Current Interpretation of Stability Measurements On Two Experimental Projects in Maryland

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The roads being evaluated are (a) a stabilized granular soil base surfaced with a double seal and (b) a soil-lime- fly ash stabilized base.

Generally, when using the Benkelman deflectometer with or without a Helmer deflection profile recorder, measurements of the vertically downward deflections of a road surface are valuable measures of the adequacy of a flexible pavement design. In addition, measurements are also made of the recoveries from deflections, as well as residual deflections. In the past, the last two measures were generally scrutinized at least to the extent that their values were not considered to be unusual.

Using the deflectometer with a profile recorder makes possible a determination of the longitudinal bending or flexing of the road surface in the general area of the test point being evaluated.

In this research, the recorded deflection profiles are being used to determine all of these measures. In addition, they are examined for evidence of potential extrusion, evidence of any traveling rolling wave ahead of the dual wheels (sometimes also found to exist behind the wheels), and evidence that the supports of the apparatus (the datum) are or are not in the zone of significant influence.

It is admitted that the recorded deflection profile leaves much to be desired in the line of accuracy. The greatest inaccuracies are considered to be caused by the zone of influence which introduces a varying bias to the profile and extrusion of the road surface materials upward between the tires. When the zone of influence is negligible, and the surface materials are stable the recorded profile is considered to be a virtual image of the deflection of the road surface along a line between the tires of the dual wheels of a moving truck.

The importance and meaning of the various data obtainable from the profiles are carefully analyzed. In the case of the soil-lime-fly ash stabilization project, the use of calcium chloride was effective in improving stability, particularly at early ages. In the base of the granular soil stabilization project the use of calcium chloride was effective in improving and maintaining stability.

● THE COMMITTEE on "Soils-Calcium-Chloride Roads" initiated certain field research investigations to evaluate the effect of calcium chloride in soil base stabilization. The State Roads Commission of Maryland has cooperated with this committee on the continuing study of these experimental projects. An interim report was published in HRB Bulletin 241.

The method adopted to evaluate these test sections was principally through use of the Benkelman deflectometer with a Helmer deflection profile recorder to measure and record the deflection characteristics of a road under comparatively natural conditions of loading. Experience in evaluation of these two projects suggest that there is a definite value in using this non-destructive method of test.

It is the hope of the committee that this report will stimulate interest in similar studies by other agencies and that they might benefit from such interpretations of stability measurements as advanced herein.

The roads selected in this study represent what might be considered to be near extremes in stabilization. The first test project, approximately 800 ft in length on Maryland Route 2, consisted of stabilizing a granular soil base course 24 ft wide. Calcium chloride was applied to six test sections at varying rates of ½, 1 and 1½ lb per sq yd per 4-in. compacted course. These quantities of calcium chloride were approximately 0.15, 0.30 and 0.45 percent, respectively, by unit weight of the granular base. Eight untreated control sections were alternated in the test area (Fig. 1). Test points for evaluation of the base were located in the outer wheel path in each lane and were spaced at 12½-ft intervals.

The project was opened to traffic in October 1957 and was cured for one month prior to double sealing the base with cut-back asphalt and stone chips. The road has since been maintained by resealing areas where failures in the form of alligator cracks would not reheal by themselves. Areas that developed holes were patched with a cold mix so as to restore satisfactory riding qualities to the road.

Visual observation is used to evaluate the performance of the road. The performance is described in terms of the type and severity of the failure. These types and severities of failures are the properties against which the recorded profiles are being compared. The profiles are also being examined for any peculiarities that recur and speculation is being made on their significance.

Deflection profiles are being made at the test points at least twice a year. On Feb. 25, 1958, a special effort was made to obtain profiles on the effects of frost action. On this occasion, there was time enough to get deflection profiles at only every other test point.

OPERATING PROCEDURE

In the process of using the Benkelman beam, with or without the Helmer recorder, it is the practice to locate the probe point of the beam 4.5 ft ahead of the dual wheels so that the front datum supports are 4.5 ft behind the dual wheels (see schematic in Fig. 9). It is still the practice to get an elevation reading of the probe point or test point as nearly the instant as possible that the truck begins to move forward. Next, the elevation reading indicating the maximum deflection is obtained, and finally, an elevation reading when the truck rear duals are estimated to be at least as far ahead of the probe point as they originally were behind the probe point. On one project where the zone of influence is extensive and is considered significant, the probe to wheel distance at which the final elevation reading is taken is 9 ft (see Fig. 9).

If a Helmer recorder is used in conjunction with the beam to trace out the changes in elevation of the test point, the elevation readings can be determined from the recorded profile as well as or better than from a dial indicating micrometer.

PROFILE USE

From experience it seems best to select a "zero" elevation reference point on the profile that is not in the zone of significant influence, and to refer the elevation of any other points on the profile to this zero elevation. The zero elevation reference point on one project was taken when the dual wheels of the truck were 4.5 ft beyond the test point and on another project when they were 9 ft beyond. When using these distances in computing for rebound deflection or residual deflection, the data are annotated by ($D_{R\ 4.5\ ft}$) or ($D_{R\ 9\ ft}$) which is intended to mean "to where on the profile the rebound deflection, etc., is referred".

When the front or rear beam datum supports are in the zone of influence, the recorded profile is variably biased. It is believed that measurement of the area and magnitude of the zone of significant influence will, along with the other measures, be a valuable measure in evaluating stability. At a time when the full length of the profiles

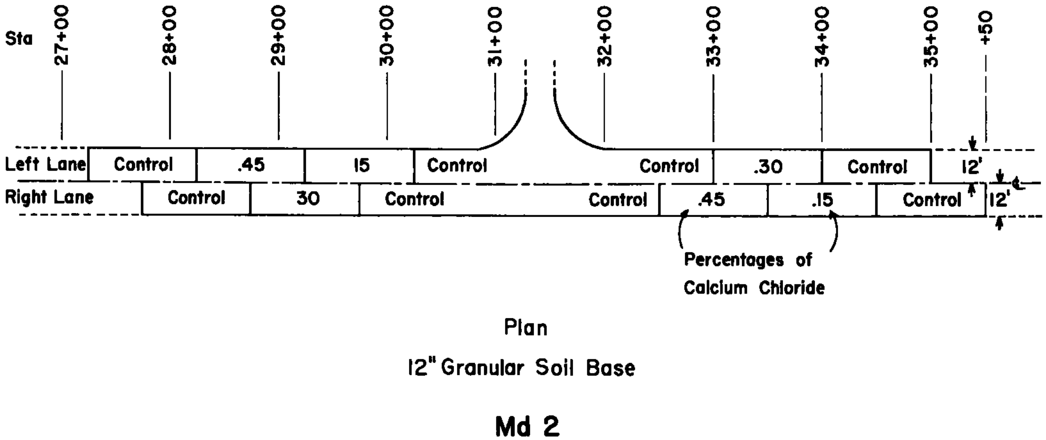


Figure I.

can be corrected for the effect of the zone of influence, all other measurements taken from the true profile should then be more realistic.

Essentially by convention, it has been suggested that signs be assigned to deflection data. Rebound deflection measurements have always been found to indicate that there always is a deflection under a load, and since the elevation of the point of maximum deflection is always lower than the rebound point with which it is compared, they are considered to be negative. The conventional measure of deflection has for the most part been found to be negative but under certain circumstances was found to be positive. Likewise, residual deflections are generally found to be negative, primarily because of the zone of influence, but, under certain circumstances they could be positive. Flection values are given a negative sign because it is intended to assign a positive sign to measure of reverse flections almost invariably found both immediately ahead and behind the part of the profile used for the regular determination of flection.

TABLE 1

ACTUAL TRUCK WEIGHTS IN POUNDS

Date	Gross	Front Axle	Rear Axle	Rear Dual Wheel
		Maryland Route 2		
2-25-58	20,760	4,760	16,000	8,000
4-9-58	18,520	4,480	14,040	7,020
10-2-58	18,840	5,760	13,080	6,540
3-4-59	19,580	5,340	14,240	7,120
10-17-59	19,480	5,620	13,860	6,930
		Maryland Route 33		
8-26-58	33,000	10,280	22,720	11,360
9-8-58	32,790	10,470	22,320	11,160
11-13-58	32,380	10,730	21,650	10,825
3-3-59	30,240	9,270	20,970	10,485
5-19-59	31,630	10,500	21,130	10,565
9-1-59	29,820	9,350	20,470	10,235

Because the rear axle load of the trucks used in the project could not conveniently be duplicated or be equal in weight of trucks used by other researchers, all of the data used in this report are reduced to inches per 1,000 lb per dual wheel. Actual wheel loads are given in Table 1.

In the future, other characteristics of the profiles (corrected for the effect of the zone of influence) that are intended to be given numerical values are: (a) the traveling rolling wave ahead of (and behind) the wheels; (b) inflection points of the profile curves; and, (c) possible estimate of transverse flection from tire tread spacing and residual deflection.

SHAPE OF PROFILES

Figure 2 shows accurate reproductions of several actual deflection profiles, not

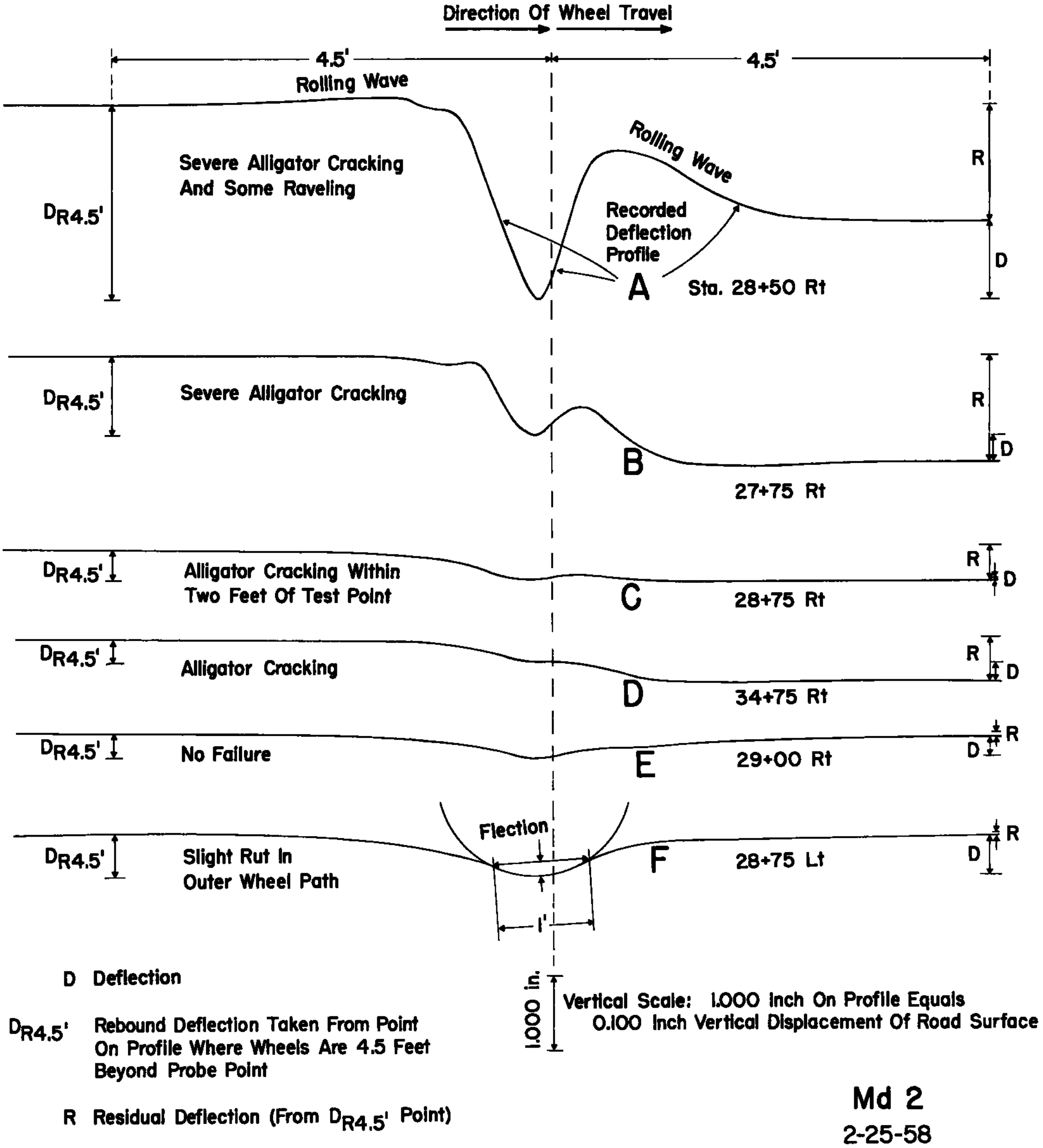


Figure 2.

corrected for the effect of the zone of influence, illustrating the variety of profiles obtained on a day during the late winter thaw (Feb. 25, 1958). Visual inspection is all that is necessary to arrive at some conclusions concerning profiles such as these.

It should be emphasized here that profiles A, C, and E cover a linear distance of only 50 ft of road and that all three of these profiles were obtained within a time interval of approximately 4 min, and further, that profile F was obtained in the other lane opposite profile C approximately 18 ft distant an hour later.

Profile A suggests a serious unstable condition existing to a considerable depth. A traveling rolling wave is ahead of the wheel. Also, a similar but much smaller wave is following the wheel. Excessive positive residual deflection (R) suggests a high potential for fine alligator cracking as is caused by what is referred to as "extrusion".

Extrusion as used in this report is defined as the movement of the double seal and base materials upward between the tires of the duals. Extrusion can also occur on warm days on bituminous pavements that are particularly rich in bitumen that has remained alive. Visual inspection of the road surface at the test point represented by profile A showed severe alligatoring and some raveling.

Profile B is similar to A with the exception that the depth of severe instability is less and the traveling rolling wave is smaller. The potential for fine alligator cracking should be nearly equal to that of profile A as might be inferred from the comparable magnitude and sign of the residual deflection (R).

Instability indicated by profiles C and D is apparently limited largely to the granular base or at least within the top stratum of the subgrade. There is a difference in the shapes of these two profiles; also, one test point showed failure and the other did not. Speculation on the profile characteristics with respect to performance of the road at these test points would be questionable, because profile D was obtained 600 ft from profile C and the profile C was obtained only 25 ft from profile A. Because of this proximity of profiles A and C, the conditions that exist at the test point for profile A may have influenced the shape of profile C; also, alligatoring extends to within 2 ft of the test point for profile C.

