Flexible Pavement Deflection Study In North Carolina

L. D. Hicks, *Chief Soils Engineer,*
North Carolina State Highway Commission, Raleigh, N.C.

Believing that excessive deflection of flexible type pavements under repeated loads cause cracking of plant mix surface courses, the author has been conducting deflection surveys in North Carolina for the past three years. Many of the surveys have been repeated for two and three years. Some of the surveys were made before and after plant mix overlays. The bases consist of soil type, aggregate type, and some aggregate type stabilized with portland cement. The subgrade soils consist of sands and clays of the Coastal Plain and plastic and micaceous soils of the Piedmont.

The deflections were measured with two Benkelman beams, one for the inner wheel path and one for the outer wheel path. Pavement condition at the time of each survey was observed for the purpose of correlating pavement condition with magnitude of deflection.

Survey data on several paved roads selected to represent the various subgrade soils, base types, and different thicknesses of bituminous surface courses are given. An analysis of the deflection data is made and, from this analysis and the pavement condition, conclusions are drawn and recommendations made for improvement in pavement design and construction.

• A KNOWLEDGE of the magnitude of deflections sustained by flexible type pavements under a known wheel load is excellent information for use in pavement analysis. It is generally an accepted fact that most of the cracking of bituminous pavement surfaces is attributable to excessive deflections caused by repeated wheel loads of a magnitude sufficient to produce the deflections. The determination of the maximum safe deflection a flexible type pavement can undergo in service involves considerable investigation and study. This paper describes such a study being made in North Carolina.

Pavement deflection is that vertical movement of the pavement that is recoverable when loaded and unloaded by moving wheel loads. Measurement of this movement is made by the Benkelman beam (*1-4*). Two of these devices are used in order to measure the deflection caused by the outer and inner wheels simultaneously.

When a deflection survey of the flexible type pavement on a certain road is to be made, points or stations are established and painted on the pavement at which the measurements are to be made. The stations alternate from one side of the pavement to the other and are not more than a mile apart for routine work, and not more than 1,000 ft apart for more detailed investigation. Four or more pairs of measurements, at 50-ft intervals, are made at each station and the pavement examined for cracks and distortion or rutting. The degree of rutting is determined by stretching a string across the pavement and measuring the depth of the ruts in each wheel path.

Deflection data as well as the condition of the pavement at each station are recorded on the form (Fig. 1). The figures in the first column designate the station number (first) and point (second). The outer wheel path is designated as O and the inner wheel path as I. The deflection

PAVEMENT DEFLECTION DATA SHEET

Location US-74, Charlotte to Monroe Sheet No. 1 of 11
Eastbound Pavement

Date 5-27-59 Time 8:15 AM / 1:15 PM Air Temp. 72° / 86° A. C. Temp. 76° / 108°

0.0 Mi. at NC-27

Test Point	Wheel Path	Wheel Load	Dial Reading Initial	Dial Reading Max.	Dial Reading Final	Defl. (D)	Recov.	Resid.	Remarks
1-1	0	7500	65	41	64	28	26	-2	2.06 Mi. Rt 1/8" - 1/8" 1/8" - 0 Crk.
1-1	1		26	9	25	34	32	-2	
1-2	0		60	44	59	32	30	-2	0 - 1/8" 0 - 0
1-2	1		15	1	15	28	28	0	
1-3	0		15	93	14	44	42	-2	1/8" - 1/8" 0 - 0
1-3	1		20	9	20	22	22	0	
1-4	0		32	20	32	24	24	0	0 - 3/16" 0 - 0
1-4	1		40	23	40	34	34	0	
2-1	0		0	90	99	20	18	-2	2.65 Mi. Lt. 1/8" - 0 1/8" - 1/8"
2-1	1		0	92	0	16	16	0	
2-2	0		2	94	2	16	16	0	0 - 0 1/8" - 1/8"
2-2	1		36	28	36	16	16	0	
2-3	0		62	50	61	24	22	-2	3/16" - 0 1/8" - 1/8"
2-3	1		59	50	59	18	18	0	
2-4	0		90	81	90	18	18	0	1/8" - 0 1/8" - 1/8"
2-4	1		61	56	61	10	10	0	

Figure 1.

is twice the difference between the maximum and initial dial readings; the recovery is twice the difference between the maximum and final dial readings. The residual is the difference between the deflection and the recovery and is recorded as plus or minus. The depth of ruts appearing in the pavement in the four wheel paths, as measured from a string stretched across the pavement, is recorded in the remarks column.

Inasmuch as deflection surveys are made when traffic is using the pavement, safety measures must be taken to prevent accidents. Two large warning signs are placed in conspicuous places at each end of the section of road being tested. The truck and one car remain on the pavement during the deflection measurement operation, the truck in front and the car behind. Each vehicle is equipped with a blinker light, and there is a large warn-

