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STUDY OF FROST ACTION IN CLASS AA SHOULDERS NEAR PONTIAC

MICHIGAN HIGHWAY RESEARCH LABORATORY DIVISION

MICHIGAN DEPARTMENT OF STATE HIGHWAYS

STUDY OF FROST ACTION IN CLASS AA SHOULDERS NEAR PONTIAC

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ABSTRACT: A six-mile section of class AA shoulders was investigated after the bituminous mat had been found to heave above the pavement surface. Condition surveys, instrumented shoulder sections, and observation of construction practices indicated that the soil foundation layers were not responsible, but that the initial (first winter) heave was caused by priming the base gravel immediately after wetting, thus sealing the pores and allowing insufficient gravity drainage before the winter freeze. The trapped water in the gravel base froze during the first winter, causing the shoulder to heave above the surface of the pavement. The cracks that developed after the first winter allowed surface water to enter the gravel base, thus accounting for the heaving--though, due to settlement, not above the pavement surface--during subsequent winters. Heaved areas open to traffic cracked, in contrast with those not open to vehicles. Cracking is thought to be the result of wheels riding on the heaved shoulder edge. Areas heaving above the pavement in subsequent winters cracked more severely each year; while those that did not heave above the pavement showed no increase in cracking. In view of the causes, it is recommended that the sawing and sealing of the longitudinal pavement-shoulder joint be discontinued. A Statewide survey is recommended in order to see if the subject shoulders exhibit typical behavior in all parts of the State.

KEY WORDS: frost susceptible soil, frost heave, frost penetration, shoulder maintenance, soil drainage, gravity drainage, freezing-thawing effects.

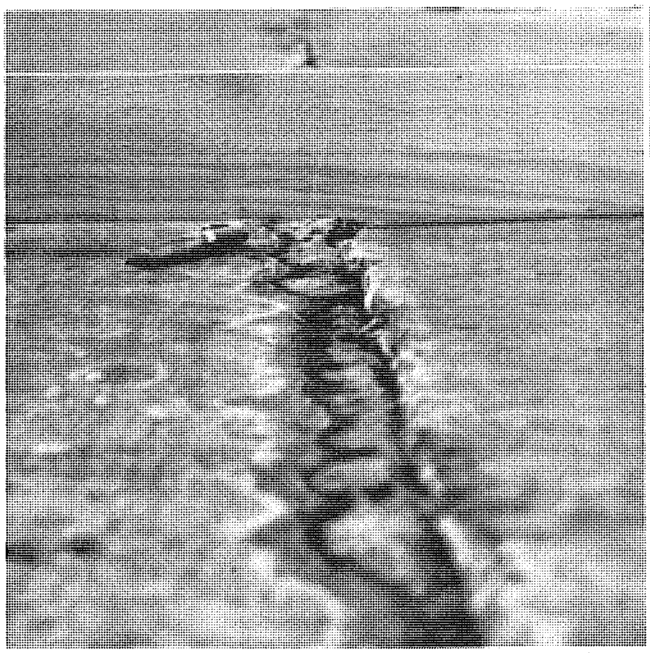
STUDY OF FROST ACTION IN CLASS AA SHOULDERS NEAR PONTIAC

This study was initiated during the winter of 1962-63 after the Pontiac District Soils Engineer reported that class AA shoulders of a newly constructed section of I 75 had heaved above the pavement surface. Inspection of all newly constructed sections of I 75 in the Pontiac District indicated that this condition was limited to a six-mile section (EBI 63172, CR5H). Shoulder heave measuring 1/8 to 5/8 in. above the pavement surface was, in most cases, accompanied by longitudinal cracking at a distance of 3 to 12 inches from the pavement-shoulder interface.

The purpose of this study was to determine the cause of the shoulder heave and cracking so that steps could be taken to prevent this occurrence in future construction. The research procedure consisted of shoulder condition surveys, instrumentation of shoulder sections, and a review of available literature concerning frost susceptibility of soil layers underlying shoulders.

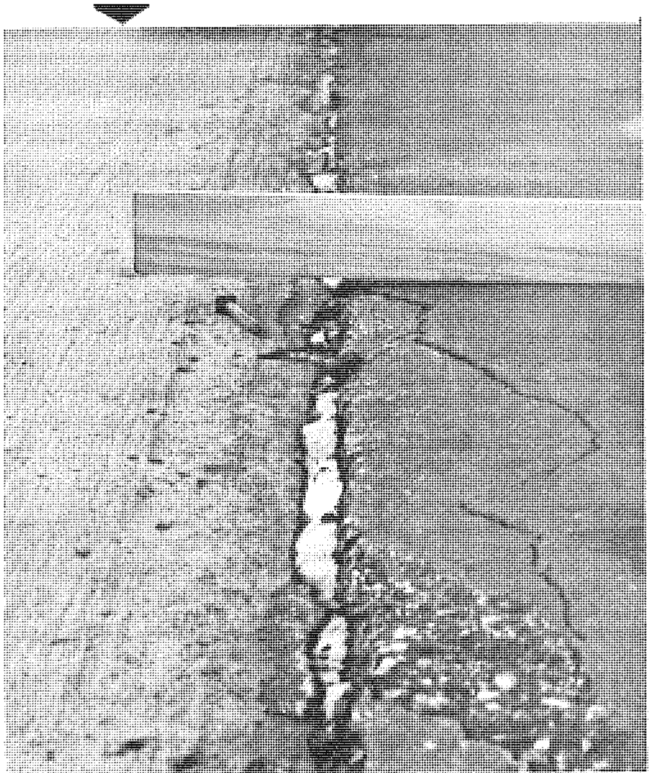
INITIAL CONDITION SURVEY

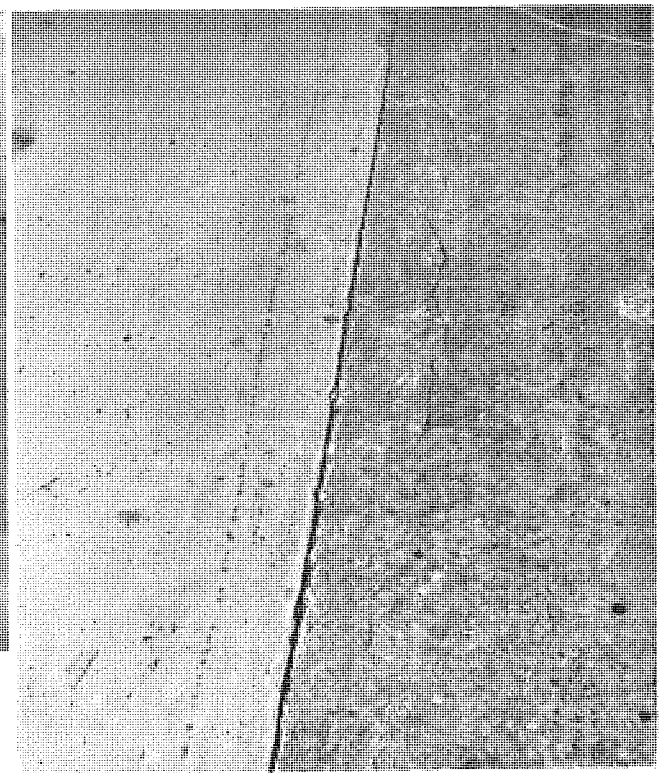
The six-mile section under study was surveyed in early February 1963 to determine the general characteristics and magnitude of the problem. Shoulder heave existed throughout this section and varied from as little as 1/8 in. to as much as 5/8 in. above the pavement surface. In general, shoulders that heaved from 1/8 in. to 3/8 in. were either not cracked or only lightly cracked. Shoulders that were heaved 1/2 in. or more were cracked more severely. The location of maximum shoulder heave varied from 3 to 12 in. from the pavement-shoulder interface, with cracks occurring at the approximate area of maximum heave. Typical moderate and severe heaving, and light and heavy cracking are shown in Figure 1. An effort was made to relate the shoulder heave to fill and cut sections but it was found that fill sections were heaved as much as cut sections. A more detailed survey, conducted in early March, showed no heave greater than 1/8 in.



Moderate heave (about 3/8 in.).

Severe heave (about 5/8 in.).





Typical light cracking.

Typical heavy cracking.