Profile E shows what might be a rolling wave ahead of the wheel; however, what appears to be a rolling wave here could actually be a slight extrusion of the road surface as might be inferred from the residual deflection. On the day that the profiles were obtained, generally the profiles had the shape of profile E with about 25 percent showing no visible evidence of what may be either a traveling rolling wave ahead of the wheel or extrusion of the road surface materials upward between the wheels.

Profile F is similar to profile E except that it appears that the subbase may not be furnishing the stabilized granular base the same support as at the test point for profile E. There may also be a natural stability deficiency in the granular base itself. Longitudinal flection or bending of the road surface can be determined as is illustrated on profile F. Actually, flection is determined as described in the Appendix.

Measures of flection from profiles such as profiles A through D are considered highly biased because of extrusion which in essence can be pictured as a transverse flection. Profile E may also be significantly biased. The magnitude of this transverse flection is actually the magnitude of the positive signed residual deflection plus approximately +0.001 in. for 1,000 lb per dual wheel or more as caused by the effect of the zone of influence. This transverse flection or extrusion is serious because it is confined to the space between the edges of the tire treads of the dual wheels. The tread spacing between the tires used in these investigations was approximately five inches.

It is admitted that the Benkelman beam is always in the zone of influence during the process of getting any deflection profile at any of the test points. It is most probable that the beam, when used in the conventional manner, is always in the zone of influence. Measurable or not, however, the magnitude under certain conditions appears to be insignificant with respect to the magnitude of some of the other measurements taken from the profiles.

For practical purposes, on this project it is assumed that the zone of significant influence does not extend more than 4.5 ft from the center of the rear dual wheels of the truck. It is thereby assumed that the elevations of the test points at or outside of

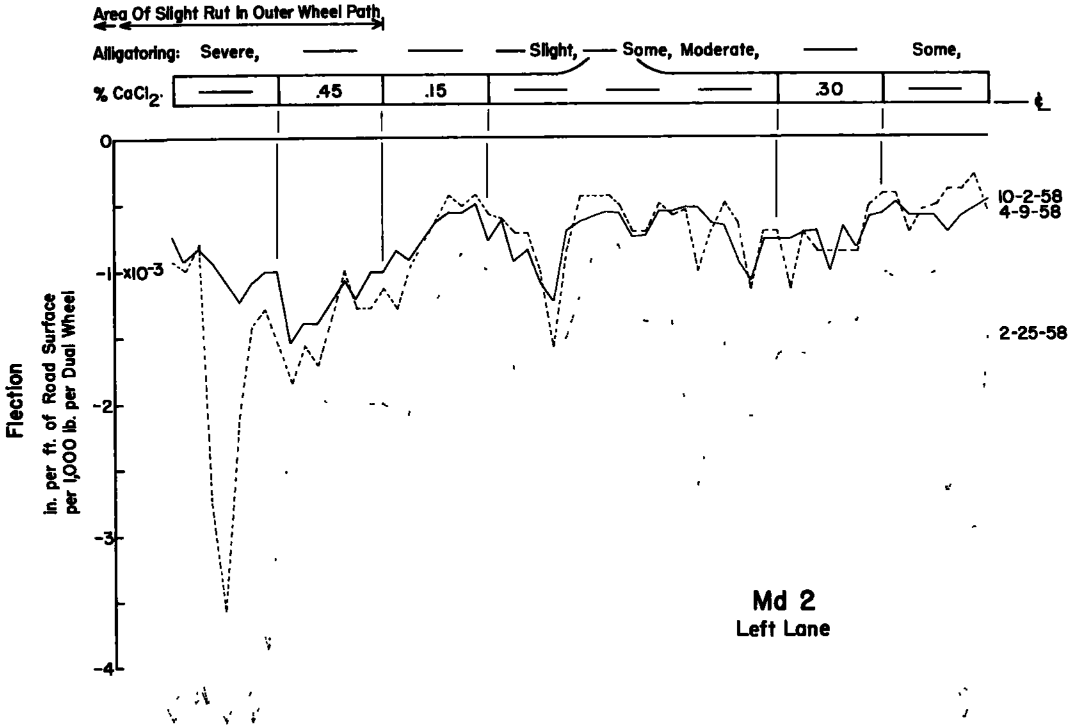


Figure 3a.

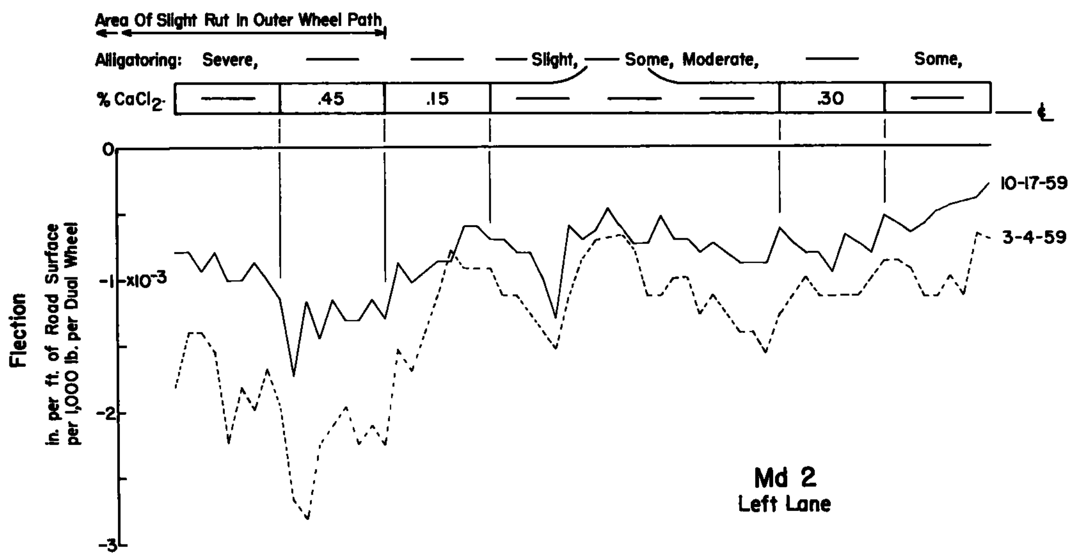


Figure 3c.

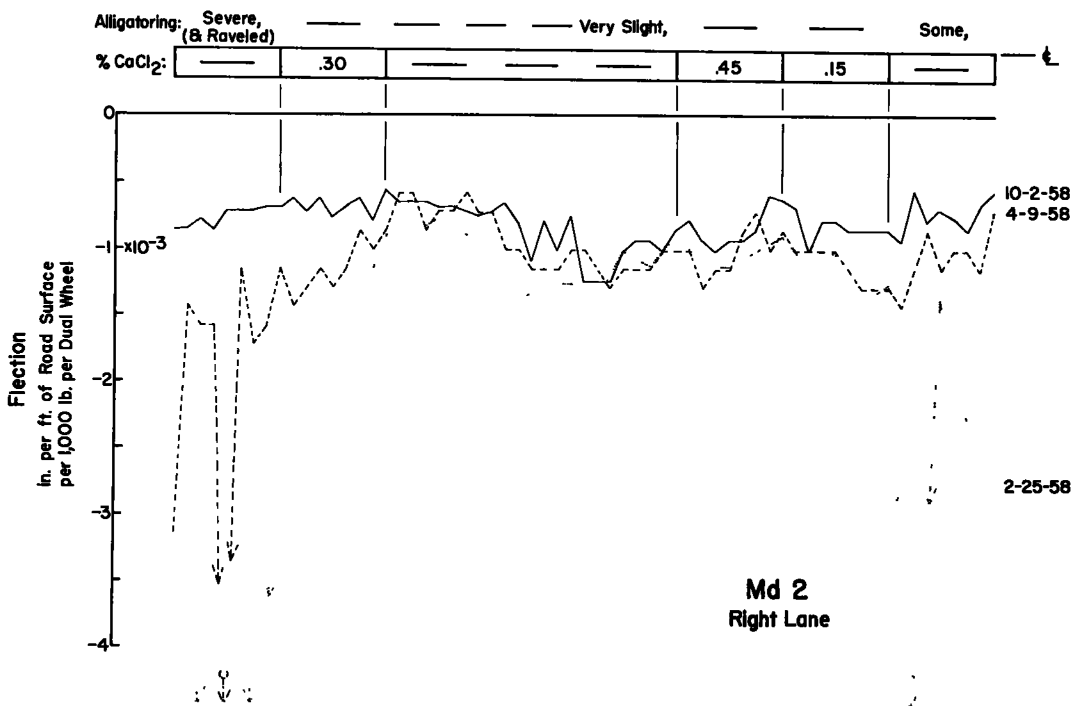


Figure 3b.

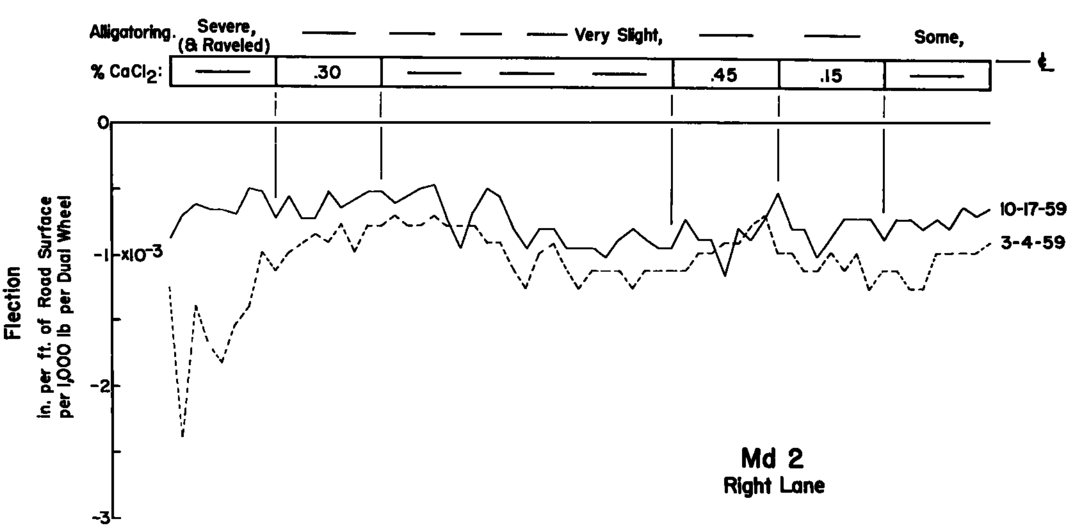


Figure 3d.

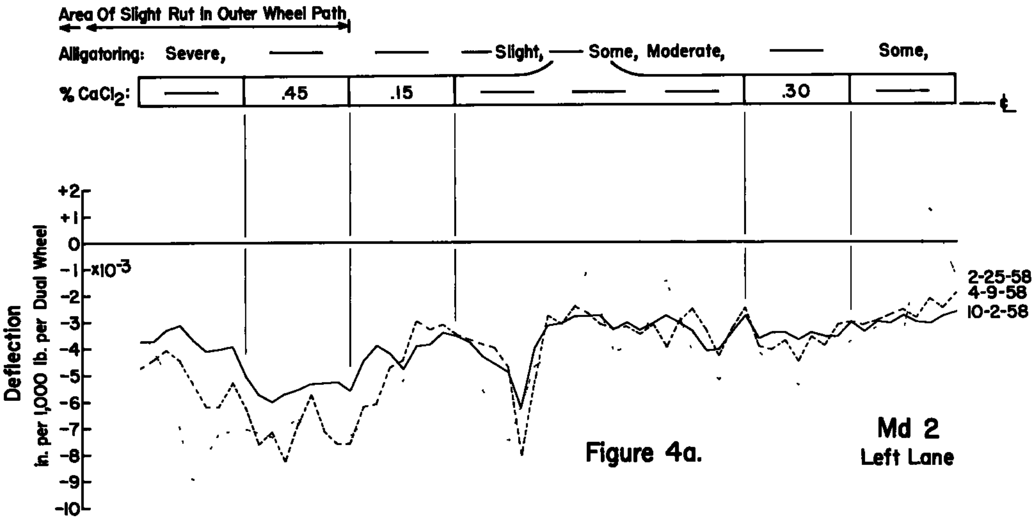


Figure 4a.

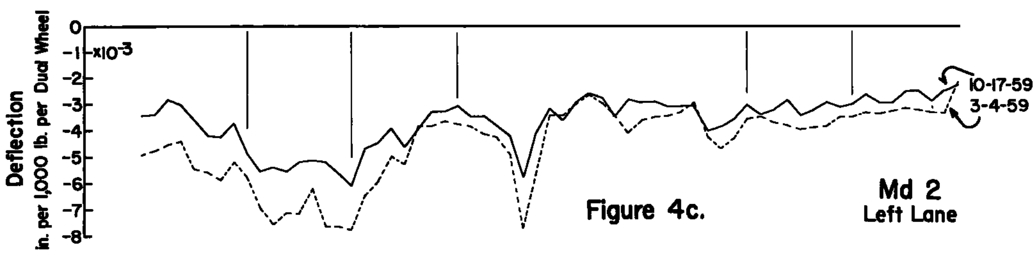


Figure 4c.

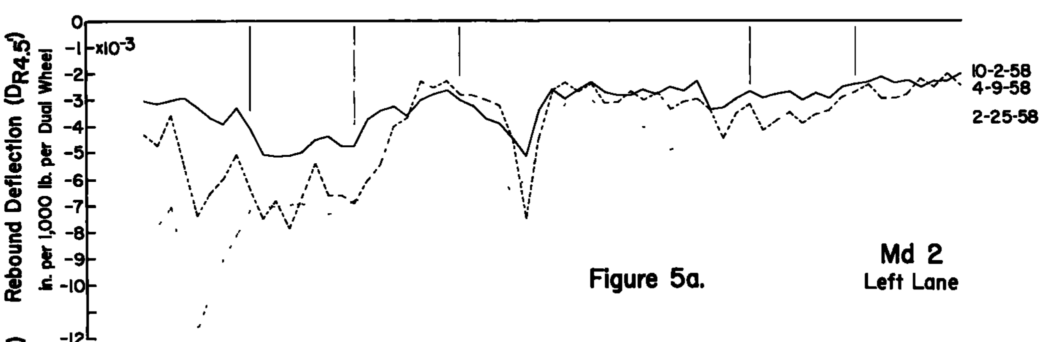


Figure 5a.

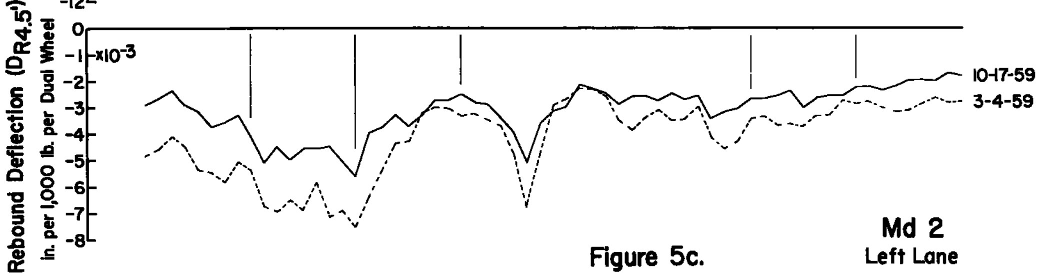


Figure 5c.