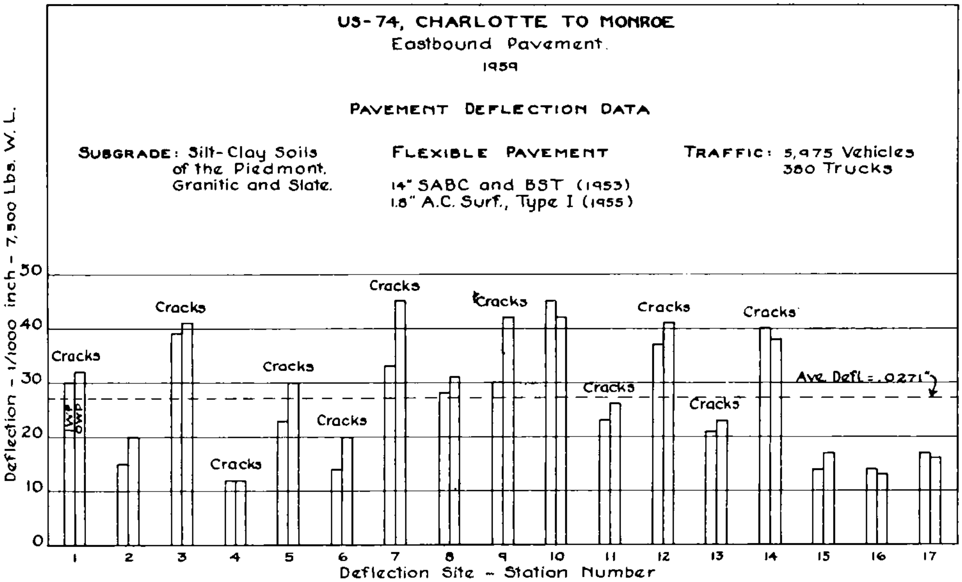

Figure 2.

ing sign on the back of the car. The men work between the car and truck.

A party of four (a truck driver, two beam operators, and a recorder) can conduct a deflection survey, but a fifth person can be used advantageously to direct the truck driver and give general assistance. This party is able to cover four to six 4-point stations per hour, provided the stations have been previously located and marked and the pavement condition survey made. It is advisable to conduct the survey in two separate operations, the pavement condition survey as one operation and the deflection measurements as the other.

The recorder makes all calculations of deflections and recovery before moving to the next point. This enables him to detect erroneous dial readings. The recorder also notes the ambient and pavement temperatures at the beginning of the survey and at other times necessary to determine an average.

The deflection surveys conducted in 1957 on a few selected pavements were made using a 10,000-lb wheel load. After some study, it was decided to reduce this wheel load to 7,500 lb because a statistical analysis of traffic restricted to axle loads of 18,000 to 20,000 lb shows that the average axle load will not exceed 15,000 lb. This change eliminates the necessity for securing a permit for operating a vehicle whose axle load exceeds the legal limit. Also, since the magnitude of the deflection is directly proportional to the load, within certain limits, deflections may be calculated for other wheel loads.

Figure 2 shows how deflection data may be graphed. The deflections are the average of 4 measurements taken at a station. The left bar is the average deflection obtained in the inner wheel path and the right that obtained in the outer wheel path. Also shown are pavement thickness and age, type of subgrade soil, average daily traffic, and pavement condition.

Figures 3 through 12 show the deflection data, arranged according to frequency of occurrence, obtained from deflection surveys made on sections of four roads. Such an arrangement reveals facts that are not apparent if presented only in the form of Figure 2. The following is

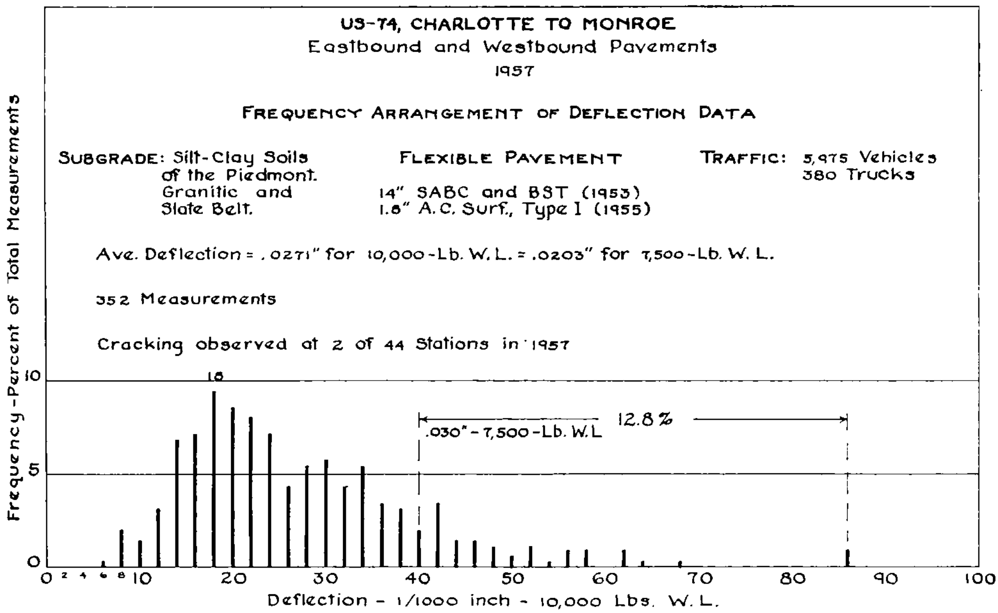

Figure 3.

a discussion of the data for each of the roads.

US 74, CHARLOTTE TO MONROE

This road is 21.54 mi in length and the pavement consists of a 14-in. stabilized aggregate base with bituminous surface treatment, constructed in 1953; and 1.8 in. (200 lb per sq yd) of bituminous concrete plant-mix surface course, placed in 1955—making a total pavement thickness of approximately 17 in. The pavement was constructed as 24-ft wide dual pavements.

The subgrade on this road is composed of silt-clay soils of the Piedmont, predominantly of Carolina slate belt material, however some granitic materials are in evidence near Charlotte. Their HRB subgrade classifications are A-4, A-6, and A-7. A subgrade bearing value of 12 psi (CBR = 5.5) was selected for designing the flexible type pavement.