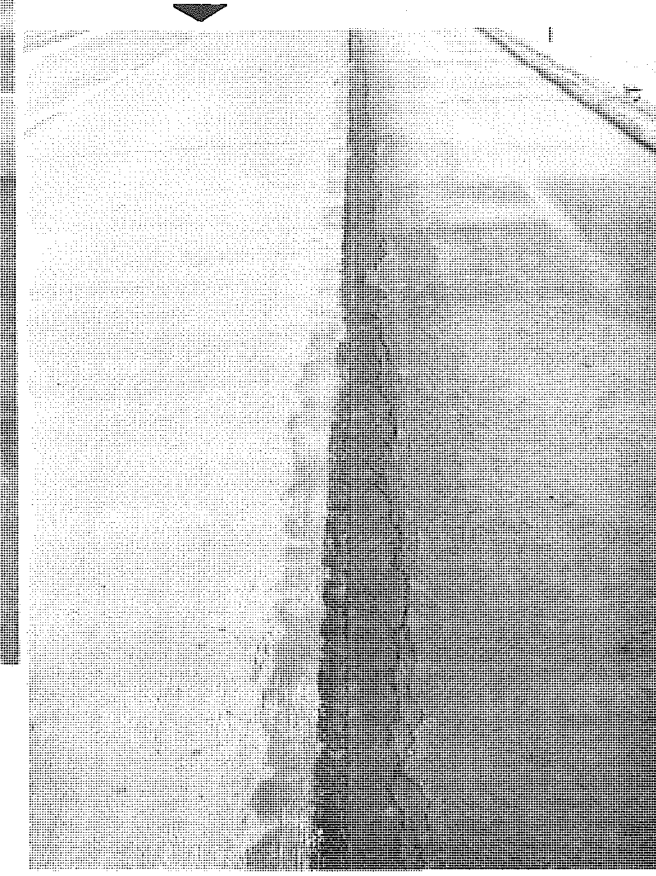


Figure 1. Typical heaved shoulders showing light cracking in moderately heaved areas; heavy cracking in severely heaved areas.

The 1962-63 freezing season was extremely cold, having a freezing index of 1196 degree days as indicated by the Pontiac State Hospital recording station located about 15 miles southwest of the subject section. The average freezing index for this area is about 650 degree days. Four brief near-thaw periods, none of which lasted more than three days, were the only breaks in the continuous freezing conditions existing from December 6, 1962 to March 1, 1963. On the basis of the freezing index, frost heave should have begun shortly after December 6 and subsided some time after March 1. It should be noted that although cumulative freezing conditions continued until March 22, cyclical freeze-thaw conditions existed from March 1 to March 22.

Construction records indicated no unusual weather conditions during construction of the shoulders. However, laying of the bituminous shoulder mat was delayed several times because of rainy weather.

Several causes for the shoulder heave and cracking have been suggested, the most logical of which seems to be frost action. If frost heave was responsible, there must be a reason why the shoulder heave was so much greater than the heave of the concrete pavement. The pavement cross-section of this area, Figure 2, shows two basic differences in the pavement and shoulder foundation soils. In some areas, the subgrade under the pavement was undercut one foot more than it was from under the shoulder. This, however, could not be a cause of the shoulder heave because the fill sections were found to heave as much as the cut sections. The second difference noted was that there is about 7-1/2 in. more base gravel under the shoulder than under the pavement. Since all other soil layers under pavement and shoulder consist of the same material and are the same thickness, it would appear that the 22A shoulder base gravel could be frost-susceptible. Otherwise, frost action could not be responsible for the shoulder heave.

FIELD RESEARCH: WINTER, 1963-64

A field study was planned to determine which, if any, of the soil foundation layer or layers caused the shoulder heave. It was thought that this could be accomplished by relating the depth of frost penetration to the height of shoulder heave. To do this, six test sites were randomly selected on the outside shoulder of the northbound lane representing both cut and fill sections. Each site was instrumented with a frost depth indicator of the type described by Carey and Andersland (1). Locations of points, whose surface elevations were to be measured, were painted on the pavement

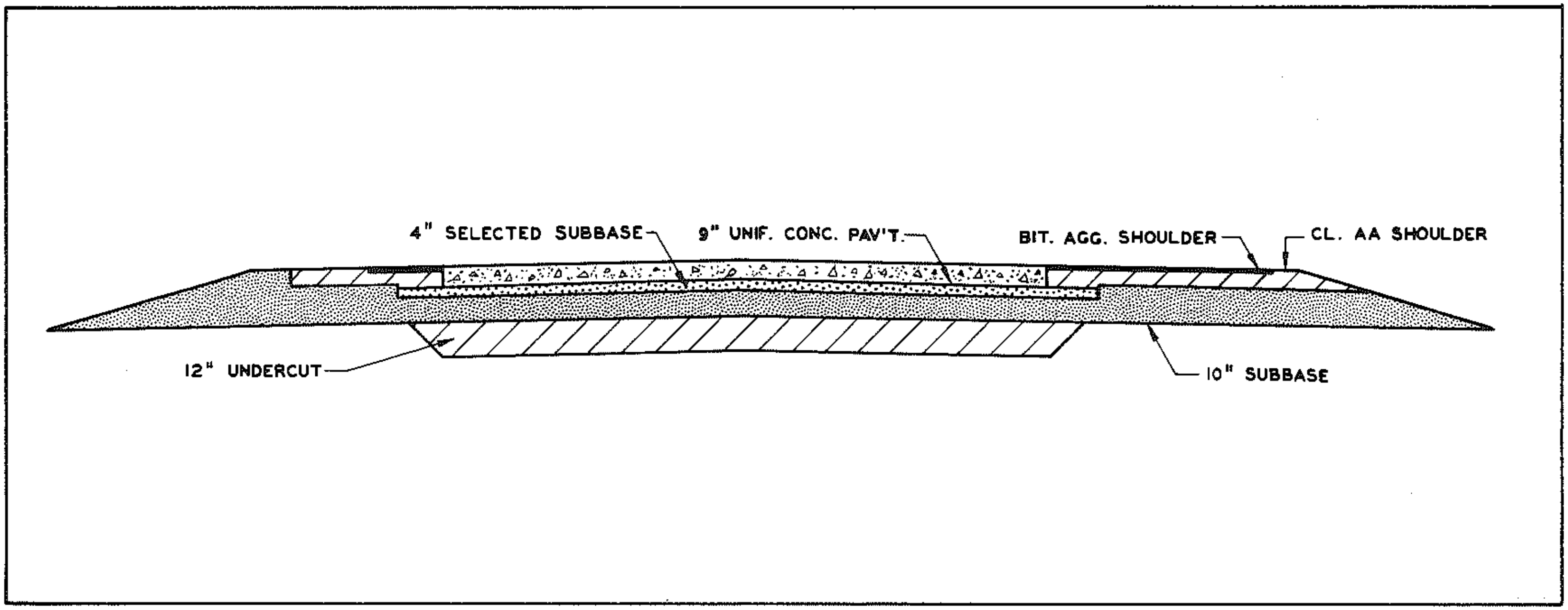


Figure 2. Typical pavement cross-section showing undercut area.

and shoulder edges. Both frost depth and surface elevations were measured and recorded weekly throughout the winter of 1963-64. Results of these measurements, summarized in Figures 3 through 9 show that:

1. Pavement and shoulders both heaved when there was no frost in the subgrade soils.

2. Heaving of both pavement and shoulders subsided during brief winter thaw periods.

3. The degree of heaving under the shoulders was slightly greater than under the pavement, but the difference was not as great as that observed during the first winter.

4. Shoulder surfaces settled below the pavement surfaces before the start of the second winter.

5. Shoulders did not heave above the pavement surface (except at Station 724+00) because shoulder settlement was greater than the differential heaving between the pavement and shoulder.

6. Station 724+00 heaved above the pavement surface because it was the only location where there had been no appreciable shoulder settlement.

On the basis of these results, it was concluded that the shoulders heaved more than the pavement because of some kind of frost action in the shoulder base gravel. This conclusion is based on the fact that heave occurred when the subgrade was not frozen so that the frost action must be taking place above the subgrade. The subsiding of the heave during short winter thaws indicates that the frost action must take place close to the pavement surface.

Because the heave occurs immediately on refreezing, and varies directly with the freezing temperature, it is concluded that the heave is caused by frost action in the base immediately below the shoulder surface.