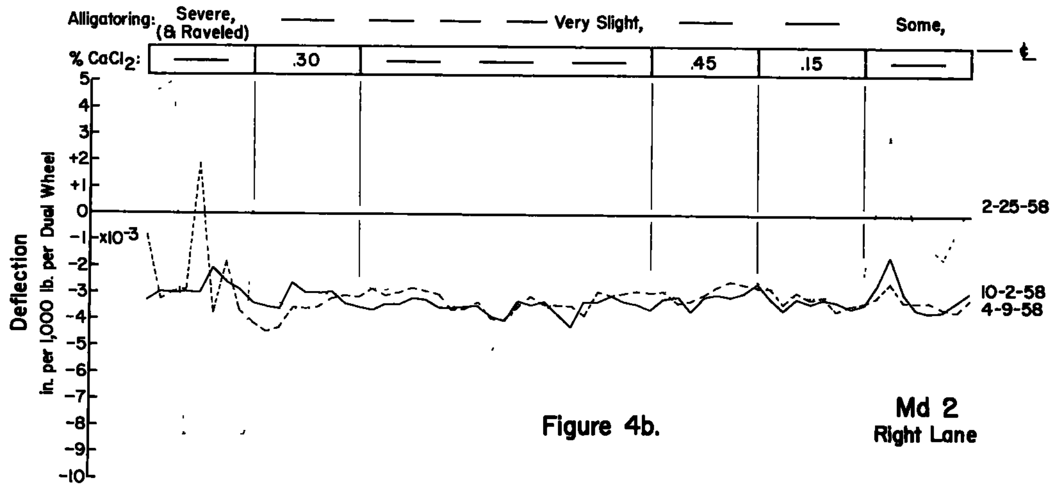


Figure 4b.

Md 2
Right Lane

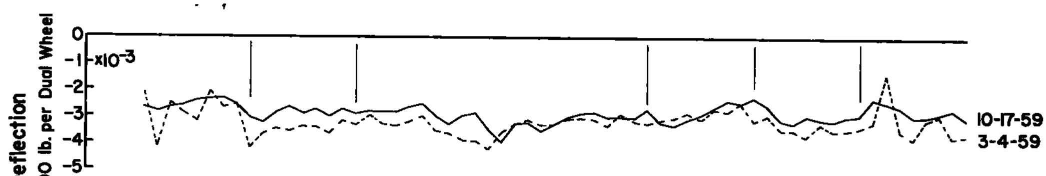


Figure 4d.

Md 2
Right Lane

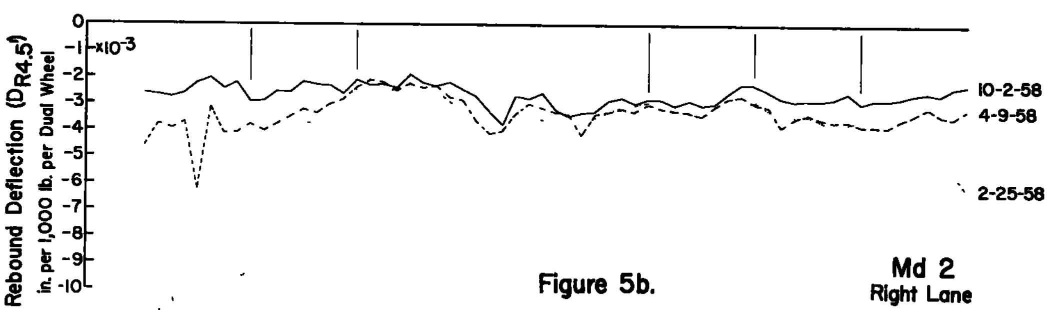


Figure 5b.

Md 2
Right Lane

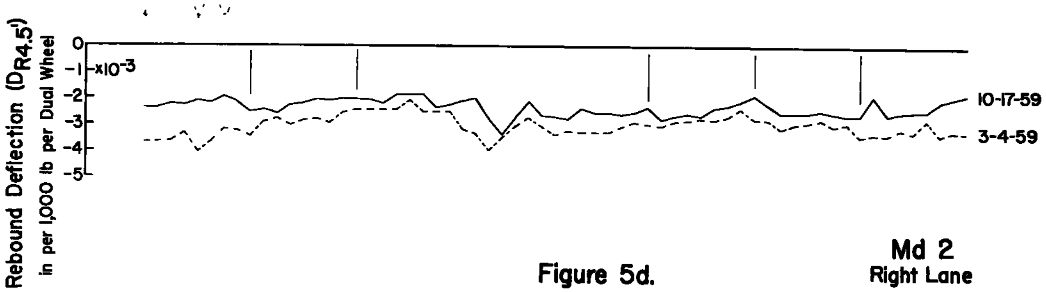


Figure 5d.

Md 2
Right Lane

that radius are not significantly affected by the vehicle. Such points are illustrated in Figure 2 by the extreme right hand limits of the profiles labeled with the D's and R's and near the left hand limits at the vertical arrows identified as measures of rebound deflections ($D_{R\ 4.5\ ft}$). It is assumed that as the profile is being recorded the recorded elevation of the test point on the profile at ($D_{R\ 4.5\ ft}$) would not change even if the test vehicle were moved much further from the test point.

Extrusion seems to bias the conventional measure of deflection to a greater extent than any other phenomenon occurring during the determination. It is believed that extrusion is not a linear continuing process continuing throughout the time that the tire treads are in close proximity and straddling the probe point. Rather, it is believed that more than 90 percent of the extrusion has taken place before the dual wheel axle is directly over the test point. On this premise, rebound deflection ($D_{R\ 4.5\ ft}$) is relied upon to be a better estimate of what ordinarily conventional deflection would satisfactorily indicate. In Figure 2, comparisons of deflections (D) with respect to rebound deflections ($D_{R\ 4.5\ ft}$) for the several profiles would indicate that the rebound deflection ($D_{R\ 4.5\ ft}$) is more realistic.

It should be emphasized that ordinarily deflection profiles will not appear as shown in Figure 2 but rather like profiles E and F and very often even flatter than profile E. Furthermore, ordinarily the conventional measured residual deflection will be negative whereas every profile in Figure 2 has a positive residual deflection.

CHARACTERISTICS OF PROFILES VS OBSERVED PERFORMANCE

Characteristics of the profiles collected over a 2-yr period following construction have been plotted against the observed performance of the road. Figure 3a and b indicate a fair association of failures with excessive magnitudes of flection for data collected Feb 25, 1958. Practically all of the data collected April 9, 1958 and Oct. 2, 1958 in Figure 3a and all of the data in the central and right (not extreme right) portions of Figure 3b indicate that there is much to be desired to be able to claim that there is a distinct effect of frost action or seasonal effect on the flection properties of this road. The data collected in 1959, Figures 3c and d, do point to a seasonal effect on the flections.

In Figures 4a, b, c and d, the conventional measures of deflection indicate a questionable correlation with the fine alligator cracking. Except for extreme values, most of the values of deflection for both years bracket each other to the extent that the seasonal effect on deflections can hardly be distinguished. At the extreme left in Figure 4b, the first two point of the Feb. 25 data are highly positive, the next two points are very negative, and, the last point is nearly 0. The erratic values are results of getting profiles such as profiles A and B in Figure 2.

Comparing Figures 4a, b, c and d with their corresponding Figures 5a, b, c and d, the measures of rebound deflection indicate a better expected general behavior for deflections of a road as a result of frost action. The correlation with the failures however is apparently not improved. The erratic values in Figures 4a and b are displaced to their proper place; that is, they are all negative in Figures 5a and b. Figures 5c and d represent the road behavior after the project had gone through its second winter of seasoning; therefore, it is believed that the rebound deflections represent what might be expected as a result of frost action in the future.

In a general comparison of Figures 3a, b, c and d, 5a, b, c and d and in part Figures 4a, b, c and d, there seems to be a remarkable repeatability of measurements on most individual test points, groups of test points and also in a consideration of all the test points in individual lanes from year to year. This repeatability is best for data collected in the autumn of both 1958 and 1959 where, for example in the middle of Figures 5a and c, there is a localized area of highly negative rebound deflections, to the left of which is an area of much lower negative rebound deflections and so on. These similarities do not appear to be accidental.

Since neither of the measures of flection, deflection nor rebound deflection ($D_{R\ 4.5}$ ft) contributed enough to good correlation with the observed failures, there remains the evaluation of any other unusual characteristics of the profile shapes such as shown

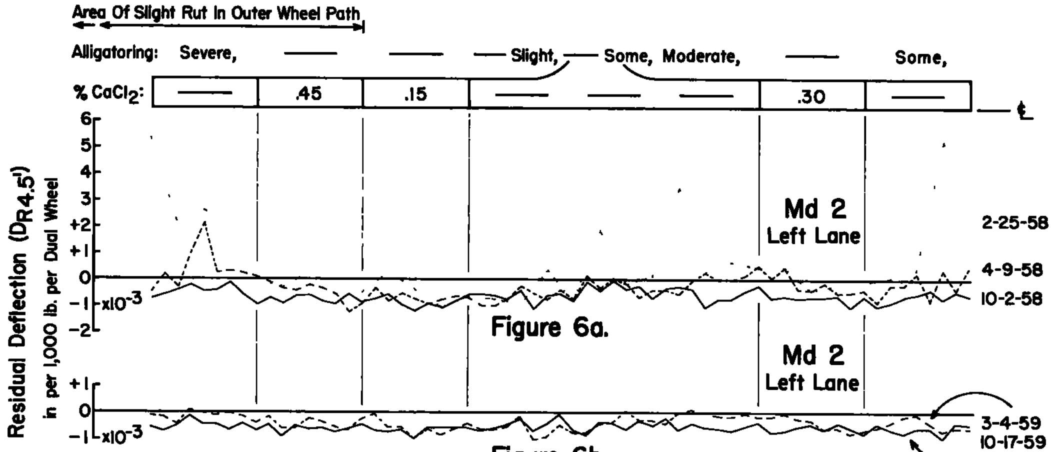


Figure 6a.
Figure 6b.

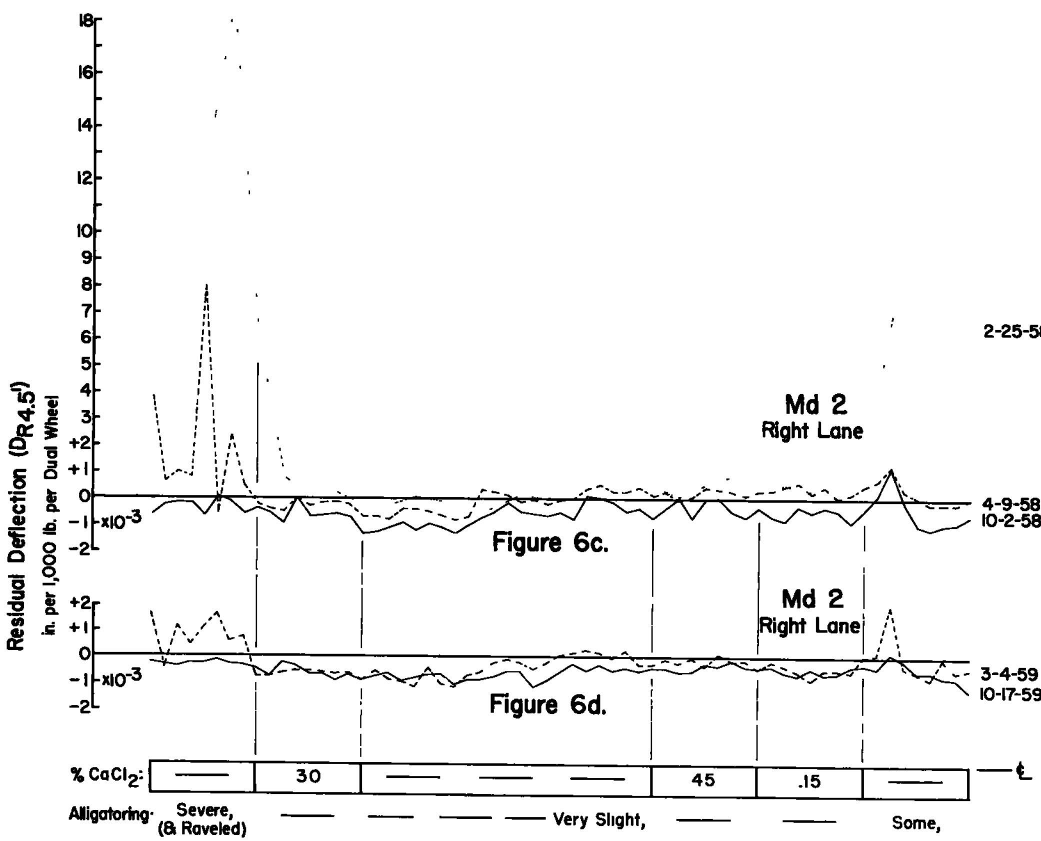


Figure 6c.
Figure 6d.

in Figure 2. Only a very few profiles show evidences of a distinct traveling rolling wave as is indicated by the extreme profiles A and B in Figure 2; however, those that have the distinct rolling wave seem to be associated particularly with severe alligatoring and raveling. The profiles were also examined for evidence of a significant bias that may have been caused by the zone of influence. It was concluded that the zone of influence was negligible and would not account for the failures either.

The several comparisons already made have left only fair to questionable correlations with the observed failures. The remaining measure to be evaluated is residual deflection ($D_{R\ 4.5\ ft}$). These measures are plotted in Figures 6a and b for the left lane and Figures 6c and d for the right lane. These data would indicate almost perfect correlation would exist with all of the alligator cracking if all positive values of residual deflections ($D_{R\ 4.5\ ft}$) of +0.001 in. or greater per 1,000 lb per dual wheel were considered as the cause of failure. In the middle of Figure 6a, the alligatoring classified as "slight" does not have a corresponding positive residual deflection ($D_{R\ 4.5\ ft}$) of 0.001 or greater. This is because no test was made at this point on this date.

Though the residual deflection ($D_{R\ 4.5\ ft}$) correlated very well with the observed failures, it appears that the weaker correlations of measures of excess flection, excess rebound deflection, and very likely the existence of the traveling rolling wave, may have contributed to the severity of the alligator cracking type of failure.