The average daily traffic (ADT), according to 1958 records, is 5,975 vehicles, 380 of which are trucks of the tractor-truck and semi-trailer type.

The flexible type pavement was designed for 10,000-lb wheel loads, which require a total thickness of 17 in. for a subgrade bearing value of 12 psi.

The first deflection survey was made in May 1957 using a 10,000-lb wheel load. Figure 3 shows a frequency arrangement of the deflection data. The following facts are apparent:

1. Pavement deflections for the 10,000-lb wheel load range from a minimum of 0.006 in. to a maximum of 0.086 in., which should (theoretically) reduce to 0.0045 in. and 0.0645 in., respectively, for a 7,500-lb wheel load.
2. The deflection of most frequent occurrence in 352 measurements was 0.018 in. for the 10,000-lb wheel load, which would reduce to 0.0135 in. for a 7,500-lb wheel load.
3. The number of deflections above 0.040 in., which would correspond to a deflection of 0.030 in. for a 7,500-lb wheel load, is 12.8 percent of all deflections measured. A deflection of 0.030 in. is the maximum deflection desired for flexible type pavements.

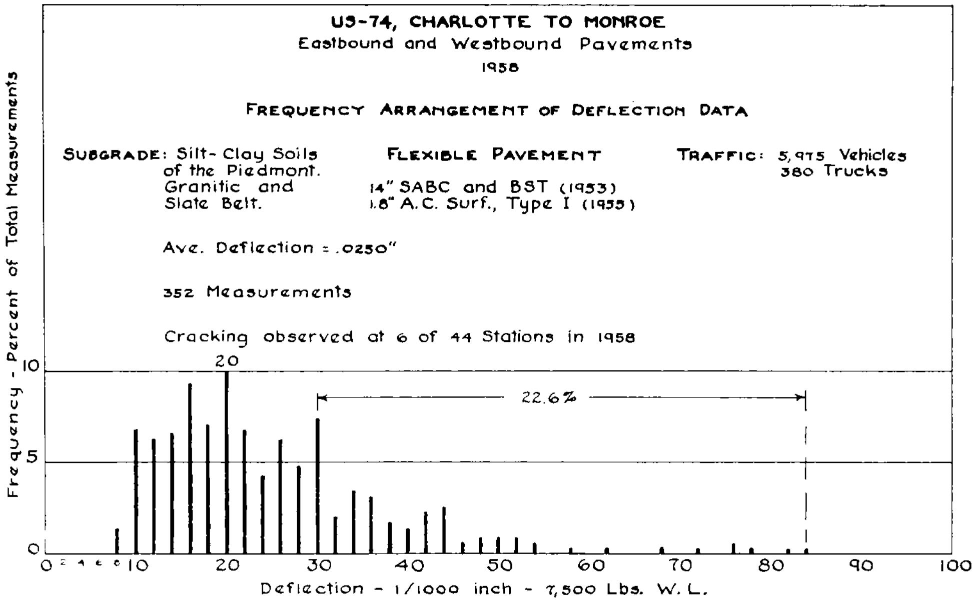

Figure 4.

4. The bars (Fig. 3) resemble a frequency curve, skewed to the right. This indicates some weak sections of pavement caused by faulty subgrade.
5. The average of the 352 deflection measurements is 0.0271 in. for the 10,000-lb wheel load, which corresponds to 0.0203 in. for a 7,500-lb wheel load.

Cracking of the bituminous pavement surface was observed at 2 of the 44 deflection stations where the deflections were as great as 0.062 in. at one station and 0.086 in. at the other. These would reduce to 0.0465 and 0.0645 in., respectively, for a 7,500-lb wheel load.

In May 1958 the second deflection survey of the pavement was made using a 7,500-lb wheel load. Deflection measurements were made at the same stations established for the 1957 survey. Figure 4 shows a frequency arrangement of the deflection data which shows the following:

1. Pavement deflections for the 7,500-lb wheel load range from 0.008 in. to 0.084 in. In 1957, the range was from 0.0045 in. to 0.0645 in. when reduced for a 7,500-lb wheel load. This indicates a weaker subgrade, and possibly, base condition due to a severe winter.
2. The deflection of most frequent occurrence in 1958 was 0.020 in. as compared with 0.0135 in. in 1957 for a 7,500-lb wheel load. This is to be expected for the same reason as given previously.
3. The number of deflections above 0.030 in. are 22.6 percent of the 352 measurements taken. The fact that this percentage is greater than the 12.8 percent obtained in 1957 further indicates that the subgrade is some weaker in 1958.
4. The skewed shape of Figure 4 is quite similar to Figure 3, with the skew more to the right. This would indicate that the weak spots of 1957 are weaker in 1958.
5. The average of the 352 deflection measurements is 0.0250 in. for 1958 which is more than the 0.0203 in. obtained from the 1957 survey, further reflecting the influence of a severe winter.

Cracking of the bituminous pavement surface was observed at 6 of the 44 stations as compared with only 2 in 1957.