FROST SUSCEPTIBILITY OF BASE GRAVELS

At the conclusion of the 1963-64 field study, it was apparent that the shoulder base gravel was the cause of some form of frost heave. However, no conclusions could be made as to how shoulder base gravel, normally considered frost-free, could be responsible for the heave. At this point,

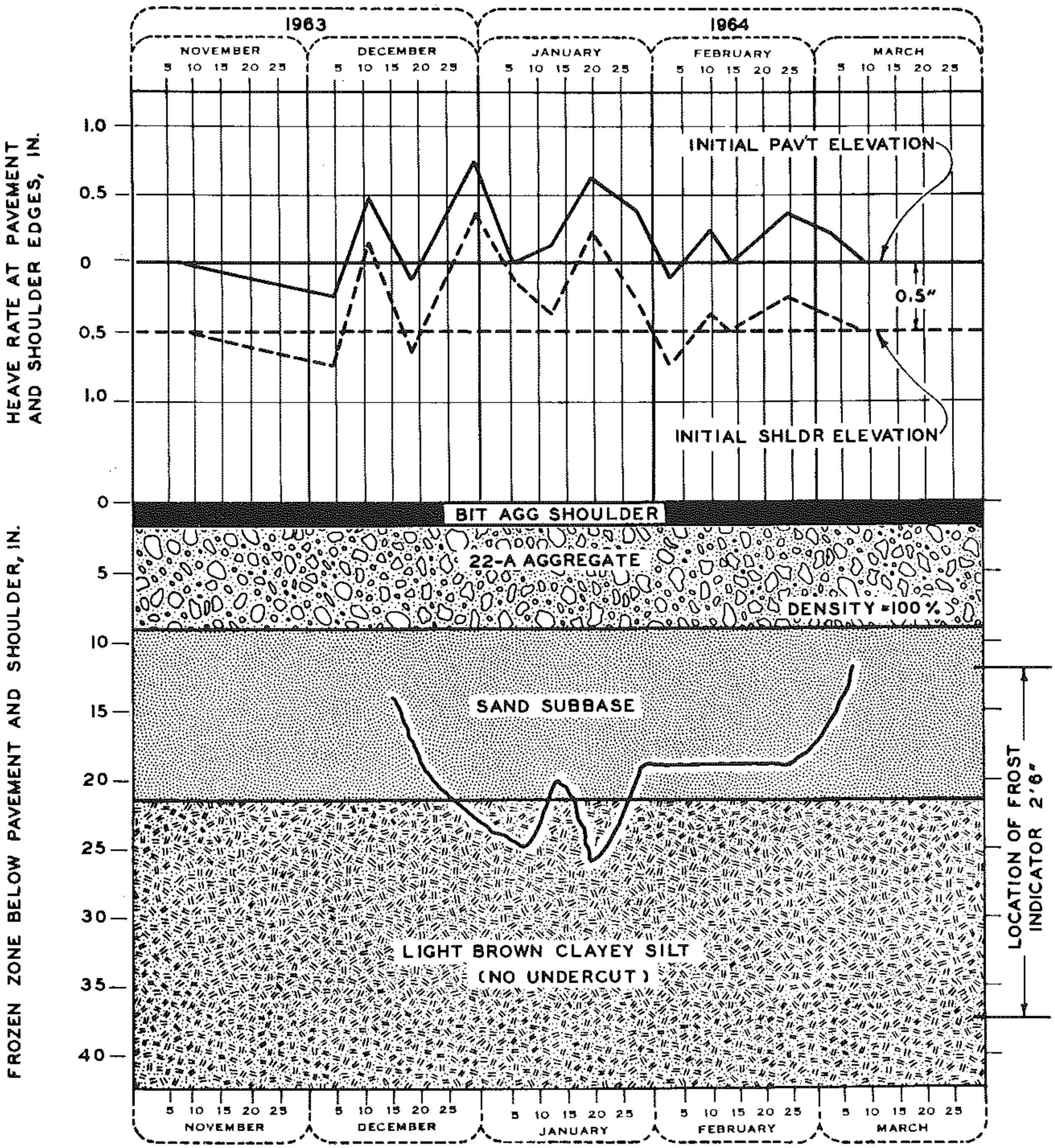


Figure 3. Relation of frost penetration to height of shoulder heave at Sta. 474+00.

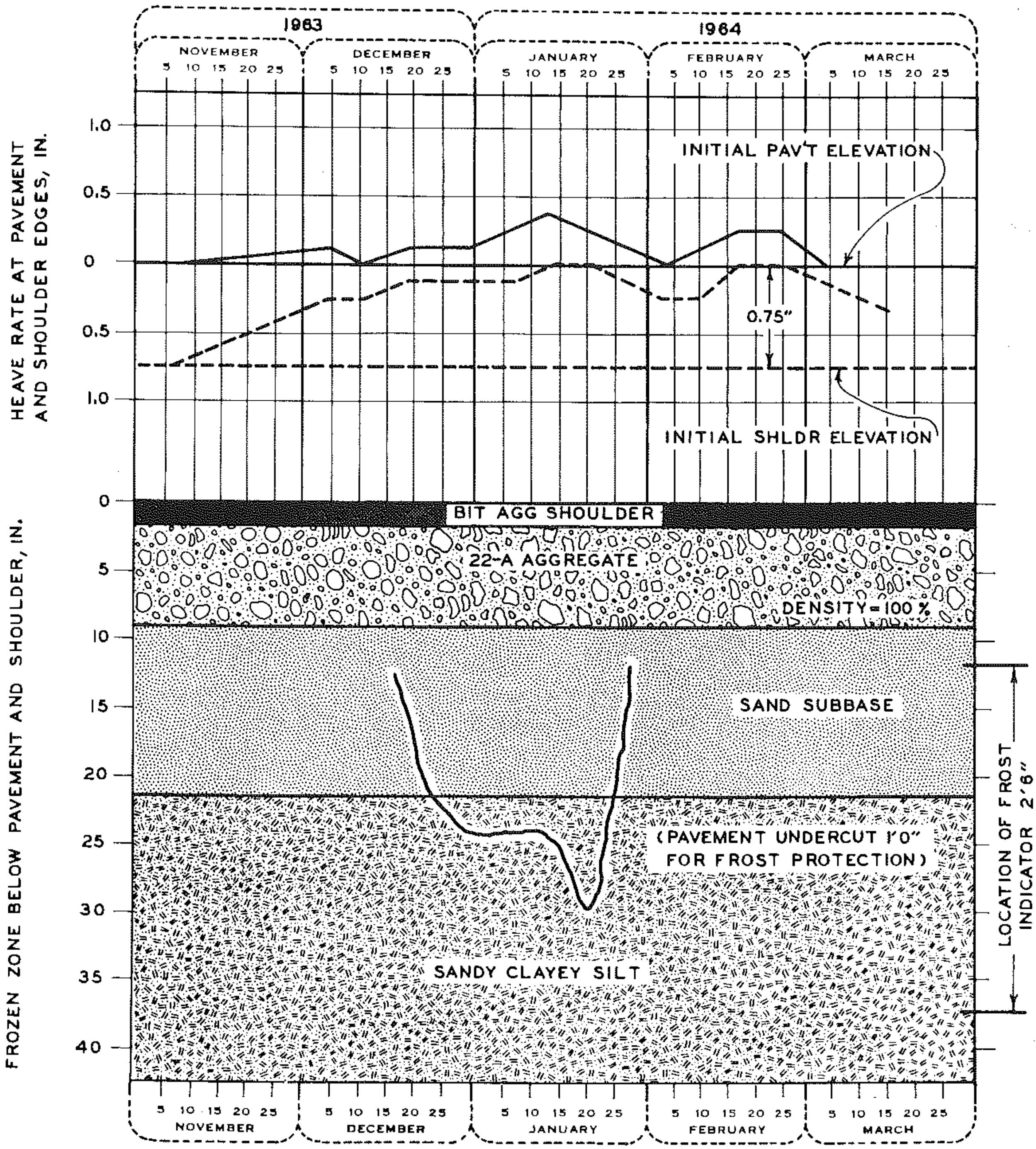


Figure 4. Relation of frost penetration to height of shoulder heave at Sta. 528+88.