In all figures representing the left lane there is a notation of a type of failure "Area of Slight Rut in Outer Wheel Path." The rut is hardly perceptible in the 0.45 percent calcium chloride section; however, it is one-half inch or more deep in parts of the adjoining control section in the same lane. From the preceding figures, the 0.45 percent calcium chloride section consistently showed high flections and high rebound deflections, and, the adjoining control section showed a similar behavior except for the Feb. 25 data. It is believed that the ordinary fine alligator cracking in some of the control sections permitted moisture to enter the base materials so as to aggravate an already unsatisfactory condition to the extent that the condition developed into a more severe one.

Because of the high year round flections and rebound deflections found generally in the left lane and the sensitivity of the road to frost action in some areas, it is speculated that when the existing double seal is covered with a higher type of bituminous surface some failures are expected to occur.

Figures 7a and b show frequency distribution plots of the seasonal effect on the flections over the 2-yr period following construction. The distribution in Figure 7b indicates a 30 to 50 percent shift in the distribution. Similar plots could be made of the rebound deflection data showing a similar behavior but perhaps with only about a 30 percent shift.

SOIL-LIME-FLY ASH PROJECT

Up to this point in the report, the measures of stability were made on what may be considered the minimum in bituminous pavement design and rigidity of a base. The remainder of the report will be devoted to the soil-lime-fly ash project on Maryland Route 33, constructed August 12, 1958, where the type of stability of the base should be regarded as semi-rigid. This project is very small but is considered valuable.

Figure 8 shows the layout of the test sections. Due to heavy rains, a high water table, poor drainage, an elevation of 18 ft above sea level, and, primarily to the uncertainty of the effects that calcium chloride would have on the stability of the base, the size of the treated sections was held to a minimum. Limiting the size was considered mandatory so that if the treated sections should fail and have to be replaced, the cost would not be prohibitive.

The only quantity of calcium chloride intended to be used was 0.5 percent by total weight of the soil-lime-fly ash mixture. It would be placed in a 100-ft section in one lane, and at the end of that, in a similar 100-ft section in the other lane. Inadvertently, the quantities of calcium chloride added were increased shortly after the treated section was being placed. This induced discrepancy later proved to be an asset.

All of the materials — soil, lime, fly ash, water and calcium chloride (if added) —

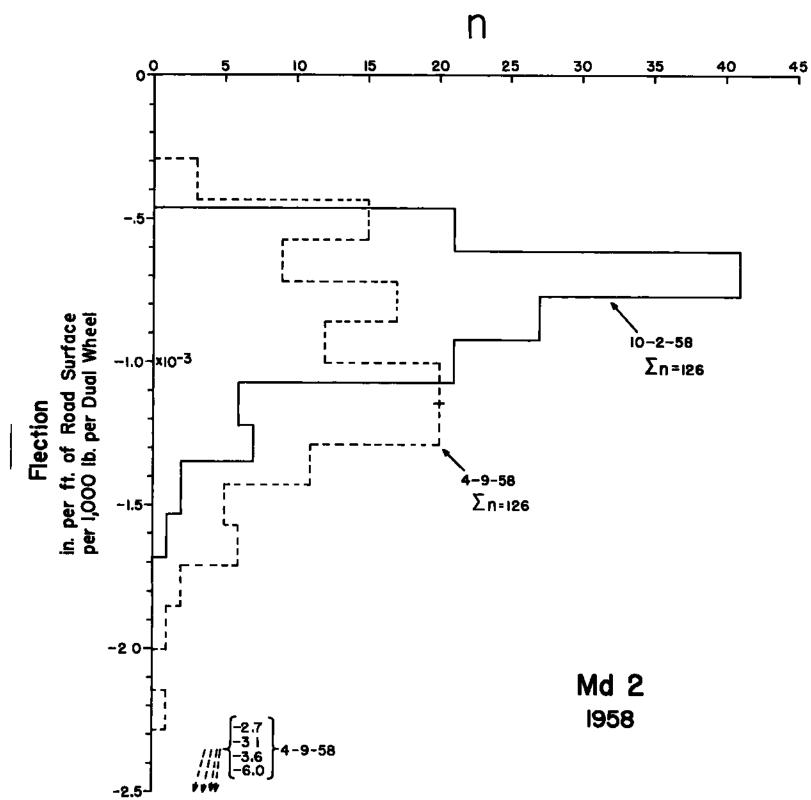


Figure 7a.

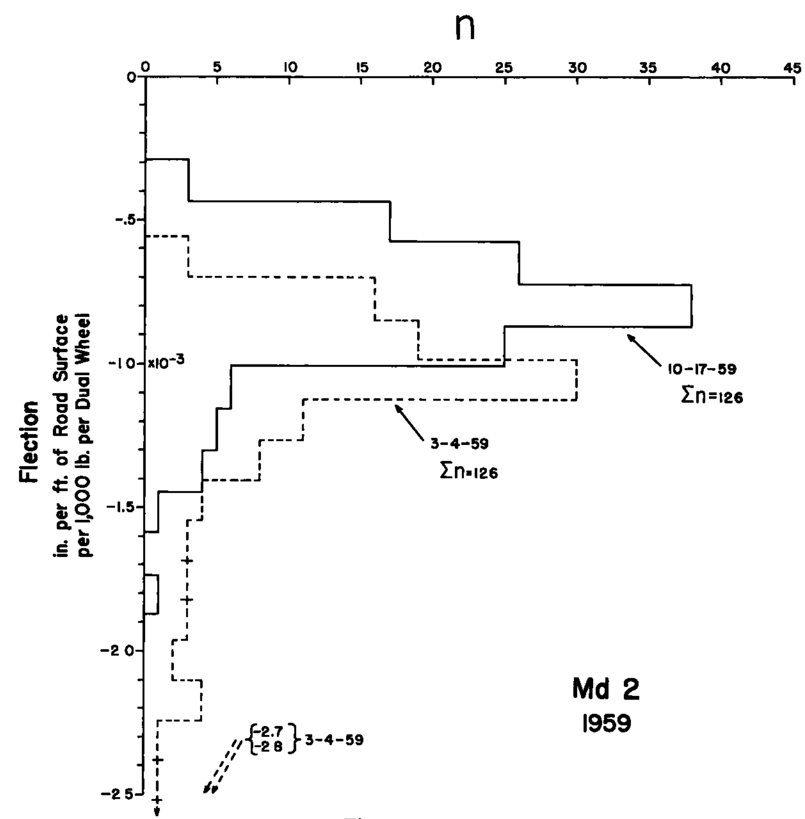


Figure 7b.

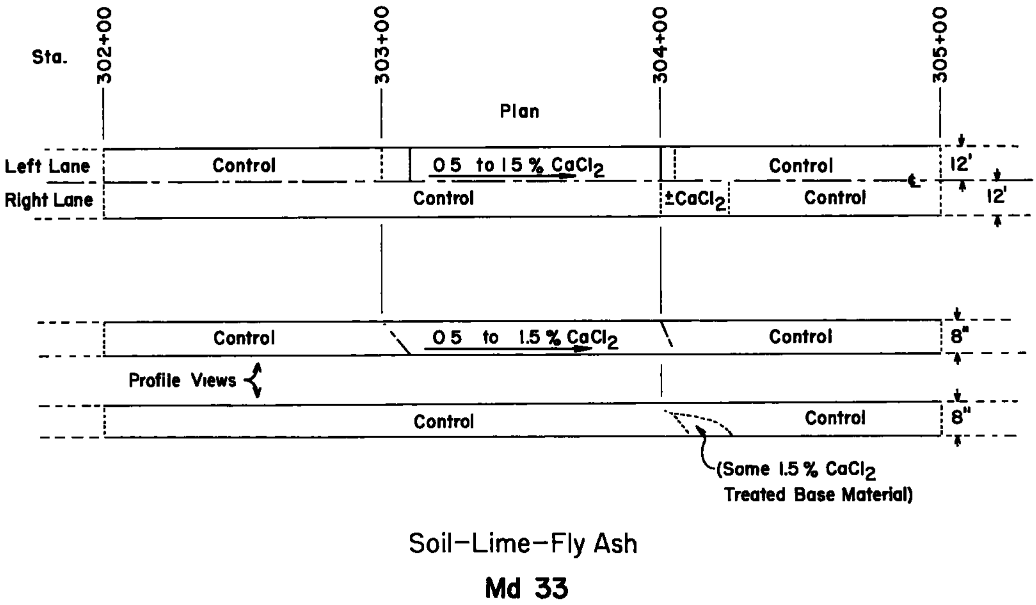


Figure 8.

were pug mill plant mixed. Spreading and primary compaction was by a bulldozer, and final surface compaction was by a rubber-tired roller. At the end of the day of construction, an estimated 2-in. rain fell. The surface of the stabilized base was shaped seven days after construction with first seal applied on the eighth day. The second seal was applied forty days after construction. The test section was opened to traffic immediately after application of each seal coat.

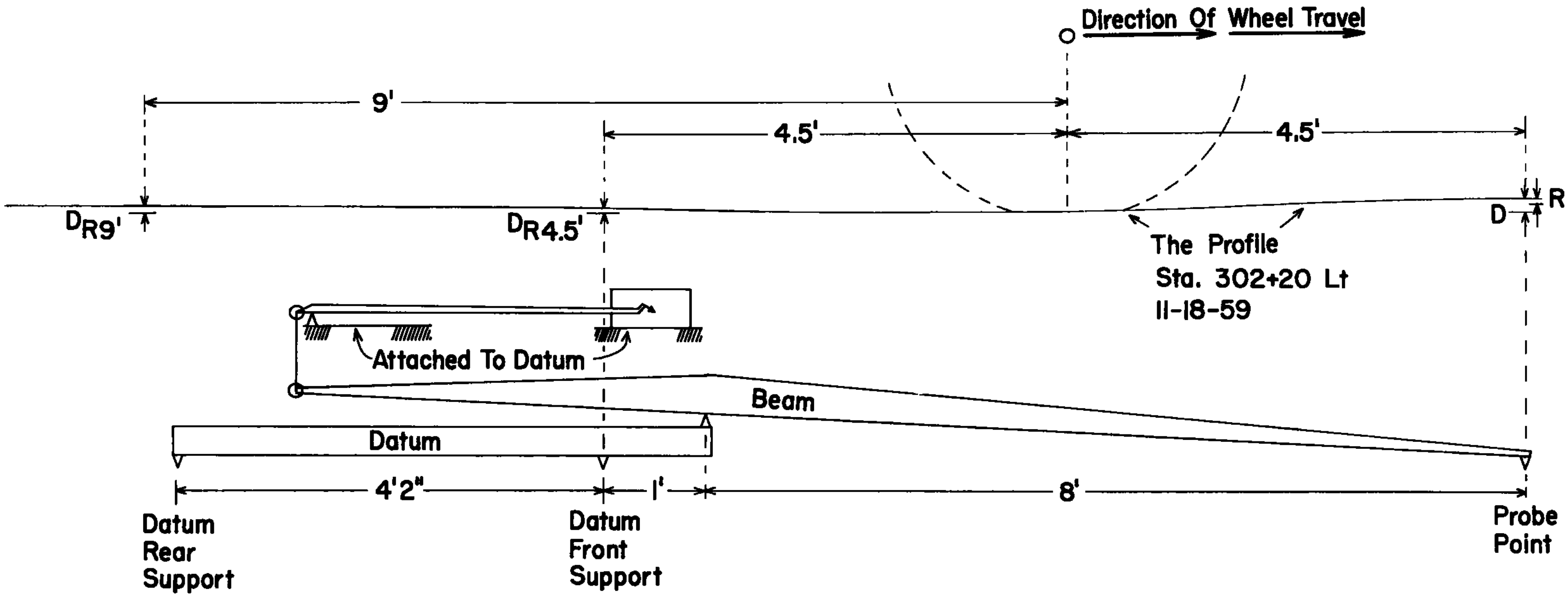
As a result of the unfavorable conditions that existed, including the rains that followed, there was practically no hope that the project would produce any information; however, the project was not abandoned.

In the course of collecting deflection profiles, it was found that shortly after construction (2 weeks), some of the test points and areas showed appreciable deflections as well as flections, while others showed considerable rigidity. With the passage of time sufficient pozzalanic reaction had taken place to stabilize the soil to an extent that the base in most areas exhibited a high degree of rigidity.

PROFILE SHAPE AND ZONE OF INFLUENCE

In the upper part of Figure 9 is a tracing of a recently obtained typical deflection profile. An outline of a rear dual wheel is superimposed on the profile 4.5 ft from the probe end. Below is a schematic of a Benkelman beam proportioned lengthwise to match the length of the road surface represented by the profile and positioned so as to indicate its relationship to the truck rear dual wheel and the virtual image of the profile. The shape of this profile is very much flatter than any of the profiles in Figure 2. Also, the beam is in the zone of significant influence.

The significance of the zone of influence can be demonstrated: referring to Figure 9, assuming that the road is uniform in the test area, with a base of rigidity such as this, the profile is variably biased because parts of the beam datum as well as the probe (the beam as customarily used in the past) are within the zone of significant influence. The influence as measured from this profile is 0.00225 in. (±0.00025 at best) on the road surface. (It is not claimed that all measurements concerning deflection profiles are accurate to ±0.00025 in. of the road surface. The end accuracy is governed by the quality of the recorded profile, and, as yet is not determinable to better than ±0.00025 in.).



D Deflection

$D_{R4.5'}$, $D_{R9'}$ — Rebound Deflections Taken From Points On Profile Where Wheels Are 4.5 Or 9 Feet Respectively Beyond Probe Point

R Residual Deflection (From $D_{R9'}$ Point)

Md 33

Figure 9.

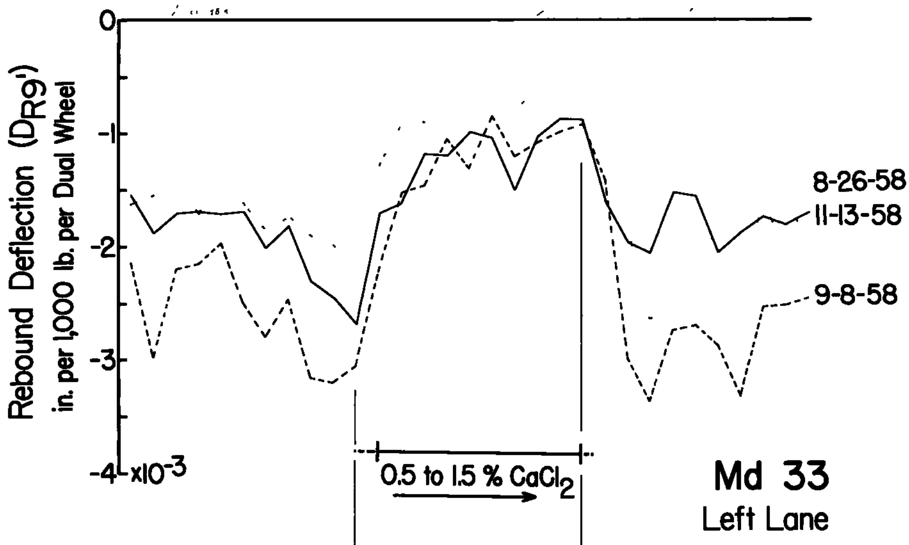


Figure 10a.