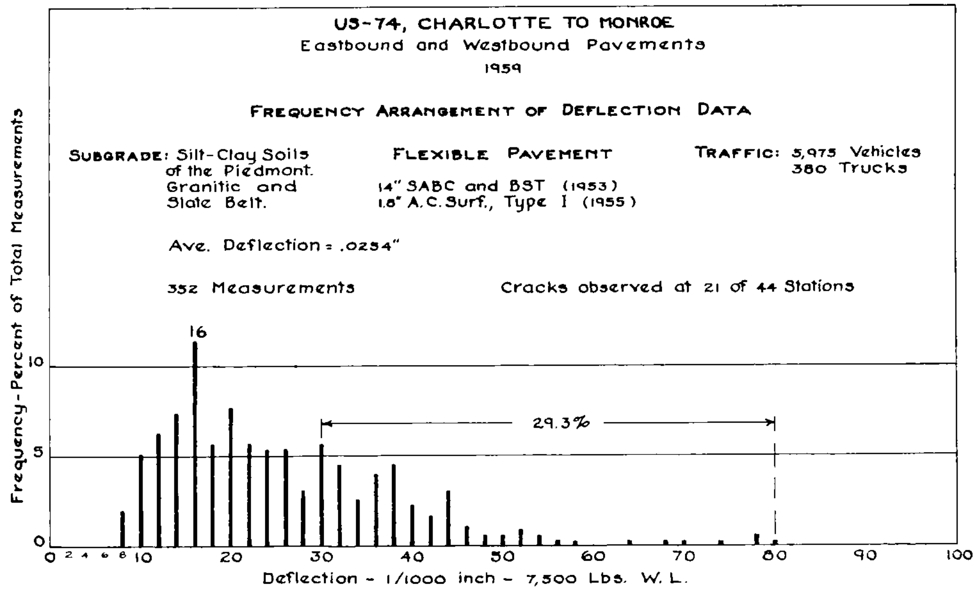

Figure 5.

Deflections at these 6 stations showed maximums of 0.044 in., 0.089 in., 0.036 in., 0.046 in., 0.044 in., and 0.084 in.

A third deflection survey was made of this pavement in May 1959 using a 7,500-lb wheel load. Deflection measurements were again taken at the same sites used in the two previous surveys. Figure 5 shows the following:

1. Pavement deflections range from 0.008 in. to 0.080 in. This is practically the same as obtained from the 1958 survey.
2. The most frequent deflection is 0.016 in. which is less than the 0.020 in. in 1958 but more than the 0.0135 in. in 1957.
3. The number of deflections greater than 0.030 in. is 29.3 percent of the total 352 measurements. This percentage is greater than the 22.6 percent in 1958 or the 12.8 percent in 1957.
4. Figure 5 is quite similar to Figures 3 and 4.
5. The average of the 352 deflection measurements of 1959 is 0.0254 in., which shows little change from the 0.0250 in. of 1958 but an appreciable change from the 0.0203 in. of 1957.

Cracking of the bituminous plant mix surface was observed at 21 of the 44 stations in 1959 which is considerably more cracking than observed in 1958 and 1957. The fact that the maximum deflections measured at 6 of the stations are less than 0.030 inch, one as low as 0.012 in., might indicate some brittleness of the plant mix surface, however future surveys and tests on samples of the surface are necessary to verify this. None of the cracking is serious as yet, except at two of the stations where the maximum deflections are 0.058 in. and 0.080 in. It is planned to continue the deflection surveys on this road and to test samples of the plant mix surface for reduction in ductility and penetration of the asphalt.

US 64, YADKIN RIVER TO LEXINGTON

In 1954, the first stage of the pavement was placed on the 7.14 mi consisting of 12 to 14 in. of a stabilized aggregate base and bituminous surface treatment.

The subgrade is composed of silt-clay

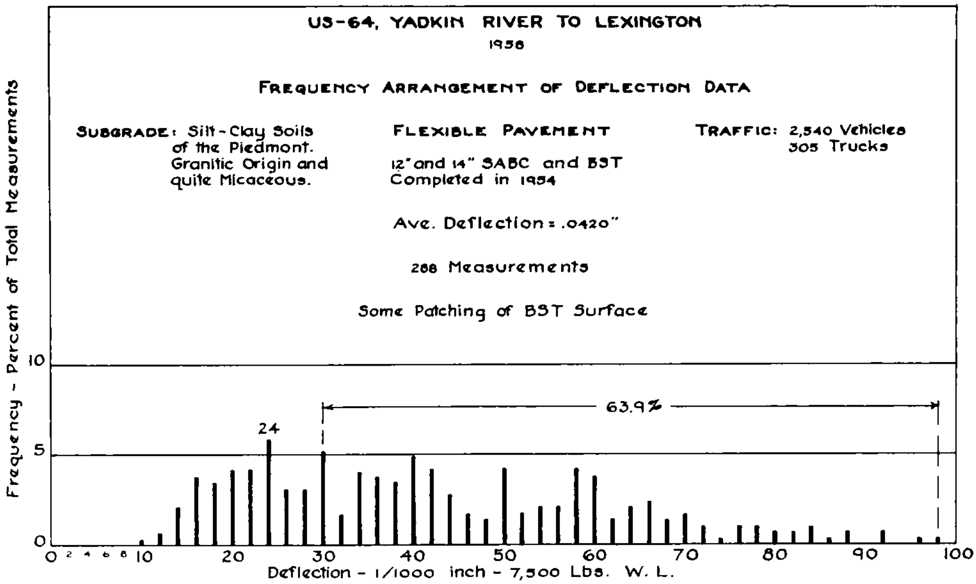

Figure 6.

soils of the Piedmont derived from granite. Much of the subgrade soil is highly micaceous, belonging to the HRB A-4 and A-5 subgrade group, with some A-7 soil in the shallow cuts. These A-4 and A-5 soils were elastic and tender, and it was necessary to stabilize them with crushed stone. The base thickness was also increased above the design thickness in many sections where these soils were encountered. A bearing value of 12 psi (CBR = 5.5) was selected for designing.