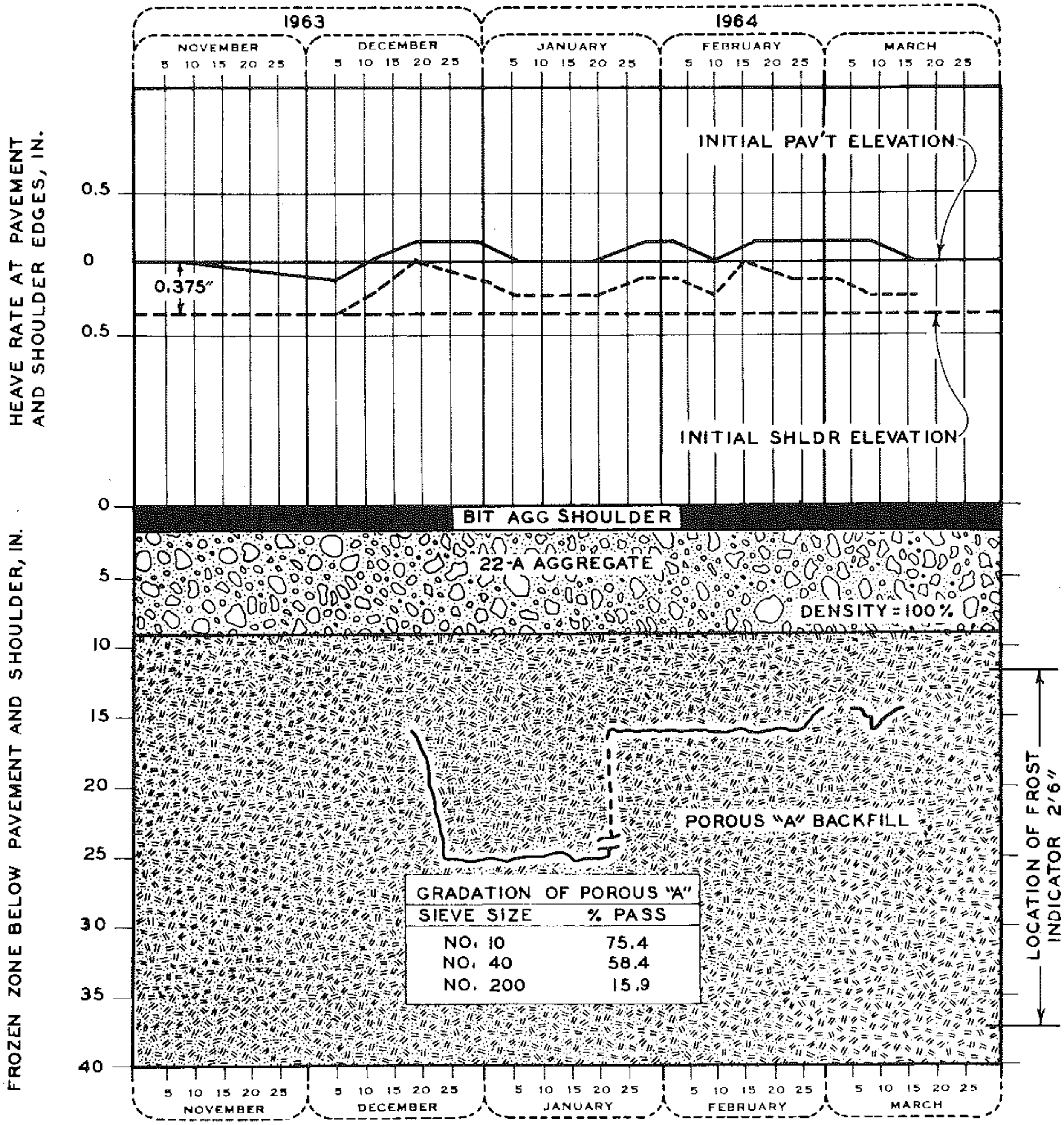


Figure 5. Relation of frost penetration to height of shoulder heave at Sta. 571+00.

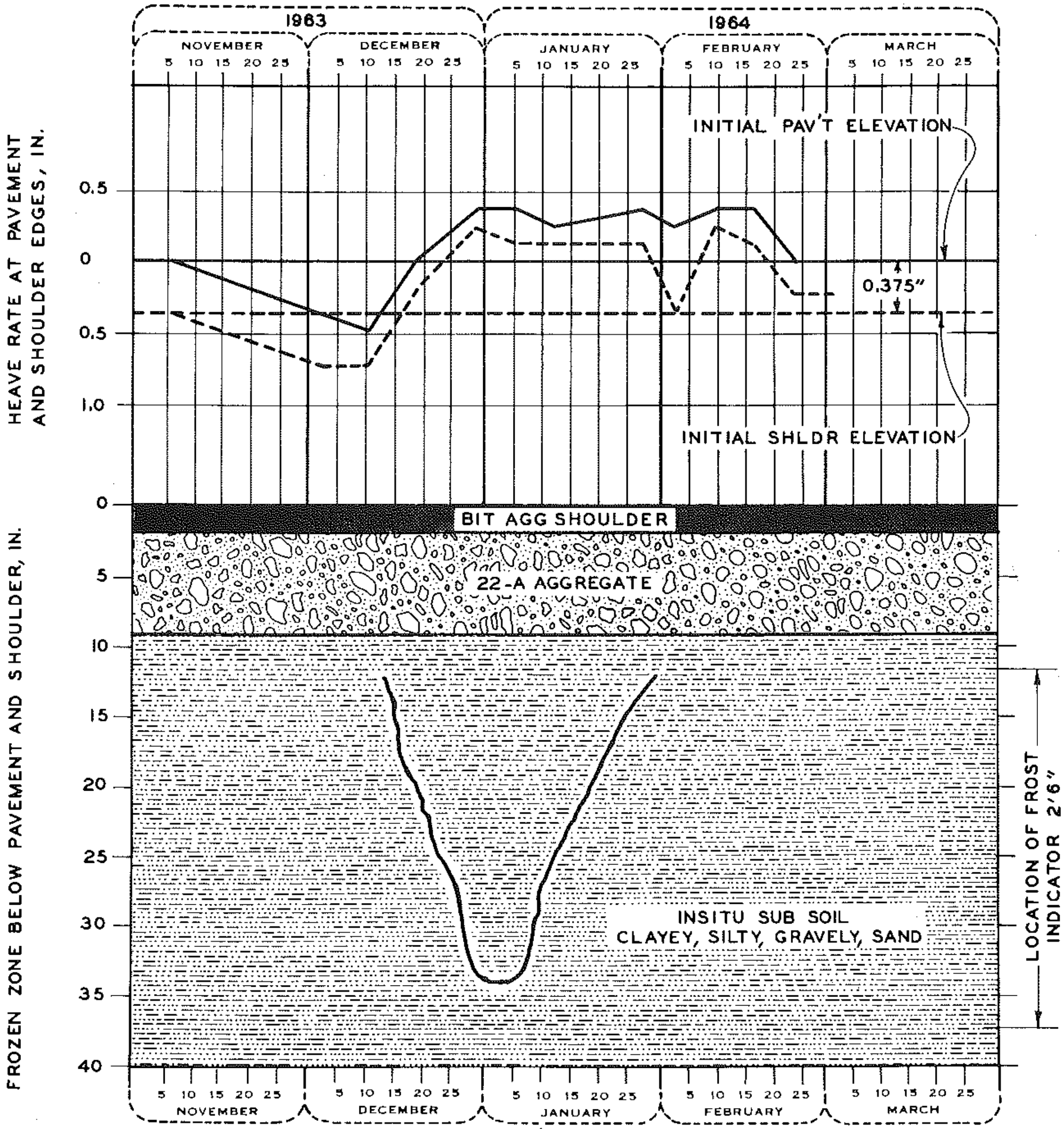


Figure 6. Relation of frost penetration to height of shoulder heave at Sta. 652+00.