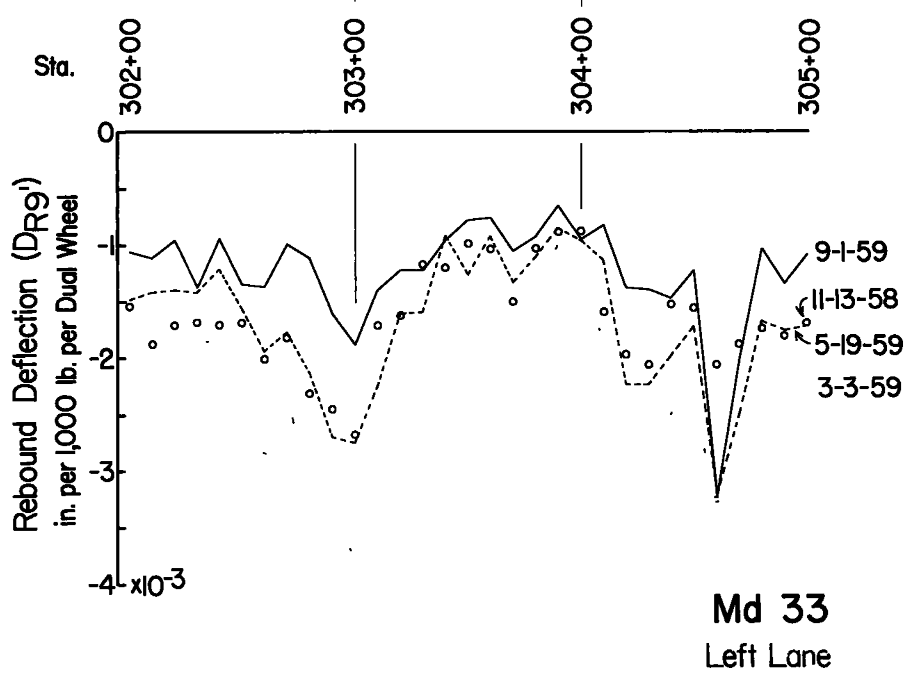


Figure 10c.

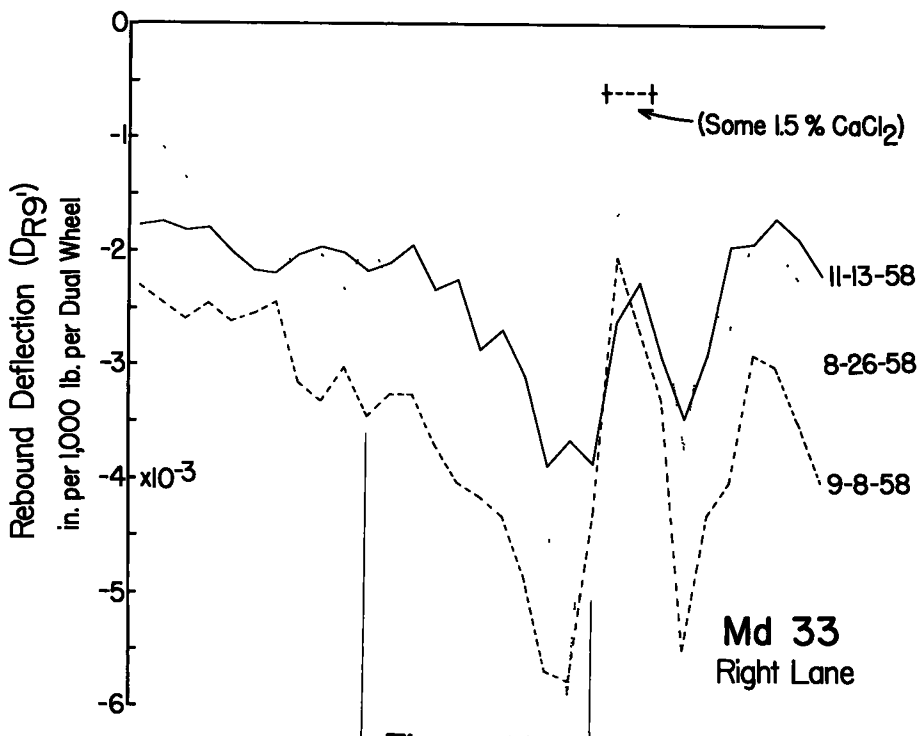


Figure 10b.

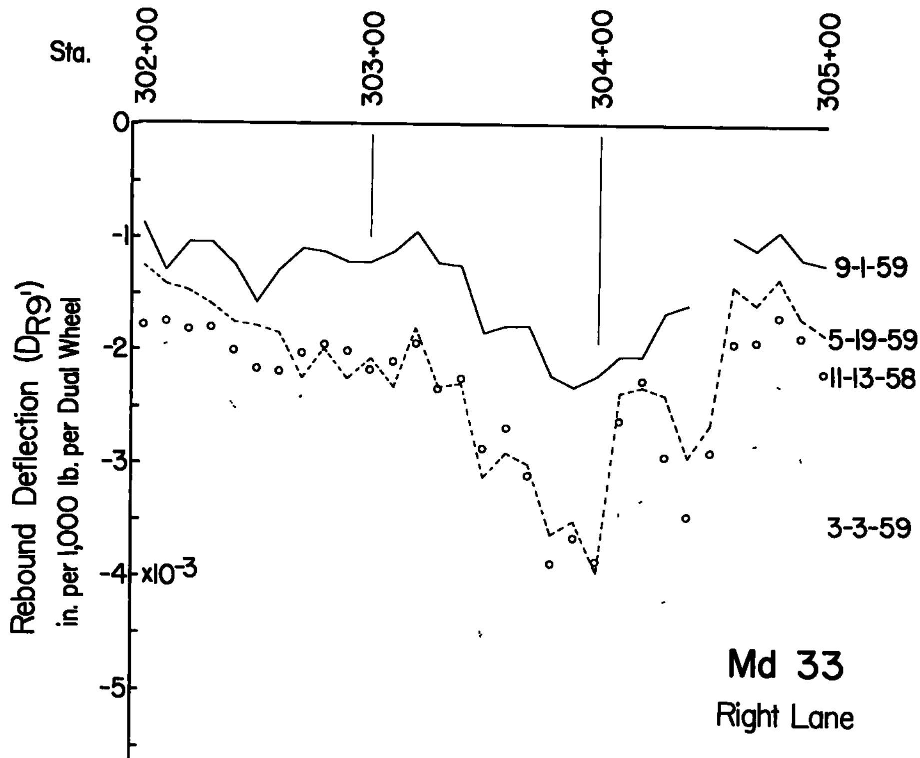


Figure 10d.

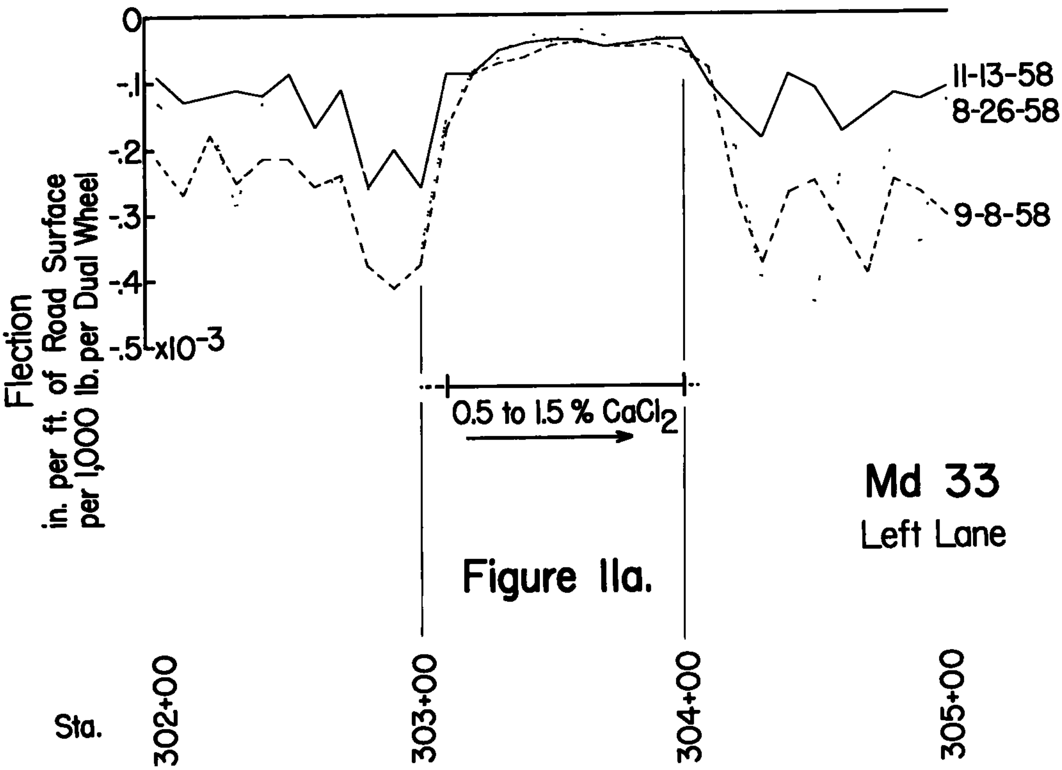


Figure 11a.

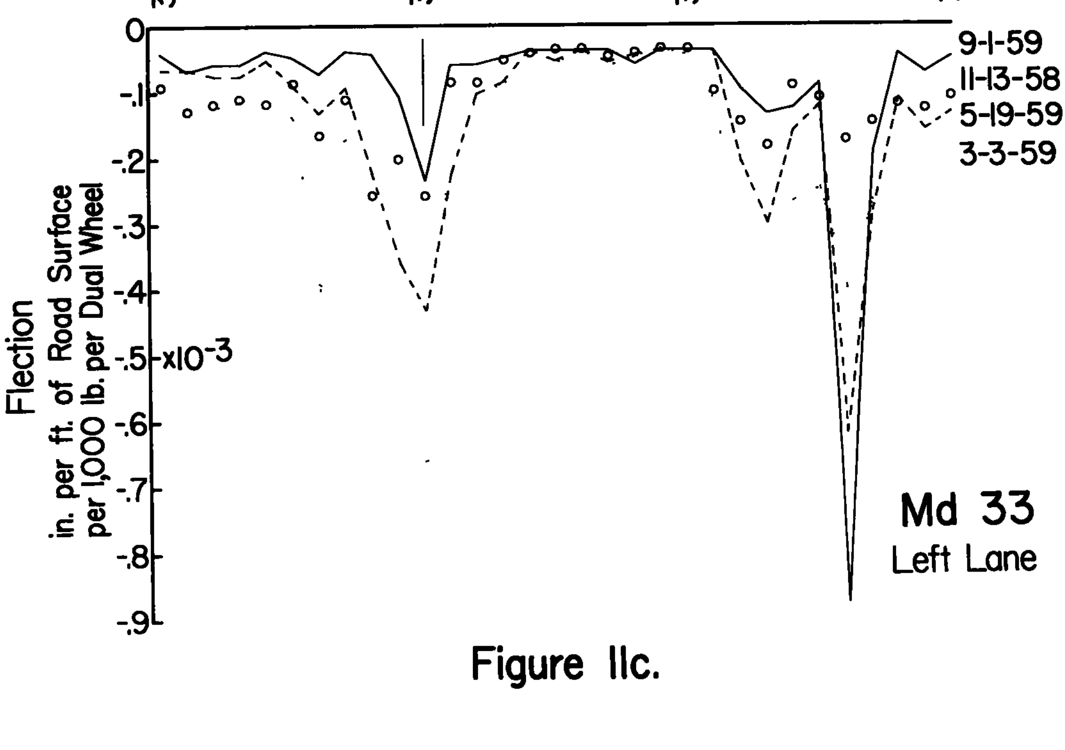


Figure 11c.

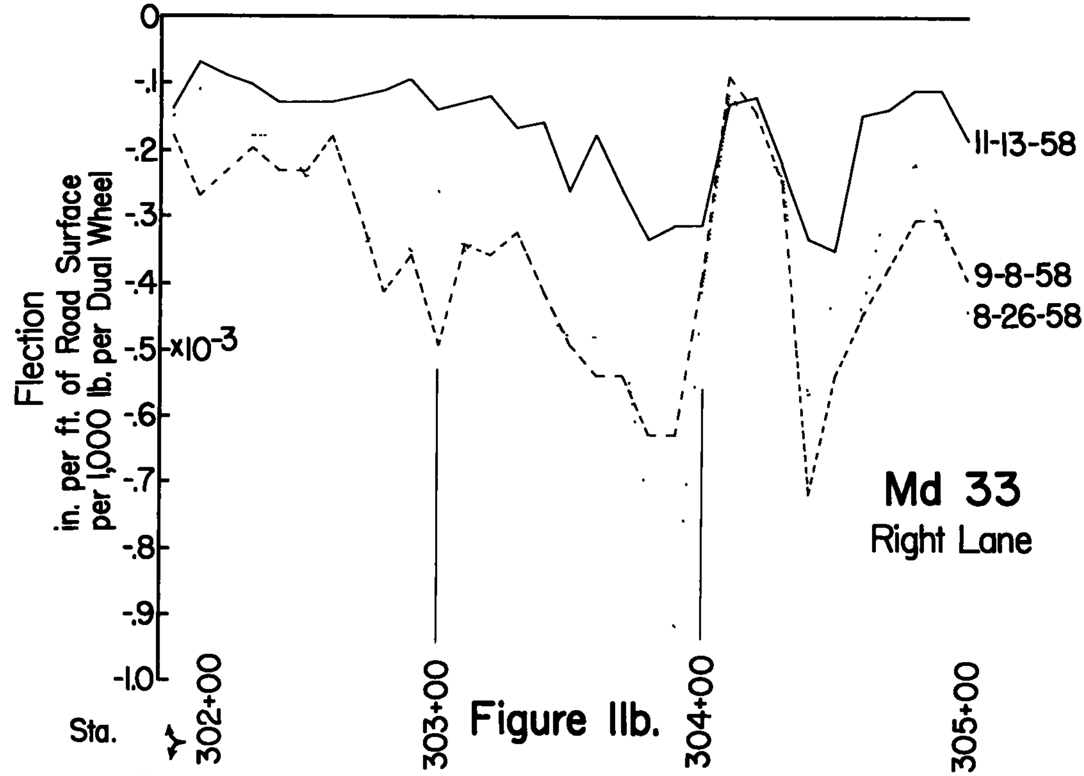


Figure 11b.