Traffic records show an ADT of 2,540 vehicles, 305 of which are trucks of the tractor-truck and semi-trailer type.

The flexible type pavement was designed for 9,000-lb wheel loads, which require a total pavement thickness of 15 in. for a subgrade bearing value of 12 psi.

The first deflection survey was made in September 1958 just before letting a contract for the plant mix surface, which was to be the second or final stage of construction of the pavement as originally designed. The prime purpose of the survey was to determine the fitness of the bituminous surface treated base for a 3-in. bituminous plant mix surface, as it was thought that there were sections where the subgrade was highly elastic or resilient, causing the pavement to deflect excessively under traffic. Deflection stations were established at intervals of 1,000 ft so that the deflection data would be of sufficient detail to warrant selection of sections for special treatment. Figure 6 shows the following:

1. Pavement deflections range from 0.010 in. to 0.098 in.
2. The most frequent deflection is 0.024 in.
3. The number of deflections greater than 0.030 in. is 63.9 percent of the 288 measurements taken.
4. Figure 6 is skewed very much to the right indicating a wide range in the deflections above 0.024 in. Also, since the slope from the 0.024-in. point is long and approaches a straight line, deflections of a much greater magnitude are appreciable in number.
5. The average of the 288 deflection measurements is 0.0420 in.

The 4-yr old bituminous surface treatment was beginning to show signs of distress in many sections, necessitating

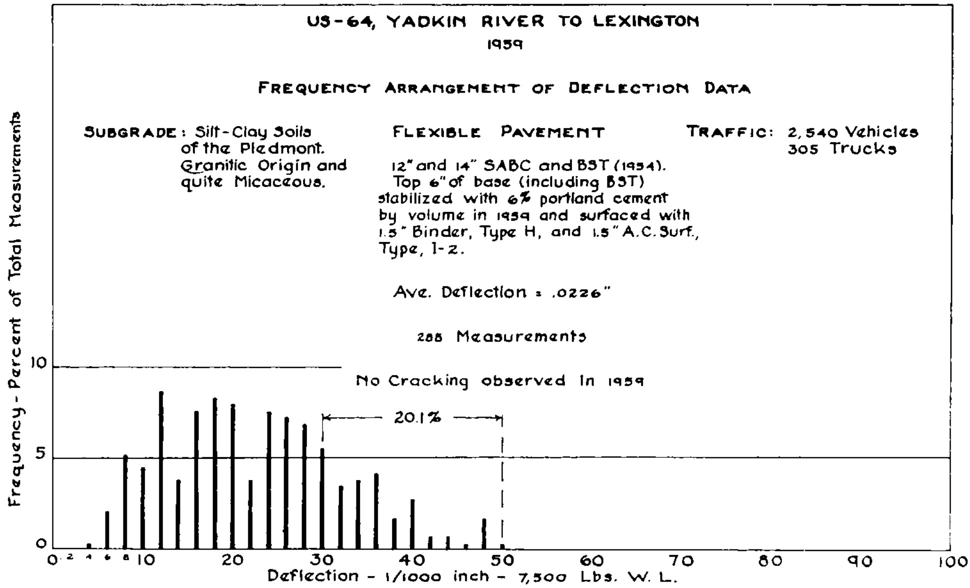

Figure 7.

patching. Base failures were not in evidence.

A study of the deflection data indicated that the existing pavement was not suitable to support the proposed 3-in. bituminous plant mix overlay except in sections too short and scattered for isolation, so it was decided to consider increasing the thickness of the plant mix overlay or treating the upper 6 in. of the bituminous surface treated base with 6 percent portland cement by volume for the entire length of the proposed project.

By inverse proportion it was calculated that 19.6 in. of pavement would be necessary to reduce the average deflection of 0.042 in. to 0.030 in. Rounding off this figure to 20 in., the overlay should be 20 in. minus 14 in. or 6 in. thick. The cost of an overlay of this thickness was estimated to exceed the cost of stabilizing the existing bituminous surface treated base with 6 percent portland cement by volume for a 6-in. depth and placing the proposed 3-in. plant mix overlay.

The existing bituminous surface treated base was stabilized and the 3-in. plant mix overlay was placed in the spring of 1959. The second deflection survey was made in June 1959 using deflection stations at the same location as in the first survey. Figure 7 shows the following:

1. Pavement deflections range from 0.004 in. to 0.050 in. Figure 6 shows a range of 0.010 in. and 0.098 in. before stabilizing the base and placing the overlay.
2. The most frequent deflection is 0.012 in. (0.024 in. in Fig. 6).
3. The number of deflections greater than 0.030 in. is 20.1 percent, considerably less than 63.9 percent (Fig. 6).
4. Figure 7 is skewed to the right, but the skew is considerably less pronounced than in Figure 6, indicating a substantial reduction in deflection magnitude and range.
5. The average of the 288 deflection measurements is 0.0226 in. which is much less than the 0.0420 in. obtained in the first survey.