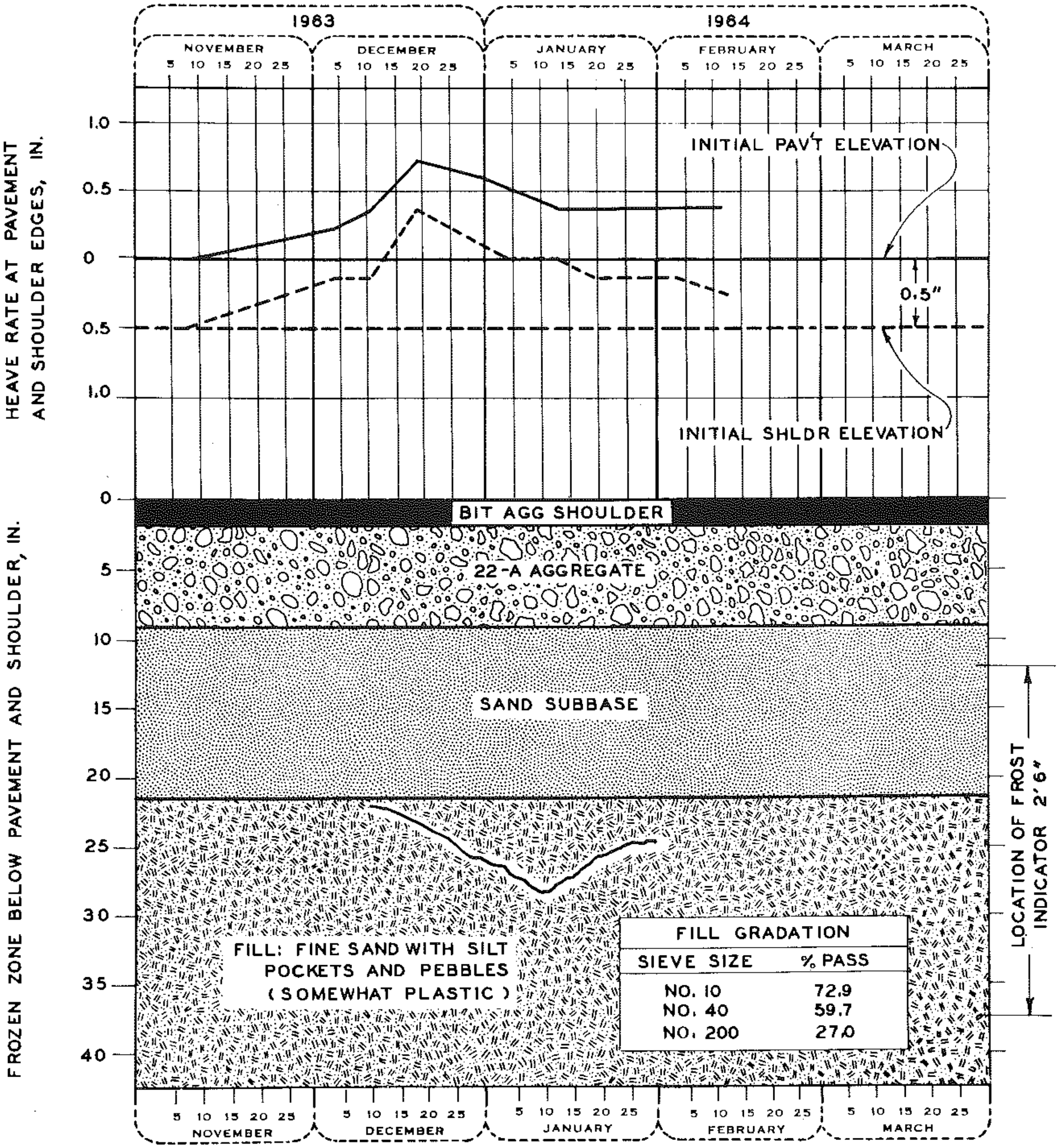


Figure 7. Relation of frost penetration to height of shoulder heave at Sta. 719+00.

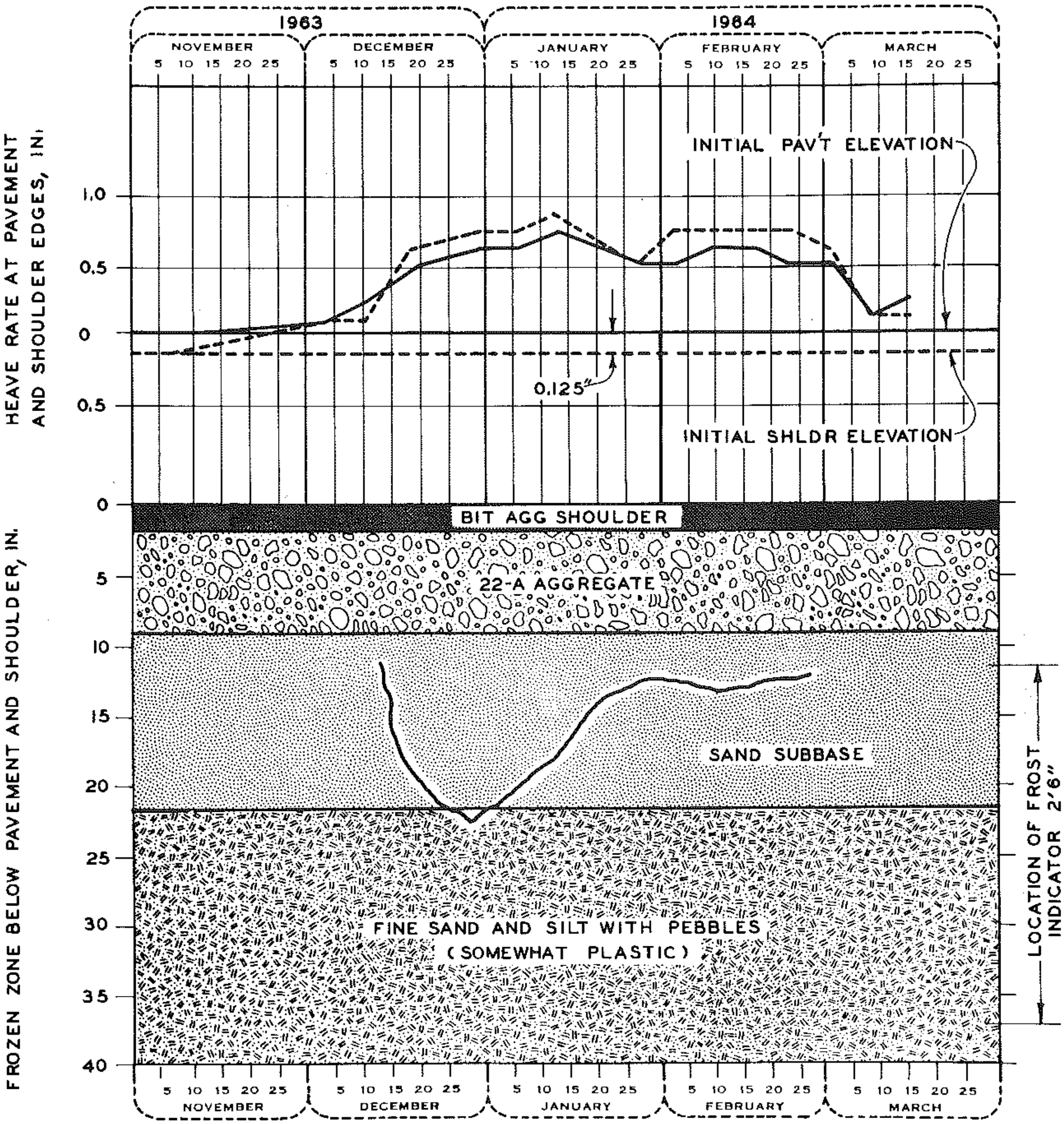


Figure 8. Relation of frost penetration to height of shoulder heave at Sta. 724+00.