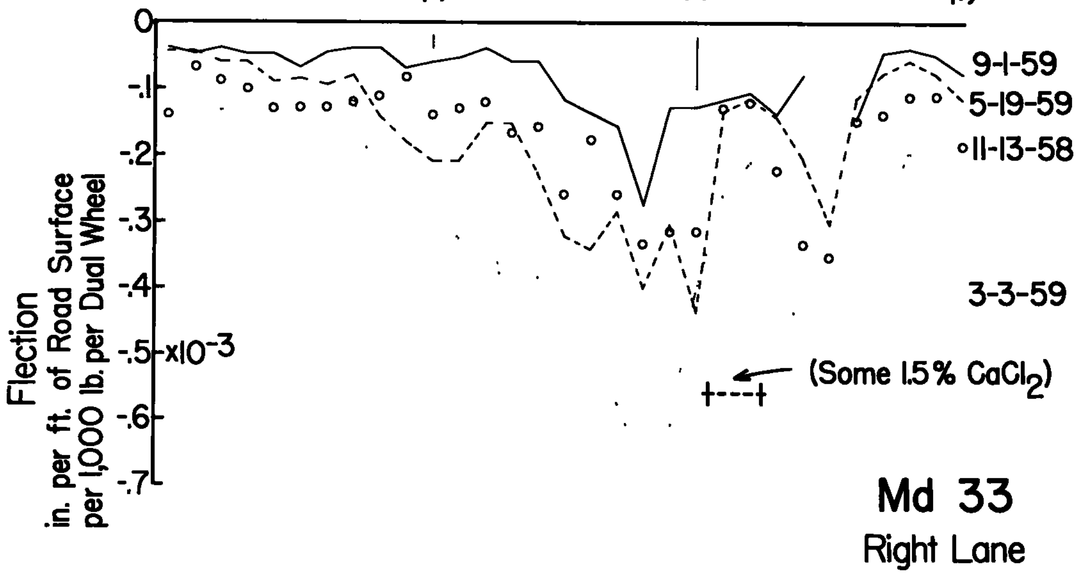


Figure 11d.

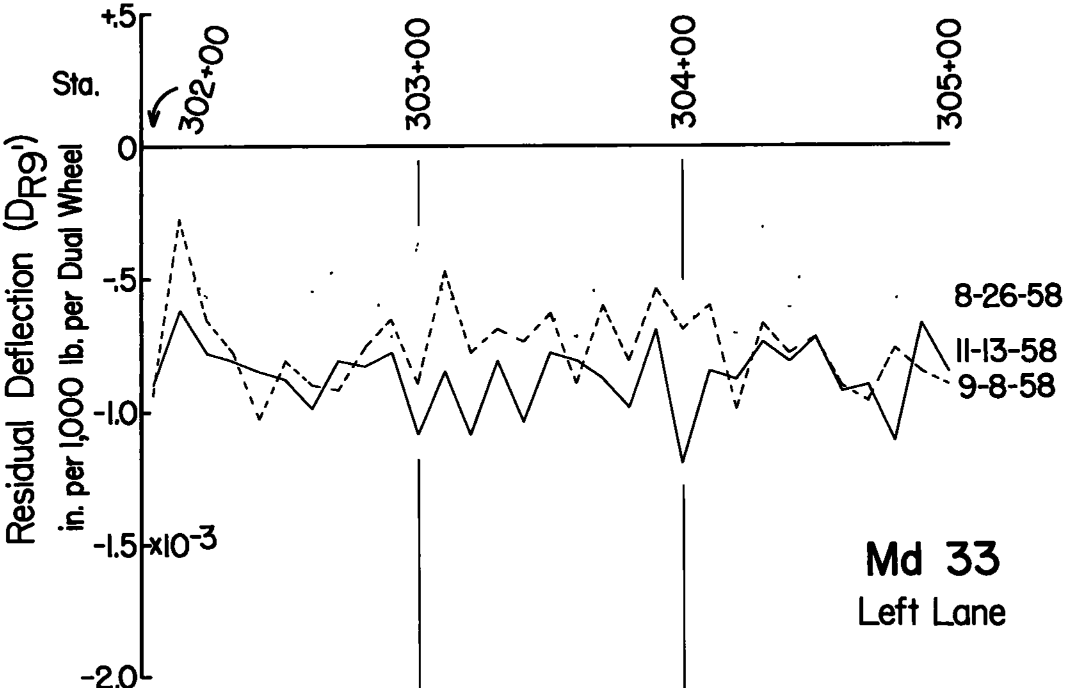


Figure 12a.

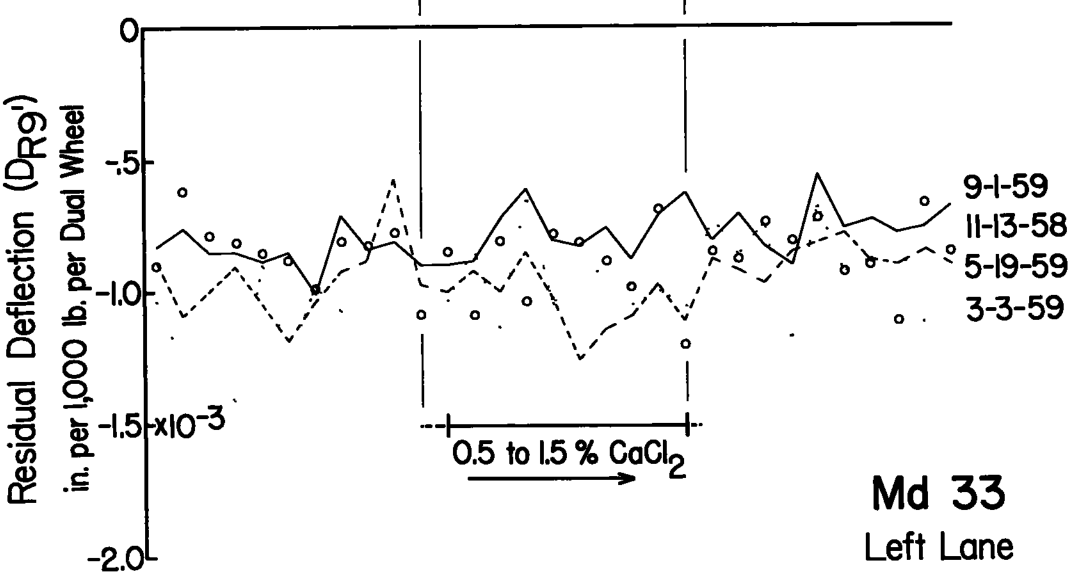


Figure 12c.

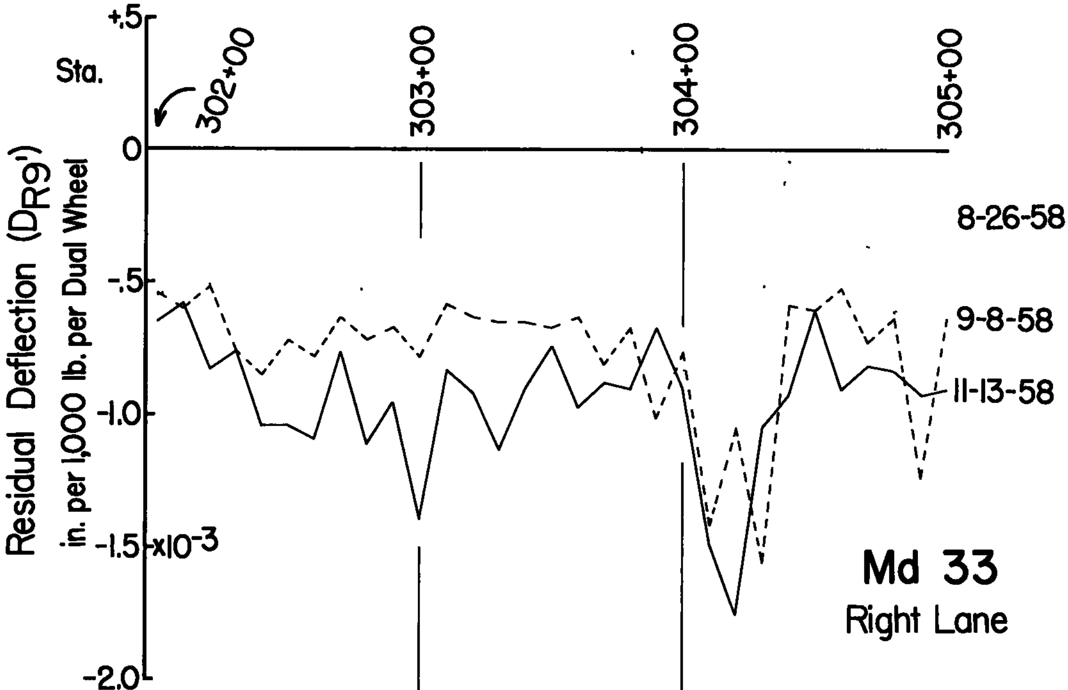


Figure 12b.

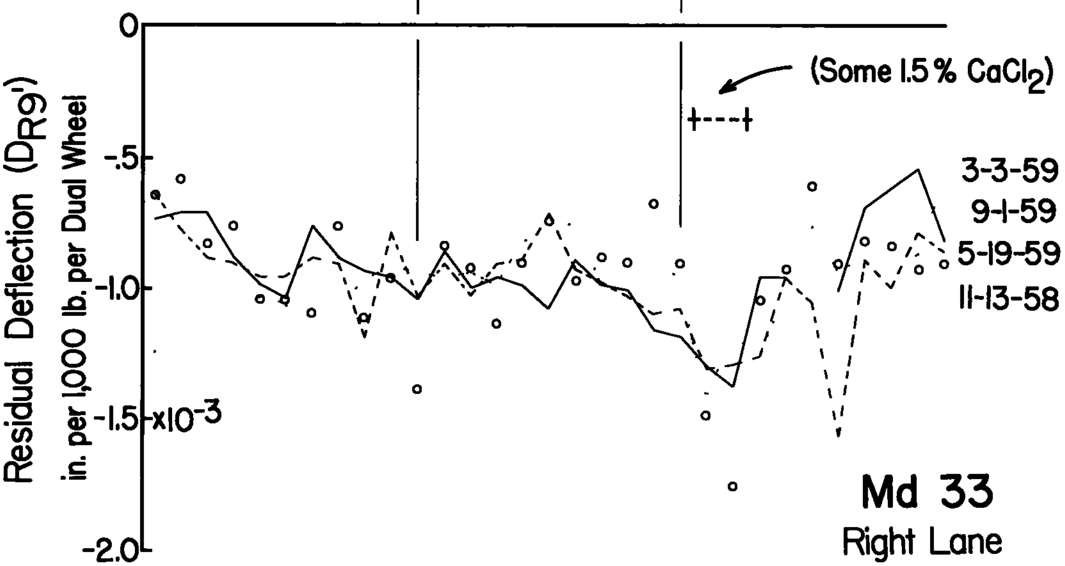
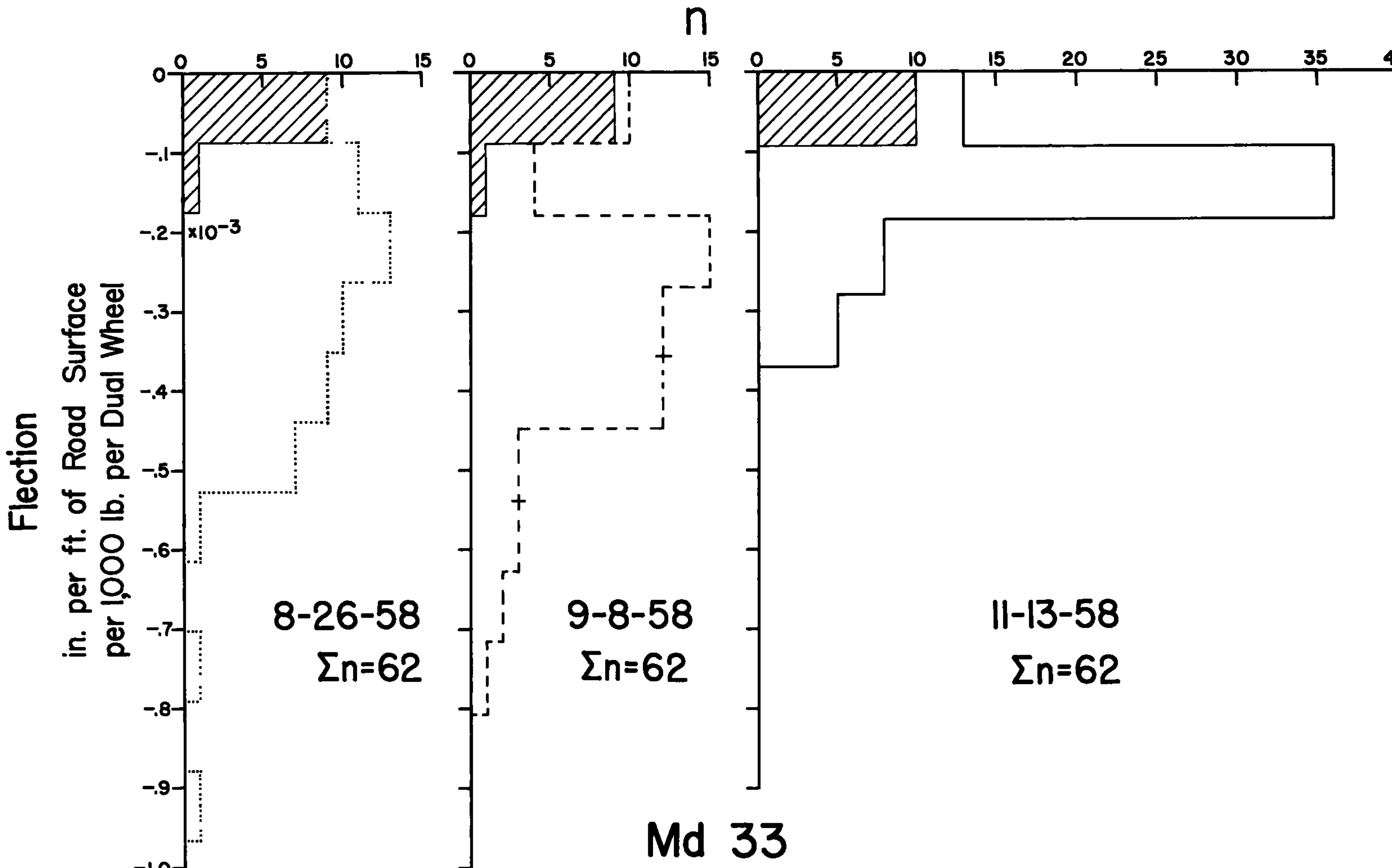


Figure 12d.