The data from the second deflection survey indicate that the pavement design is a success, however future surveys are planned to prove or disprove this indication. Also, it is believed that deflection survey data can be used to evaluate pave-

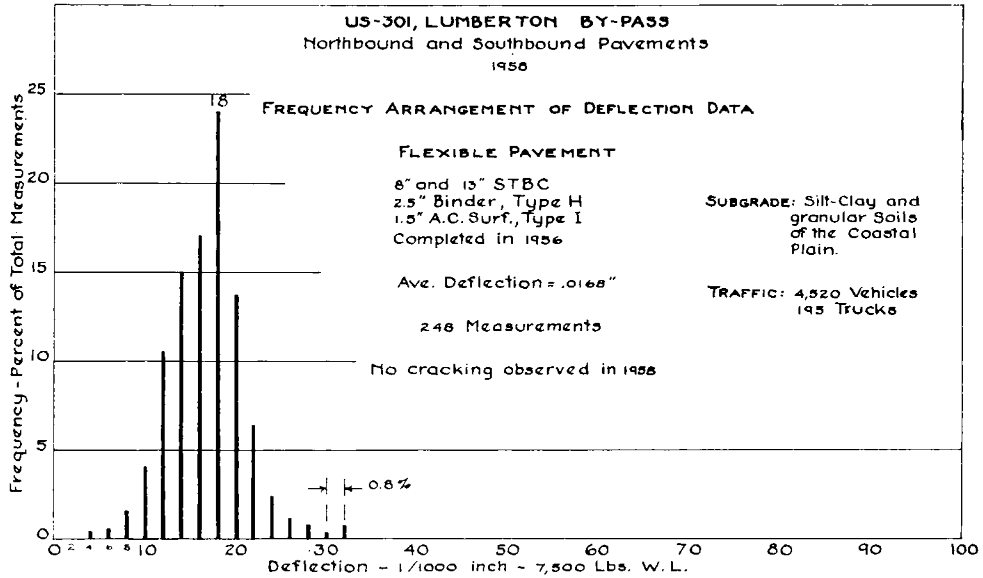

Figure 8.

ments and calculate the thickness of overlays. It is unfortunate in this case that the 6-in. overlay was the most expensive, for it would have been an excellent opportunity to test the validity of this method of evaluation and design.

US 301, LUMBERTON BY-PASS

This section of road is 8.01 mi long and the dual pavements consist of 8 in. and 13 in. of a soil type base and 4 in. of plant mix surface, constructed in 1956.

The subgrade on this project consists of both silt-clay and granular soils of the Coastal Plain. The silt-clay soils will classify as HRB A-6 and A-7 and the granular soils as A-2 and A-3. The silt-clay soils are located on the northern 3 mi. A subgrade bearing value of 12 psi (CBR = 5.5) was selected for designing the pavement on the silt-clay section, and a bearing value of 20 psi (CBR = 10) was selected for the granular type subgrade section.

The ADT is 4,520 vehicles, 195 of which are trucks of the tractor-truck and semi-trailer type.

The flexible type pavement was designed for 10,000-lb wheel loads, requiring a total thickness of 17 in. for the silt-clay subgrade section and 12 in. for the granular soil type subgrade. A 4-in. plant mix surface was required over soil type bases, so the silt-clay section needed a 13-in. base and the granular soil section needed an 8-in. base.

The first deflection survey was made in July 1958. Figure 8 shows the following:

1. Pavement deflections range from 0.004 in. to 0.032 in.
2. The most frequent deflection of the 248 measurements was 0.018 in.
3. The number of deflections above 0.030 in. was only 0.8 percent of the total measurements. Since the maximum deflection is only 0.032 in., this amount is insignificant.
4. Figure 8 shows practically no skew. This indicates a rather narrow range of deflections or a pavement of uniform strength. Furthermore, the average of the deflection measurements on the 17-inch pavement was within 0.001 in. of the average of the deflection measurements on the 12-in. pavement.

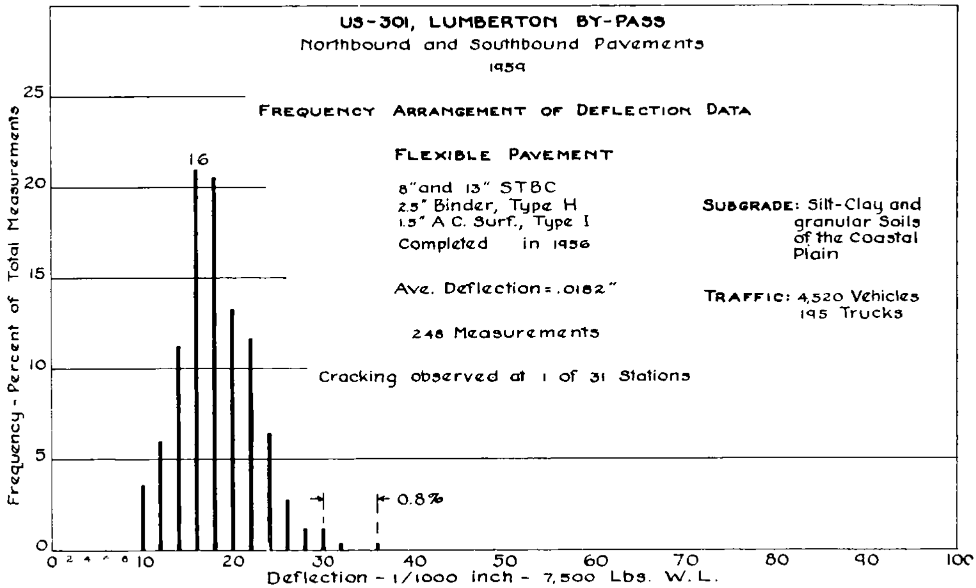

Figure 9.