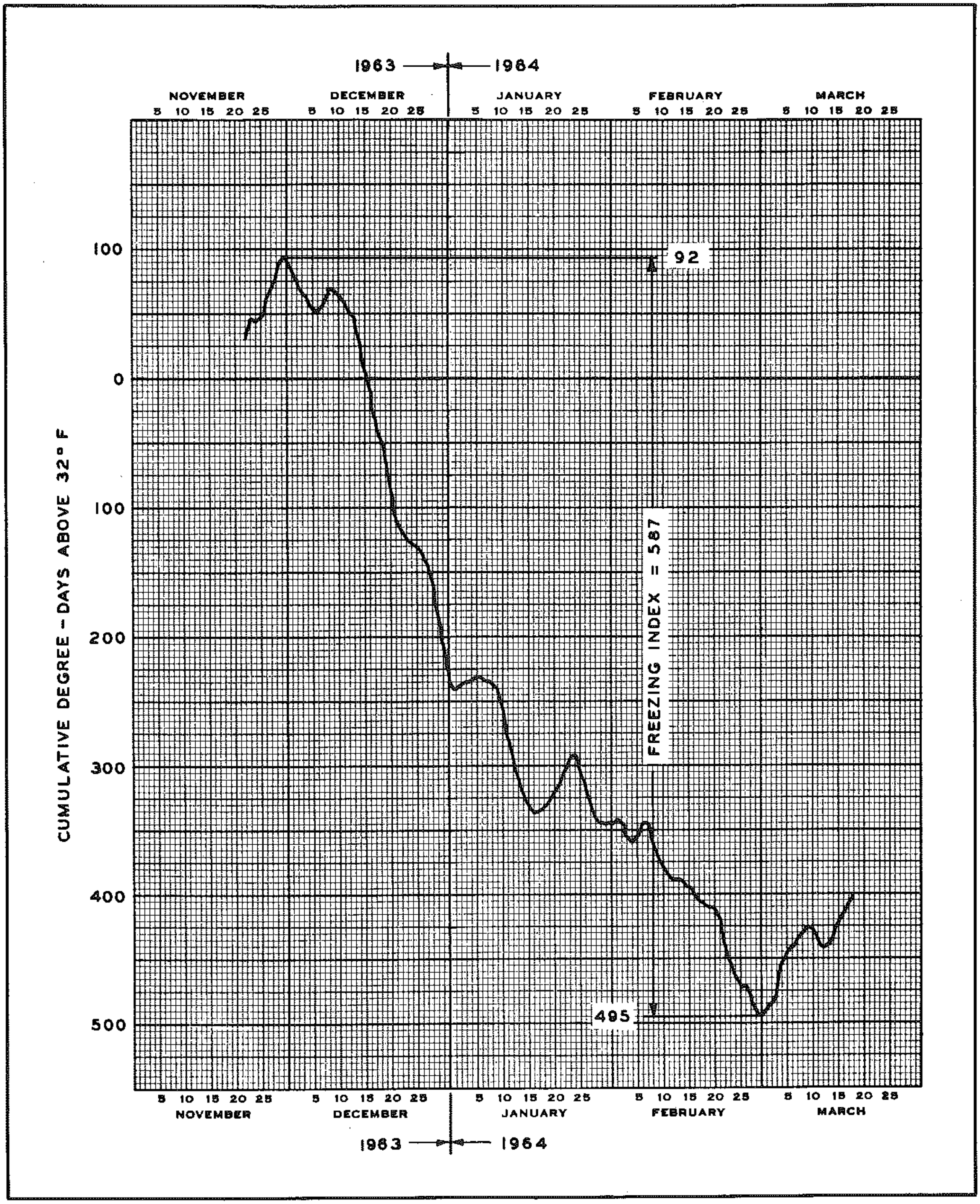


Figure 9. Freezing index of test area (32 degree base).

it was necessary to examine two different types of frost action to which granular materials canbe subject. The first, reported by the U. S. Corps of Army Engineers (2) is that densely graded gravels of high and low minus-200 material contents are frost susceptible in the same sense as silts. That is, densely graded gravels under ideal frost heave conditions have medium to high frost heave rates in terms of mm/day. This type of frost action requires a continuous supply of water. Gradation curves of medium and high frost susceptibility gravels compared with 22A gradation limits are shown in Figure 10.

A second cause of frost heave of granular materials, reported by Mullis (3), is that as the pore water of the soil freezes, it expands about 8.5 percent when changing from the liquid to the solid state. For heave to occur as a result of this phenomenon, the soil must be more than 91.5-percent saturated when frozen. The height of heave that results will vary directly with the percent of saturation at the time of freezing and with the thickness of the gravel layer. The likelihood of gravels being susceptible to this type of frost heave increases as their permeability coefficient decreases and as the amount of chloride or other water-retaining agents increases.

In considering these two forms of frost action, it was concluded that the latter--expansion of the pore water on freezing--was responsible for the shoulder heave since the subbase should have prevented water from being conducted to the shoulder base gravel, thus preventing the type of heave requiring a continuous supply of water. The remaining question was, how could the shoulder base gravel become over 91.5-percent saturated before the first winter's freeze? The answer began to appear while observing construction of shoulders on I 94 near Ann Arbor. It was noted that some base gravels lost density due to drying and no longer met density requirements after compaction. This problem was overcome by wetting and compacting the gravel base until it did meet density requirements, at which time it was immediately primed. Priming seals off the gravel pores, thus preventing further gravity drainage. The base gravel would, therefore, retain its general level of saturation until the pore water could be removed in the vapor phase or until an air passage--such as obtained by the formation of a crack in the shoulder mat--could be opened, permitting air to enter the pore spaces and allowing gravity drainage. Since first observing this practice in 1964, it has been found to be common for most gravel base construction. From these observations, it is concluded that water added during construction causes the gravel base of the shoulder to heave during the first winter. Heave occurring after the first winter results from the expansion of pore water entering the base through cracks

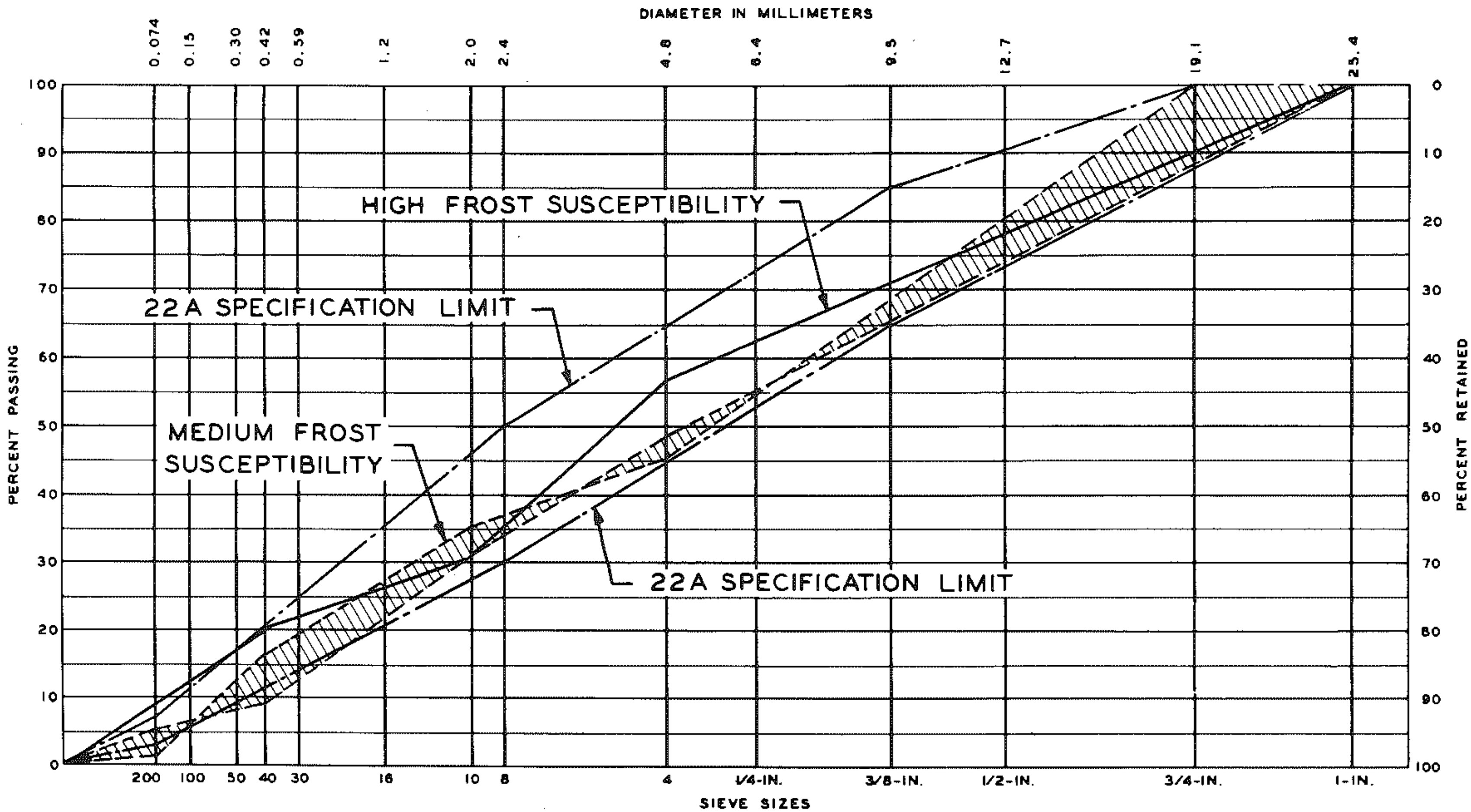


Figure 10. Comparison curves of frost susceptible gravels and 22A aggregate.

in the shoulder mat and through pavement joints. The amount of heave a shoulder experiences after the first winter depends upon the rate at which gravity water can drain out of the gravel, the amount of water infiltrating the gravel base, and the proximity of freezing weather.