Md 33

Figure 13a.

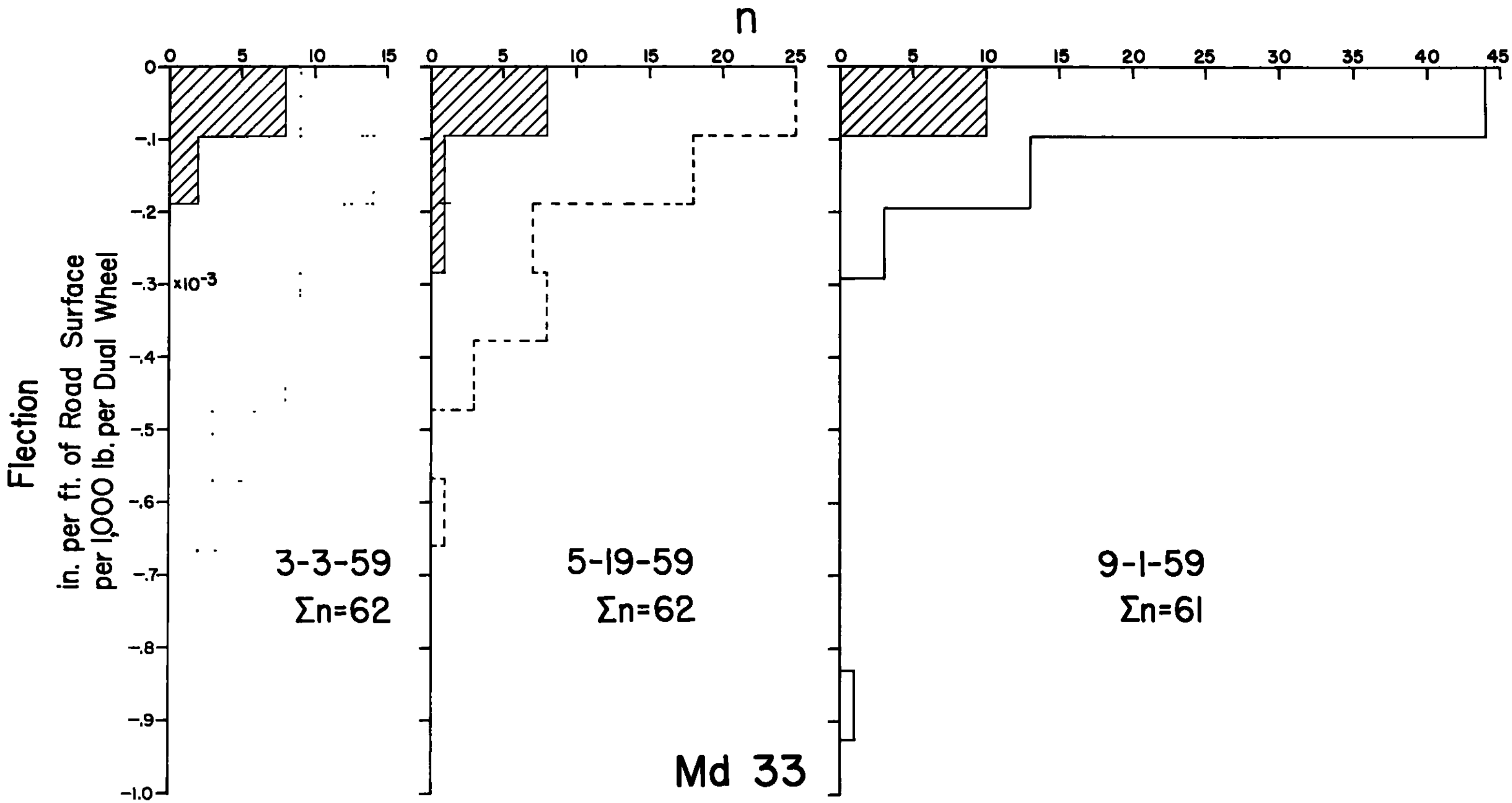

n
Flection
in. per ft. of Road Surface
per 1,000 lb. per Dual Wheel
x10⁻³
0
-.1
-.2
-.3
-.4
-.5
-.6
-.7
-.8
-.9
-1.0
0 5 10 15
0 5 10 15 20 25
0 5 10 15 20 25 30 35 40 45
3-3-59
Σn=62
5-19-59
Σn=62
9-1-59
Σn=61
Md 33

Figure 13b.

Because of the distances between the datum supports and the probe point (for this particular beam), the zone of influence amplification factor is 3.160. The bias added to the profile at the probe end then becomes -0.00711 ± 0.0008 in. on the road surface. Conventionally the total maximum deflection (D) would be -0.01750 in. The rebound deflection at ($D_{R\ 4.5\ ft}$) would be -0.00650 in. and at ($D_{R\ 9\ ft}$) would be -0.00875 in. These last rebound deflection values are obtained by assuming the elevation of the probe point is zero and outside of the zone of influence when the rear dual wheels are 4.5 or 9 ft, respectively, ahead of the probe point. If deflection (D) is taken to be equal to -0.01750 in. and the zone of influence bias is taken to be +0.00711 in., a more accurate deflection (D) would be on the order of -0.0104 in. which is not too different from the rebound deflection ($D_{R\ 9\ ft}$) value of -0.00875 in. (Similar data shown in figures are reduced to inches per 1,000 lb per dual wheel.)

CHARACTERISTICS OF THE PROFILES

Figure 10a and b are plots of rebound deflections ($D_{R\ 9\ ft}$) the first of which were obtained Aug. 26, 1958 or 14 days following construction, the second group Sept. 8, 1958 or 27 days after construction, the third group just before cold weather set in. A particular pattern of rebound deflections exists and is repeatable with respect to time. The reversal of the magnitude of these rebound deflections appears to be significant; however, for the present it remains without an explanation.

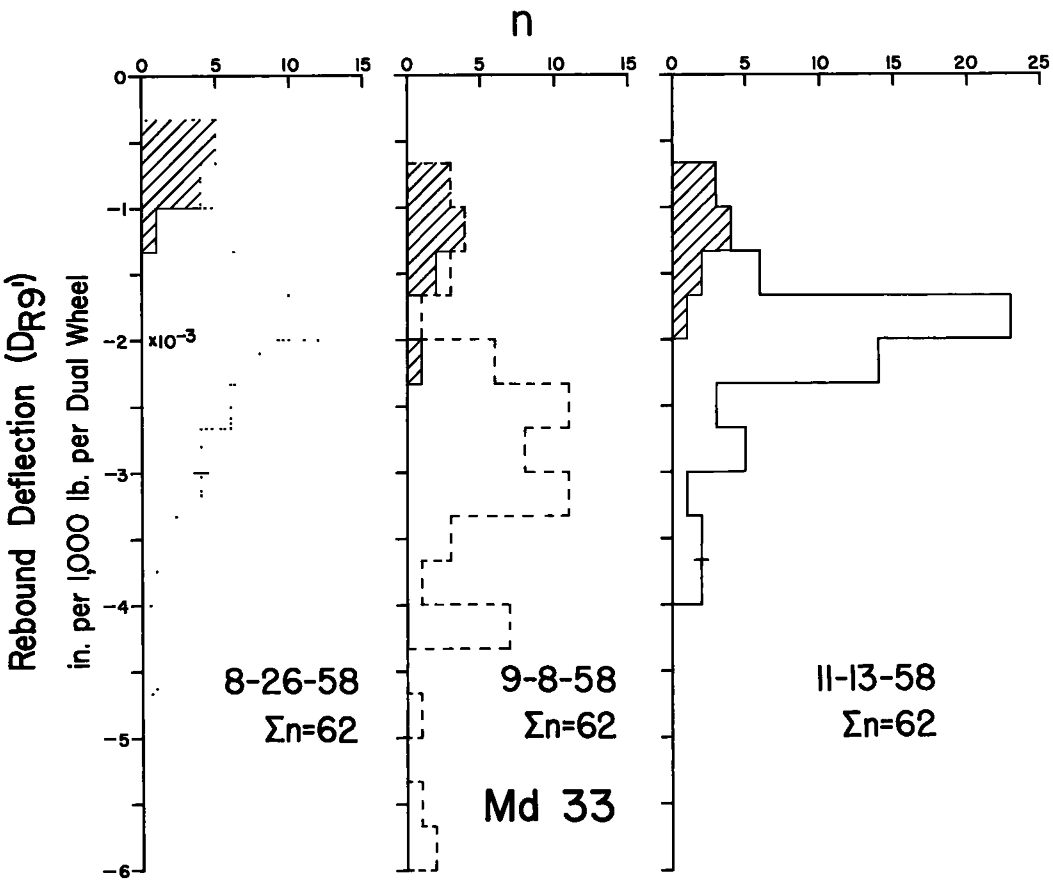


Figure 14a.

Figures 10c and d are plots of the rebound deflections as found in 1959. For comparison, the autumn 1958 values are plotted as circles. It is evident that frost action caused appreciable increases in the rebound deflections but recovered around the middle of May. By September 1 many of the test points seem to be reaching a general ultimate value of about -0.001 in. per 1,000 lb per dual wheel.

Just as measures of deflection of a relatively rigid base are biased by the zone of influence, it is assumed that the measures of flexing of the road base or pavement are likewise biased and believed to be biased in direction of exaggerating the flection. Until the device is available that will correct the profiles for the zone of influence, the values for flection will continue to be used as they have been in the past, that is, making the assumption that the profile is still a virtual image of the road surface deflection. Used as such, Figures 11a and b show some rather erratic behavior of the flections at early ages except for the section containing the calcium chloride. Values for flection of less than -0.04×10^{-3} in. per ft per 1,000 lb are not generally determined, mainly becaus of the quality of some of the profiles and also because of the limits of the template used to determine the flection from the profiles. It is entirely possible that a number of values for flection plotted to equal -0.04×10^{-3} could be much less. With respect to the measure of flection it appears that the approximately 1.5 percent calcium chloride treated material reached its ultimate values within the first 14 days of curing, whereas the 0.5 percent calcium chloride area seems to have lagged behind. A number of the

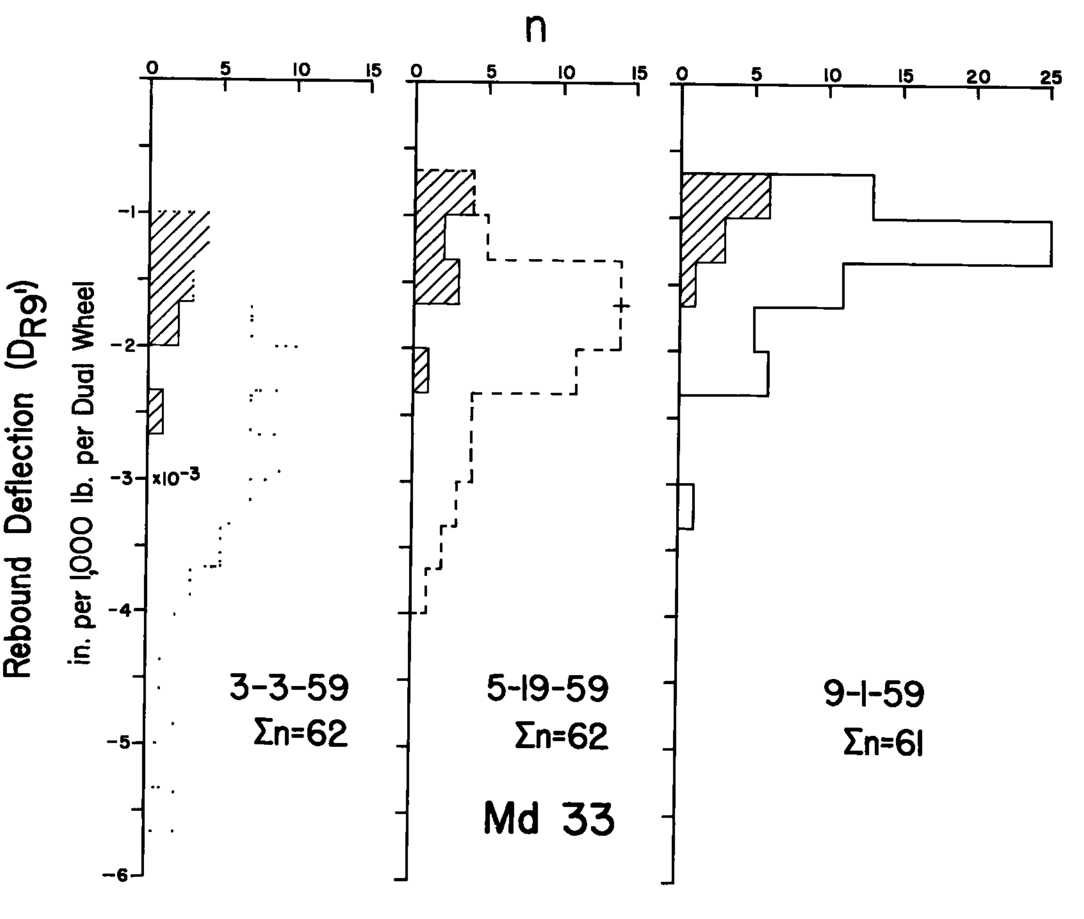


Figure 14b.

areas not containing calcium chloride still have a long way to go to get a flection value of -0.04 x 10^{-3} in. per ft per 1,000 lb (Fig. 11c and d). Figures 11c and d also show the effect of frost action on the flections and the recoveries later in the spring and summer. Indications are that the calcium chloride section was not particularly affected by the frost action. Interesting also is the behavior of the test point at Station 304+60 Rt (Fig. 11c) for which there is yet no explanation. It is difficult to dismiss the reversal in behavior of the flection measures as accidental.

In evaluating the effect of base ridigidty on the measures of the residual deflection ($D_{R\ 9\ ft}$), Figures 12a, b, c and d and Table 2 suggest that eventually all values will be negative and will level off at a value on the order of -0.001 in. or somewhat less per 1,000 lb per dual wheel.

In Figure 12b there is evidence of what probably is slight extrusion upward of the base materials between the dual wheels at Station 303+80 Rt and also probably at 304+40 Rt.