5. The average of the 248 deflection measurements is 0.0168 in.

No cracks were observed in the 2-yr-old bituminous plant mix pavement in 1958.

In May 1959 the second deflection survey was made on this section of road. Deflections were measured at the same points used in 1958. Figure 9 shows the following:

1. Pavement deflections range from 0.010 in. to a maximum of 0.036 in. These extremes are higher than the 0.004 in. and 0.032 in. in 1958.
2. The most common deflection measured in the 1959 survey is 0.016 in., only slightly less than the 0.018 in. obtained in the 1958 survey. The 0.018-in. deflection occurs almost as frequently as the 0.016-in., so it may be considered that the difference in the two surveys in this regard is negligible.
3. The number of deflections above 0.030 inch is 0.8 percent of the 248 measurements. This is in exact agreement with the 1958 survey.
4. Figure 9 closely resembles Figure 8, indicating very little difference in the data for two surveys.
5. The average of the 248 measurements is 0.0182 in., only slightly greater than the 0.0168 in. of 1958.

It appears that the pavement is performing satisfactorily and is of adequate design. Very slight cracking of the bituminous plant mix surface was observed at one of the stations where the maximum deflection in 1958 was only 0.022 in. and in 1959, 0.026 in. Also, the inner wheel path was rutted to a depth of one-half to three-quarters of an inch. The slight cracking could be due to the rutting which in turn could have been caused by insufficient compaction or instability of the soil base at the time the bituminous plant mix was placed.

NC 49, MT. PLEASANT TO JACKSON TRAINING SCHOOL

This road is 9.78 mi long, and the pavement was constructed in stages. The first stage consisted of placing a 12-in. stabilized aggregate base and bituminous surface treatment in 1953. The second

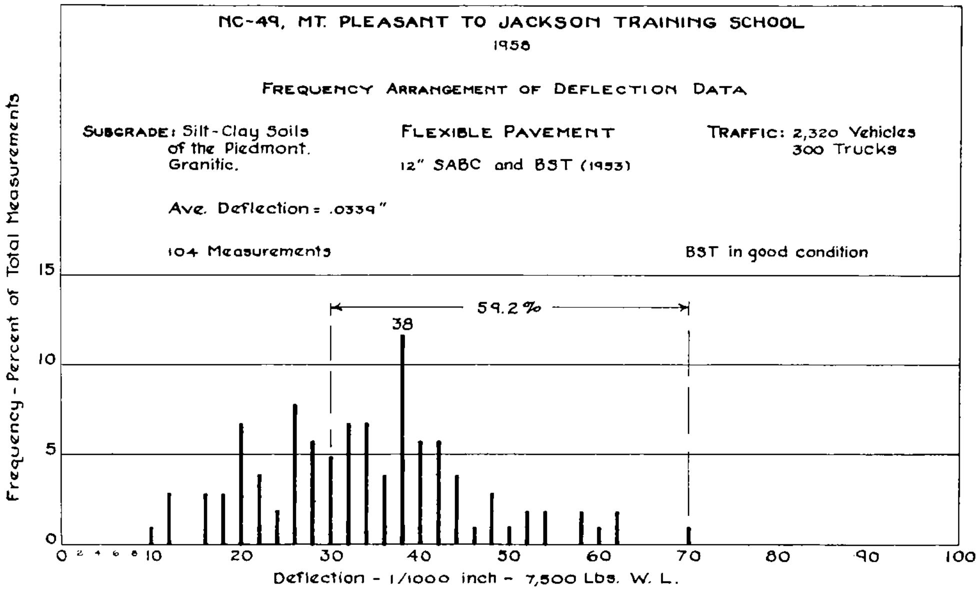

Figure 10.

stage consisted of placing the plant mix bituminous wearing surface which consisted of 2½ in. of bituminous concrete binder, Type H, and 1½ in. of bituminous concrete surface course, Type I-1. The completed pavement has a 17-in. total thickness.

The subgrade on this section of road is composed of silt-clay soils of the Piedmont derived from granitic materials. Their HRB subgrade classifications are A-4, A-5, A-6, and A-7. A subgrade bearing value of 12 psi (CBR = 5.5) was selected for designing a flexible type pavement.

The ADT is 2,320 vehicles, 300 of which are trucks of the tractor-truck and semi-trailer type.

The flexible type pavement was first designed for 9,000-lb wheel loads and was to consist of a 12-in. base and 3 in. of bituminous plant mix. However, it was decided to obtain a 17-in. thickness for 10,000-lb wheel loads, by increasing the thickness of the bituminous plant mix overlay.

The first deflection survey was made May 1958 when the pavement consisted of a 12-in. aggregate base and bituminous surface treatment. Figure 10 shows the following:

1. Deflections range from 0.010 in. to 0.062 in.
2. The most frequent deflection is 0.038 in.
3. The number of deflections above 0.030 in. is 59.2 percent of the 104 measurements made.
4. Figure 10 is only slightly skewed to the right. This indicates a pavement that shows no sign of failures developing.
5. The average of the 104 deflection measurements is 0.0339 inch.

The bituminous surface treatment wearing surface was in good condition after 5 years of service, however it did show signs of needing re-treatment.