CAUSES OF SHOULDER CRACKING

At first it was assumed that a strong bond between the pavement and shoulder, and development of frictional resistance as the shoulder heaved, prevented the shoulder edge from heaving as much as the rest of the shoulder, thus causing the mat to bend and crack at the point of maximum stress. However, in observing newly constructed shoulders on I 69 south of Marshall, it was found that shoulders on those sections not opened to traffic were heaved but not cracked. However, shoulders located in sections opened to traffic were heaved and cracked (Fig. 11). It should be noted that both the heaved shoulders and the heaved and cracked shoulders have sawed and sealed joints at the pavement-shoulder interface. This observation has led to the conclusion that shoulder cracking is not a direct result of heaving alone, but rather as a result of traffic riding the shoulder edges at a time when the shoulder base gravel is thawed but in a heaved position. Under these conditions, a wheel load on the shoulder edge forces the edge back down to the pavement surface level. Because this load and resulting movement occur so quickly, the shoulder mat cracks at the point of maximum stress. The severe bending caused by the frost heave apparently does not cause cracking because the bending stress develops over a relatively long period allowing time for the mat to stress-relieve itself.

LONG-TERM EFFECT OF HEAVE AND CRACKING ON SHOULDER PERFORMANCE

The long-term performance of the shoulders was studied through a series of photographs taken at randomly selected locations from February 1963 (the start of the project) through the Winter of 1967-68. The same locations were used for each series of observations. Two sets of photographs, Figures 12 and 13, show the following two distinctly different shoulder performance characteristics: (1) where the shoulder no longer heaves above the pavement surface, which includes almost all six miles of shoulder under study, the condition of the shoulders has not changed since February 1963; and (2) where the shoulder continues to heave above the pavement surface each winter (area around Station 724+00) the shoulder cracking has continued. No maintenance repairs, however, have been required for any

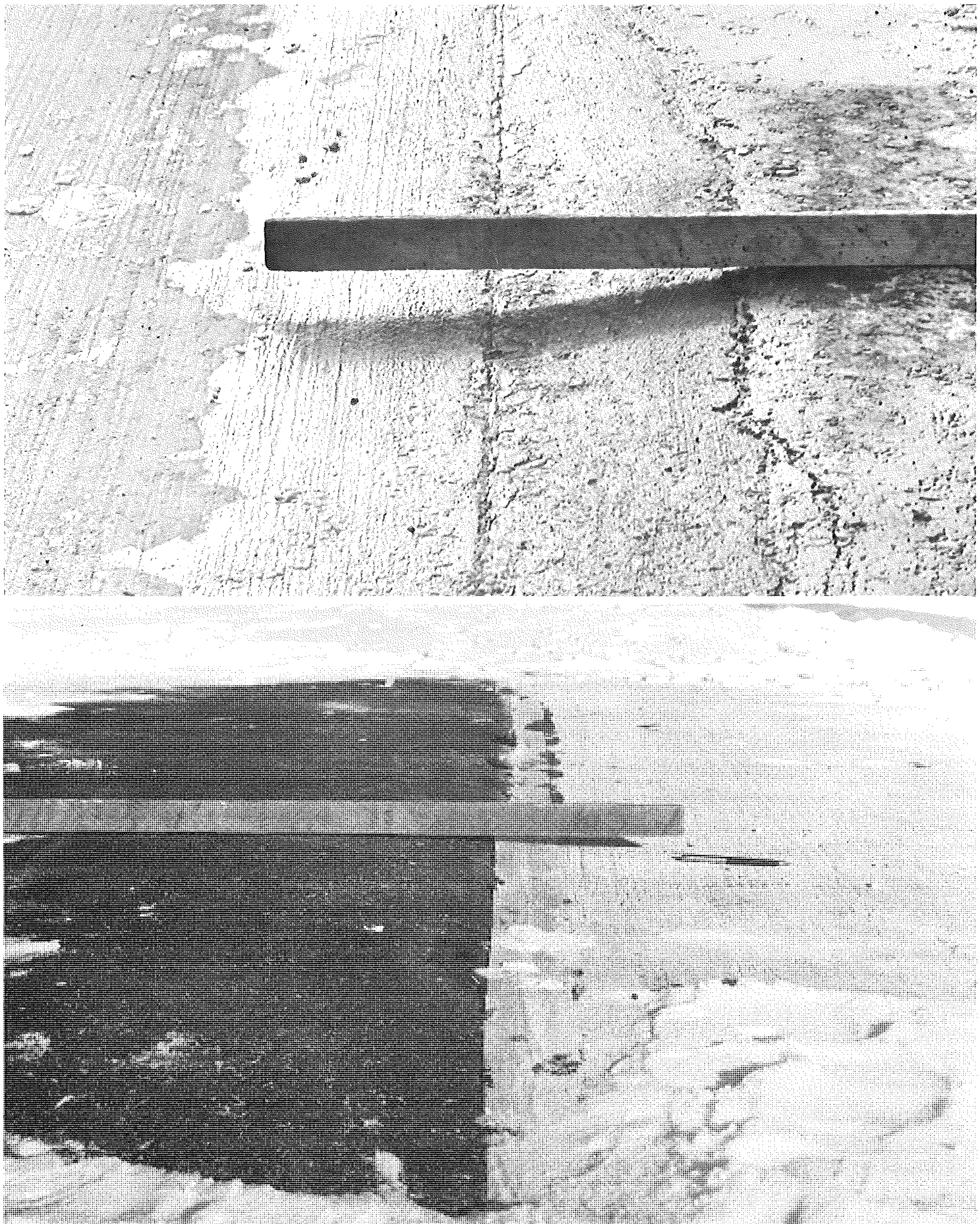


Figure 11. Condition of heaved shoulders where open to traffic (above) and not open to traffic (below).

