taken to quantify the effect of the crack on the stress developed. An increase in stress usually resulted. The study shows that the maximum tensile stress in the treated layer occurs adjacent to the crack at the bottom of the layer and that it acts parallel to the crack. The magnitude of the increase in stress depends on the thickness of the treated layer and the width of the crack, and the maximum increase appears to be 1.4 times. The increase in vertical compressive strain in the subgrade in the vicinity of the crack may be considerable—as much as 14 times—although it is likely to be much less some distance away from the crack.

Treating road-building materials with cement or lime has always been a popular practice because it increases the strength of the material. Both cement- and lime-treated materials do, however, have a tendency to exhibit initial cracking—also called shrinkage cracking—soon after construction. For structural design purposes, materials treated with cement or lime should therefore be considered in the same way; a general term for both—treated material—is used in this paper.

Examples of the extent and width of the initial cracks in pavements that have cement-treated crushed-stone bases are shown in Figure 1. The width generally depends on the quality of the treated material and the position of the layer in the pavement structure. In an ex-