In Figure 12a, and more so in Figure 12b, indications are that the residual deflections ($D_{R\ 9\ ft}$) become more negative with respect to time. This is believed attributable essentially to the seasoning of the subbase and only in a very small part to rigidity. Rigidity is all but ruled out as being a major contributing factor to the increase in negativeness of the residual deflections except where rigidity is practically nonexistent. This conclusion is based primarily on Figures 12a and c where if it were not known that calcium chloride has been incorporated in that particular lane, the plots of residual deflection certainly would not suggest where it might be incorporated, whereas, Figures 10a and c, and 11a and c would.

In Figures 12b and d at Stations 304+10 and 304+20 where some 1.5 percent calcium chloride treated base materials were placed as a part of the lower level of the 8-in. lift, the residual deflections do not conform to their general behaviors elsewhere on the project. Neither the exact cause nor the significance of this irregularity is known.

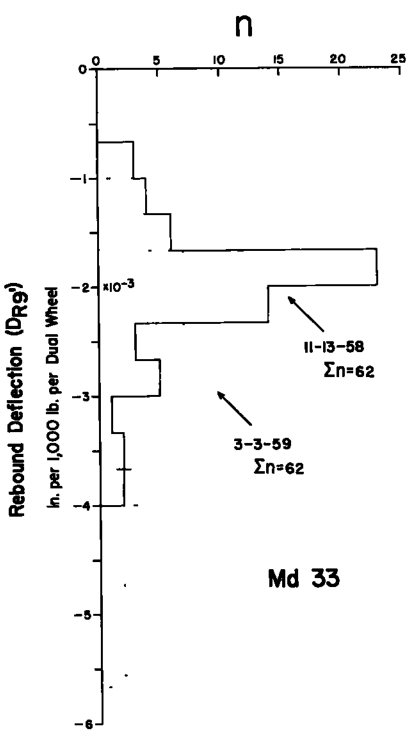


Figure 15a.

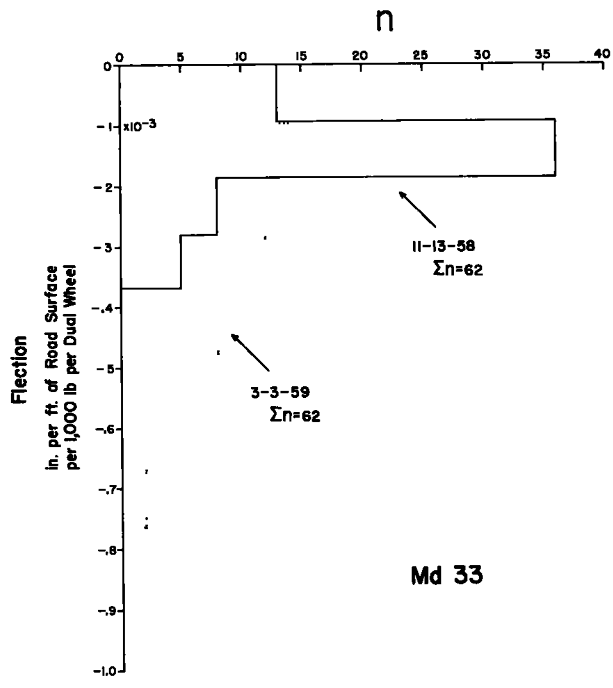


Figure 15b.

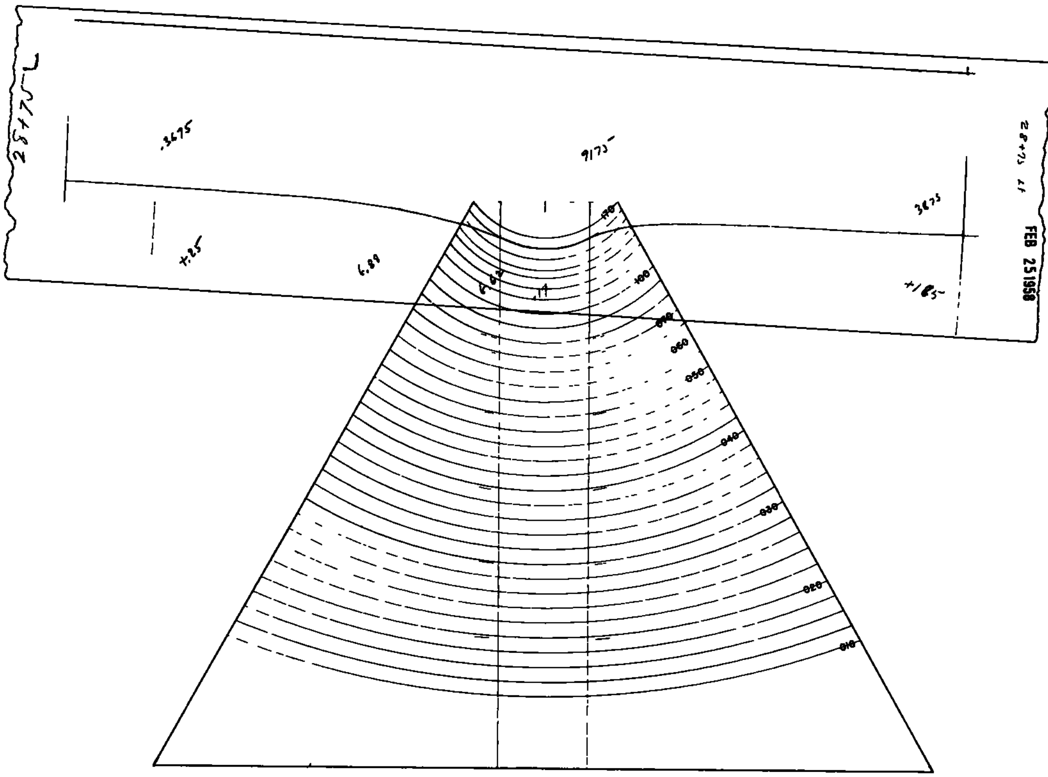
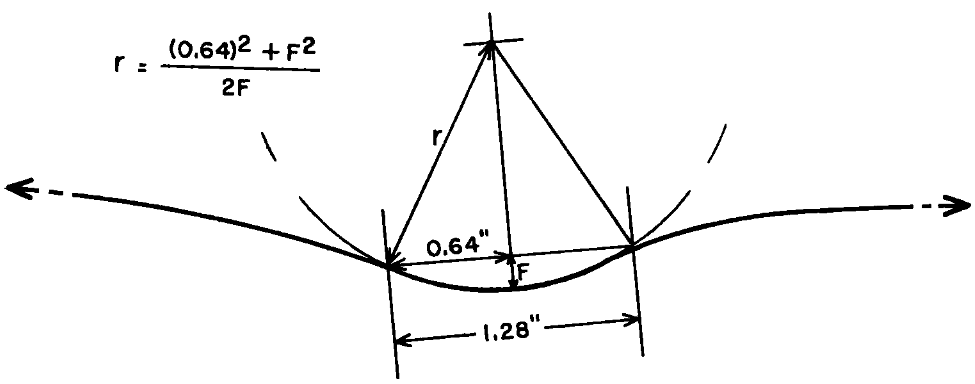


Figure 16a.



PROFILE TO ROAD DIMENSIONAL RELATIONSHIPS

LONGITUDINALLY: 1.28" ON PROFILE EQUALS 1' ON ROAD

VERTICALLY: 0.010" ON PROFILE EQUALS 0.001" ON ROAD

Figure 16b.

TABLE 2

AVERAGES AND ESTIMATES OF THE STANDARD DEVIATION IN INCHES[a]

Date of Test	Left Lane Average	Left Lane Est. of Std. Dev.	Right Lane Average	Right Lane Est. of Std. Dev.
8-26-58	-0.52×10^{-3}	0.14×10^{-3}	-0.44×10^{-3}	0.16×10^{-3}
9-8-58	-0.76	0.16	-0.76	0.21
11-13-58	-0.88	0.13	-0.94	0.21
3-3-59	-0.99	0.17	-0.98	0.17
5-19-59	-0.95	0.13	-0.97	0.17
9-1-59	-0.79	0.10	-0.93	0.17

[a]As determined from average deviation x 1.25 for the residual deflections ($D_{R\ 9\ ft}$) for Figures 12a, 12b, 12c, and 12d.

The frequency distributions in Figures 13a and b show quite dramatically the great changes in the measures of flection that take place on gain in stability to where the base can be regarded as semi-rigid. The hatched portion in each histogram indicates the position with respect to measures of flections that the calcium chloride treated materials occupy. Similarly, frequency distribution plots of the rebound deflections ($D_{R\ 9\ ft}$) in Figures 14a and b show considerable changes with respect to time but perhaps not so spectacularly as the similar plots of flection. The hatched areas in the histograms in Figures 14a and b again represent the values for the calcium chloride treated materials.

The frequency distributions in Figures 15a and b need no more explanation other than that they were plotted to show the detrimental effects of frost action on measured rebound deflections and flections.

Appendix

The longitudinal flexing of the road surface is actually determined by matching arcs of precomputed radii with the curvature of the deflection profile. The arcs of precomputed radii are inscribed on sheets of transparent plastic thereby making overlay type of scales and are referred to as "flection scales".

Figure 16a is a photograph of a flection scale with its 0.160-in. arc overlaying the highly flexed portion of the profile. This scale has arcs of 34 differing radii covering a range for total flections of 0.170 to 0.016 in. per ft of pavement. Another scale has 29 arcs extending the range to 0.004 in. per ft of pavement. As can be seen from the flatness of the profile in Figure 9, there is a need for a flection scale that will extend the range of arcs to a straight line.

Figure 16b is an actual-size tracing of the highly flexed portion of a deflection profile. Superimposed on the profile in the highly flexed zone is an arc of the radius r subtending a cord of a length equivalent to a linear foot of road surface. In the Figure 16b,

F = total flection in inches as exaggerated by a ratio of 10:1, and
r = radius for an arc that fits the curvature of the profile and subtends a cord 1.28 in. long (the 1.28-in. dimension is for the particular beam used in this study and not necessarily for any other beam).

As illustrated in Figure 16b, r is determined by solving for the length of the hypotenuse of a right triangle one leg of which is ½ of the cord length.

$$r^2 = (0.64)^2 + (r - F)^2 \quad \text{or} \quad r = \frac{(0.64)^2 + F^2}{2F}$$

TABLE 3

SUGGESTED F VALUES (in in.) FOR WHICH r SHOULD BE DETERMINED FOR FLECTION SCALE CONSTRUCTION

Scale No. 1		Scale No. 2		Scale No. 3	
F	ΔF	F	ΔF	F	ΔF
0.0100	—	0.100	—	0.70	—
—	0.0005	—	0.005	—	0.02
0.0050	—	0.050	—	0.30	—
—	0.0002	—	0.002	—	0.01
0.0000	—	0.020	—	0.10	—
—	—	0.010	0.001	—	—

It has been found preferable to keep F independent so that select values could be assigned to it. Values of F selected for an experimental model of a flection scale ranged from 0.02 to 0.50 in. in uniform increments of 0.01 in. This scale is no longer being used except for flections in excess of 0.170 in. per ft. The values of F as well as the increments of F selected for the two new flection scales used most often make it possible to get greater accuracy in flection determinations. The extended range of the new scales permits estimation of flection of much higher type bituminous pavements.

As a result of some experience in using the flection scales, the profiles and the quality of the profiles would suggest that three scales each with a different range should be constructed. Table 3 is given as a possible guide for the scale construction suggesting the ranges, increments and inferred best expected accuracy from the increments.

Discussion

W.H. CAMPEN and L.G. ERICKSON, Omaha Testing Laboratories — There appears to be confusion in regard to the making of deflection tests on the surface of pavements.

In making the test, engineers are attempting to measure the amount of downward deformation by applying load on rigid steel plates or by applying load through inflated tires. By either method, the total downward movement or total deflection is measured when the load is applied. After the load is removed, the permanent deformation (residual deflection) is then measured. The difference between the total deflection and permanent deformation is denoted as elastic deflection.

If the test is made in this manner, the permanent deformation (residual deflection) cannot exceed the total deflection. Nevertheless, engineers making this type of test sometimes report, as in this paper, residual deflections which are greater than total deflection.

The question now is: under what conditions can residual deflection be greater than the total deflection? The only way such conditions can be visualized is to assume that the test is being made with a beam (as in this case) and that as the wheels approach the indicator point of the beam, the general area goes down while the surface is squeezed up between the spacing of the dual tire. After the load is removed, the general area rebounds and the surface which has been squeezed upward rises higher than its original position. When this condition prevails neither the total, elastic or residual deflection is correct because the squeezed portion of the surface has vitiated these readings.

The above reasoning leads to the conclusion that the beam test should not be used when the surface or the layered system beneath is so weak as to cause squeezing to take place between the dual tires. The plate method, however, could be used for determinations under these conditions.

It should be pointed out that the main purpose for making deflection tests is to determine the amount of elastic deflection which the surface can tolerate without the production of cracks. The maximum load which can be applied without the production of cracks is then designated as the load carrying capacity of the pavement. It is evident, therefore, that deflection tests are not made for the purpose of detecting obviously weak flexible pavements. Rather they are made on good flexible pavements for the purpose of determining their load carrying capacities.

CLOSURE, J. Eldridge Wood and William B. Greene — It is extremely unfortunate that the complete paper could not be made available for distribution at or prior to the 39th Annual Meeting of the Highway Research Board. The preprint that was available was actually a brief on the paper in preparation.

The writers are entirely correct in recognizing that extrusion of the road surface can occur during the deflection determination. This extrusion does subtract from the conventional measure of deflection, however, it is felt very certain that the rebound deflections are only slightly affected by the extrusion except in extreme cases of extrusion. It was recognized that there were the biases and influences of the several movements, elastic and plastic, on the shapes of the deflection profiles and that more than one of the movements can be taking place at the same time and variably. These movements are sometimes additive on some measurements; sometimes they may cancel each other out or even show complete reversals of normal expected behaviors.

Because plate bearing determinations on either of these projects were not made it cannot be concluded that the plate bearing test would or would not have been more appropriate.

It seems that a misunderstanding developed concerning the purpose behind these research projects. In the case of the granular soil base project that is showing questionable performance, and in similar new construction it is preferred to delay the placing of a high type bituminous surface for approximately a year. On this project, deflection profiles were obtained throughout the placing of the granular soil base materials and frequently thereafter until stability was attained and winter had set in. The profiles obtained prior to and during attainment of stability provided clues as to how the profiles might be interpreted should stability be lost regardless of the cause. It was the intent to obtain deflection profiles from both these experimental projects under both the most favorable as well as the most unfavorable conditions during which the road would be open to unlimited natural traffic. Although it was attempted, there is no guarantee that these roads have been tested for deflections, etc., under either their most unstable or stable condition periods of the year. These projects will continue to be followed in the future though the evaluation may change.