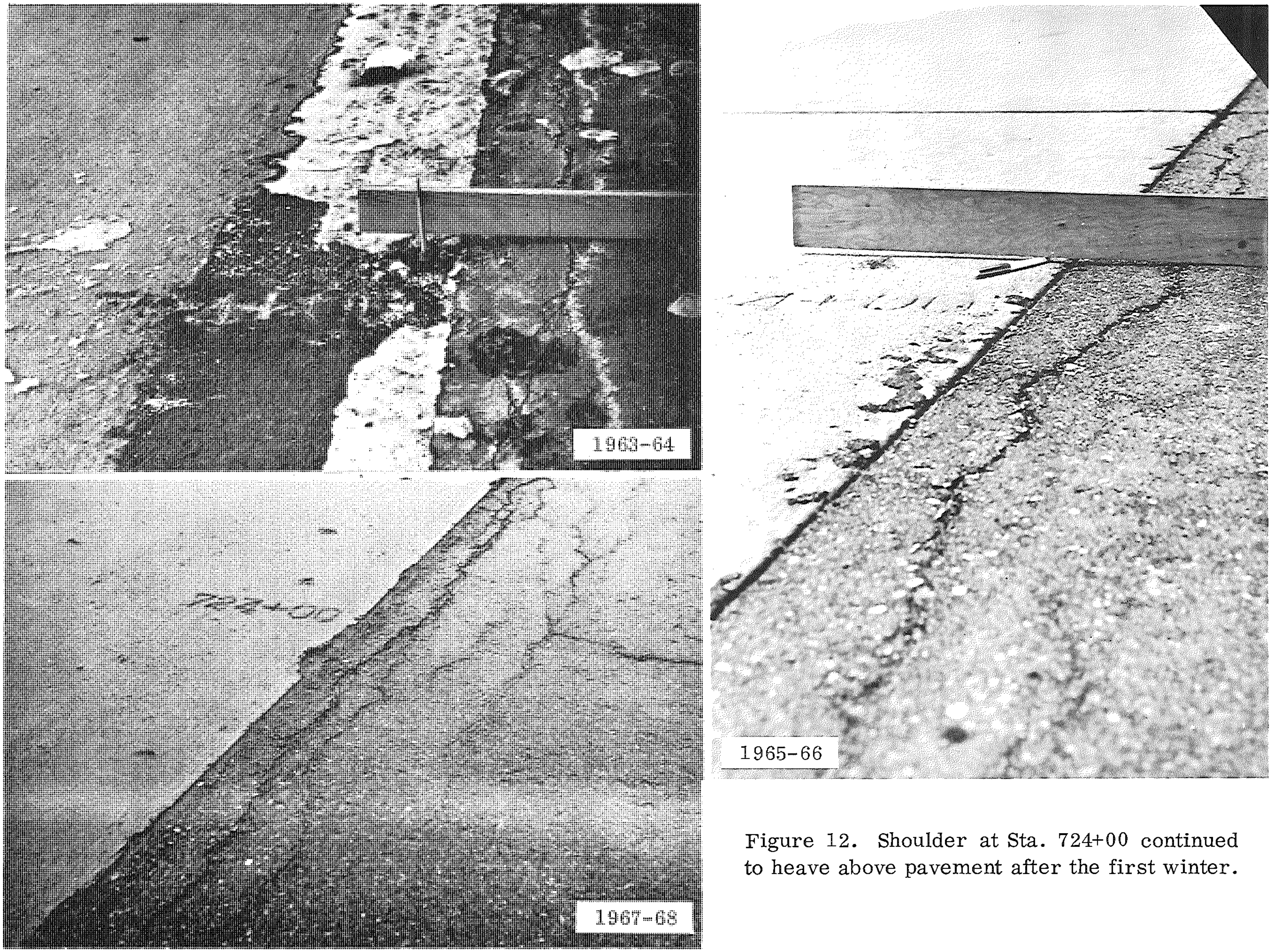
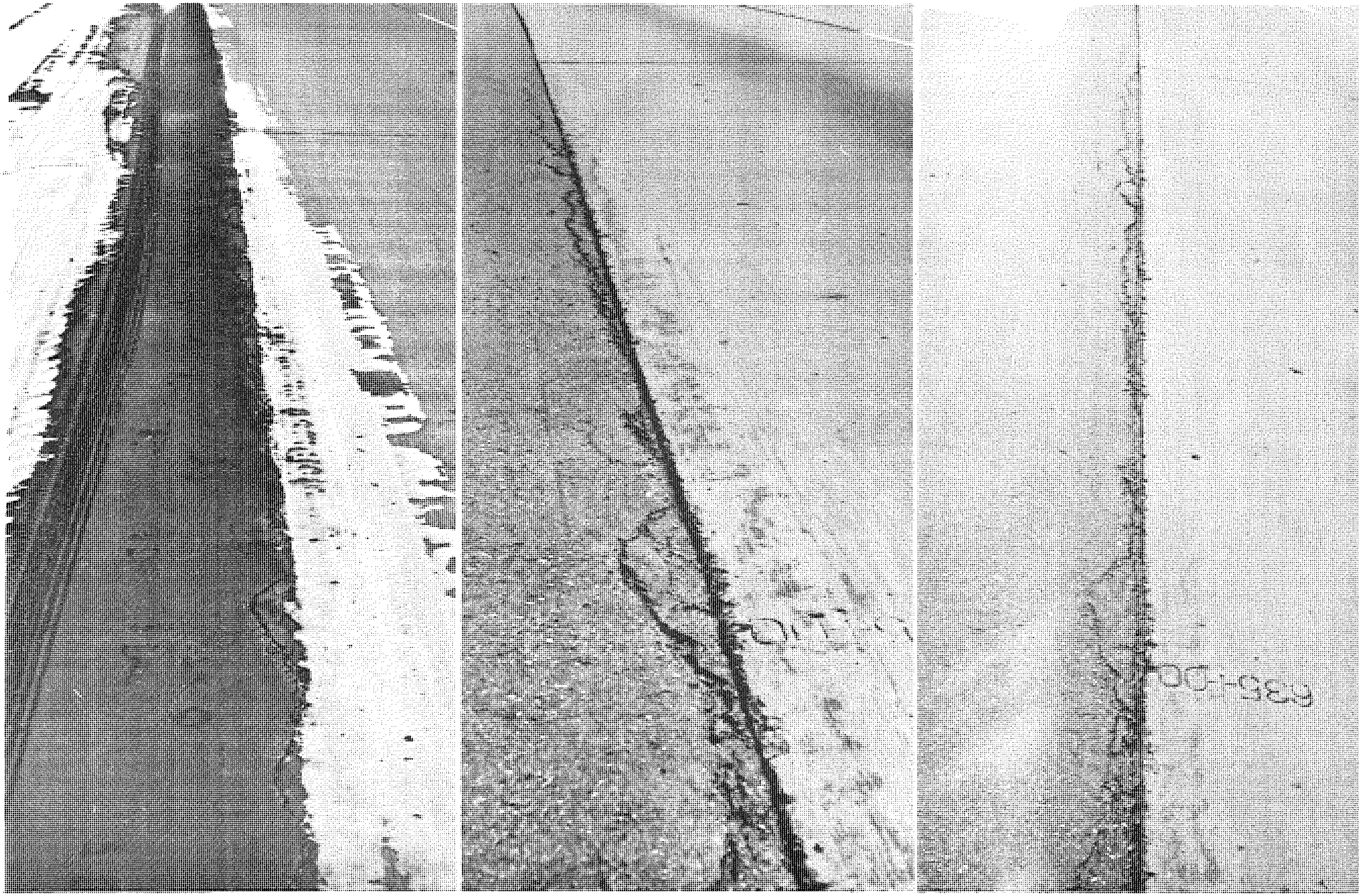


Figure 12. Shoulder at Sta. 724+00 continued to heave above pavement after the first winter.



1963-64 1965-66 1967-68

Figure 13. Typical shoulder (Sta. 635+00) no longer heaves above pavement.

portion of the shoulders under study. The significance of these findings is, that measures to prevent shoulder heave may or may not be required, depending upon whether the shoulders continue to heave above the pavement surface each winter.

The performance of the Pontiac shoulders indicates that, other than for proper control of moisture during construction, efforts to prevent heaving and cracking may not be justified. During their six years of service, the Pontiac cracked shoulders have performed as well as the uncracked shoulders except for the area where they did not settle below the pavement surface. This would indicate that good performance is the result of sufficient settlement to prevent heaving from ever extending above the pavement surface. To extend this concept throughout the State, it would be necessary to conduct a State-wide shoulder condition survey to determine whether the performance of the Pontiac shoulders is typical of that of shoulders throughout the State.

On the basis of this information it is concluded that no decision should be made at this time regarding steps to prevent shoulder heave and cracking. Instead, it is recommended that further study in the form of State-wide condition surveys of existing class AA shoulders be made to evaluate the effect of heave and cracking on general shoulder performance.

CONCLUSIONS

1. The Pontiac shoulder study indicates that heaving of the shoulders above the concrete pavement surface level resulted from expansion of pore water in the gravel base when freezing occurred at moisture contents above 91.5 percent of saturation.

2. Longitudinal cracking occurred as a result of wheel loadings on the edge of the shoulder at a time when the shoulder was heaved above the pavement surface and its base had thawed. No cracking occurred when the shoulder surface was not heaved above the pavement surface.

3. Shoulder heave during the first winter was the result of priming the base gravel before it had a chance to drain to less than 91.5 percent saturation. Priming prevents entrance of air into the voids and prevents any further gravity drainage of pore water. Shoulder heave after the first winter was caused by water which entered the base through the cracked shoulder surface.

During the Pontiac shoulder study, it was noted that the Construction Division has attempted to prevent shoulder heave and cracking of newly constructed class AA shoulders by sawing and sealing the joint at the pavement-shoulder interface. In view of the cause of the shoulder heave it is apparent that the joint in no way limits or prevents shoulder heave and cracking. It is, therefore, recommended that the practice of sawing these joints be discontinued.

4. There has been no basic change in the condition of the shoulders since the Winter of 1962-63. They have performed as well as uncracked shoulders, and have required no maintenance repair. This indicates that special construction measures to prevent shoulder heave and cracking may not be justified. However, because the performance of the Pontiac shoulders may not be representative of all class AA shoulders in the State, the results of this study alone cannot be used to determine the proper course of action to be taken on future class AA shoulder construction. A State-wide evaluation of the performance of class AA shoulders is required to provide the information needed to make this decision and it is recommended that this work be expedited.

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