In May 1959 the second deflection survey was made about 10 months after a 4-in. bituminous plant mix overlay had been placed. Deflection measurements were made at the 1958 stations. Figure 11 shows the following:

1. Pavement deflections range from 0.006 in. to 0.050 in. As expected, these

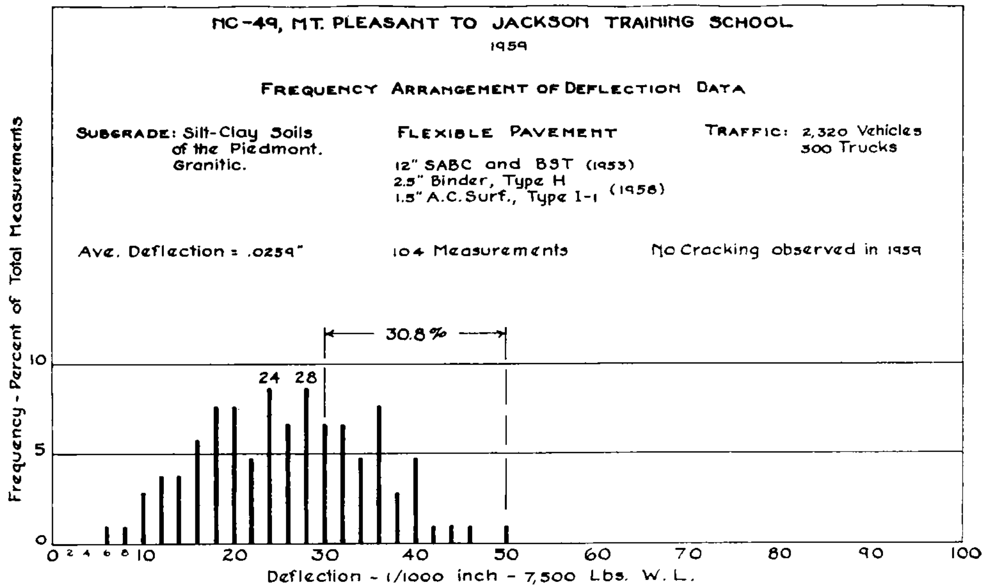

Figure 11.

extremes are less than the 0.010-in. and 0.062-in. values obtained in the 1958 survey, due to the 4-in. bituminous plant mix overlay.

2. Two deflection values occurred more frequently than any others in this survey, 0.024 in. and 0.028 in. In 1958, the most frequent deflection was 0.038 in.

3. The number of deflections greater than 0.030 in. is 30.8 percent of the 104 measurements made. Only four deflections exceeded 0.040 in.

4. Figure 11 is similar to Figure 10, showing only a slight skew to the right. Most of the deflections range from 0.016 in. to 0.040 in.

5. The average of the 104 measurements is 0.0259 in. The 1958 average without the 4-in. bituminous overlay was 0.0339 in.

The deflection with the 4-in. overlay can be calculated from the 1958 data. The 1958 pavement thickness was 13 in., and the average deflection was 0.0339 in. By inverse proportion, $^{13}\!/_{17} = x/0.0339$; $x = 0.0259$ in., the average deflection obtained in 1959.

CONCLUSIONS

This paper has described the procedure used in North Carolina for conducting deflection surveys on flexible type pavements. Deflection surveys have been in progress in this state for three years and during this period deflection measurements have been made on the flexible type pavements of some 24 roads. On several of the pavements, surveys have been made for the years 1957, 1958, and 1959.

The data obtained from the deflection surveys of four roads, selected to represent certain subgrades, types of base materials, and thickness of bituminous wearing surface, have been presented. The data is arranged according to frequency of occurrence of deflection magnitude, which is believed to bring out certain facts not revealed in other arrangements of deflection data.

A deflection survey is an excellent means of flexible pavement evaluation and it has been shown how the data can be used to calculate the thickness of overlays to reduce the magnitude of pavement deflections. It is realized that this procedure is not correct according to theory, but, within certain limits, it is usable.

The determination of the maximum deflection a bituminous plant mix pavement can sustain without excessive cracking is a complex problem that will require much investigation. Highly stable pavements are likely to be brittle and all bituminous pavements harden with age. Hveem has contributed to the solution of this problem (*5*). He sets the maximum deflection at 0.017 inch for four inches of plant mix, 0.020 inch for three inches of plant mix, and 0.025 in. for 2 in. of plant mix. The report on the WASHO Test Road (*3, 4*) where the plant mix was 2 and 4 in. thick, sets the maximum deflection at 0.030 in. in winter and 0.040 in. in summer. In North Carolina the desirable limit has been tentatively set at 0.030 in.

The author believes that excessive deflection of flexible type pavements must be controlled in the preparation of the subgrade. Resilient soils should be removed and replaced with more suitable material, or the subgrade stabilized with portland cement. Proof or test rolling has been used effectively in certain instances and is an excellent method for locating faulty subgrade, especially in cut sections and shallow fills where most of the faulty subgrade occurs. High water tables and springs are located readily with a 50-ton test roller.

All opinions expressed in this paper are the author's and not necessarily those of the engineering staff of the North Carolina State Highway Commission.

REFERENCES

1. CAREY, W. N., JR., "Benkelman Beam Deflection Indicator." *Highway Research Abstracts,* 23:8,1-4 (Sept. 1953).
2. CAREY, W. N., JR., "Benkelman Beam Pavement-Deflection Indicator, Latest Design and Comments on Utility." *Highway Research Abstracts,* 24:8,1-4 (Sept. 1954).
3. "The WASHO Road Test, Part 1." HRB Special Report 18 (1954).
4. "The WASHO Road Test, Part 2." HRB Special Report 22 (1955).
5. HVEEM, F. N., "Pavement Deflections and Fatigue Failures." HRB Bull. 114, pp. 47-73, 83-87 (1955).