Pavement Cracking

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Data are presented for some field and laboratory experiments that have been conducted periodically over 45 years and that involved cracking of pavements constructed over high-volume-change soils in Texas. The reports of others are coordinated with these findings. A graphic solution is presented for estimating the width of the granular base behind the curb necessary to prevent excessive dry-weather cracking. The same criteria are applicable to estimating the width of shoulders for roads and highways. The theory for this procedure is based on experience and the calculation of the values of potential vertical rise.

The purpose of this paper is to call attention to publications that pertain to pavement cracking and to offer some suggestions relative to design widths of base materials behind curbs. It is intended that use of the suggestions will materially reduce damage due to volume change of soils.

A completely analytical approach to the problem of street-pavement cracking is difficult for any one person. There are several reasons for this: (a) No one has enough experience with soils, paving materials, design, construction, and maintenance, and (b) sometimes pavement cracking is caused by one factor and develops to a point at which other factors appear to be the cause of the trouble. This is a most unfortunate circumstance because pavement cracks tell an interesting story about mistakes that we are not capable of comprehending. Perhaps research should be directed to studies of the life of pavement cracks from their first appearance until rehabilitation of pavement is necessary. One of the 10 most important research needs identified by the Workshop on Structural Design of Asphalt Concrete Pavement Systems in December 1970 contained the following statement (1):

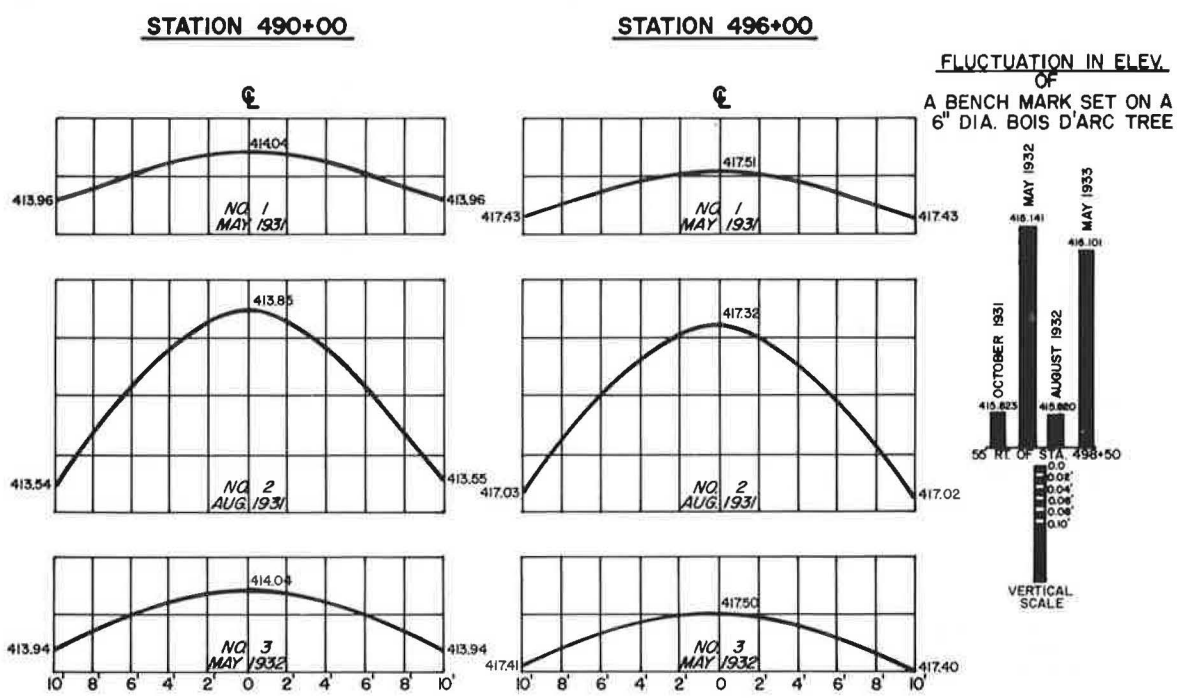
> The problem: Pavement failures are related to the development of cracks and/or excessive deformation due to repetitive loads or environmental conditions. The analysis and prediction of failure would be aided by the development of procedures for explaining the initiation, propagation, and accumulation of cracks.

Francis N. Hveem, former materials and research engineer for the California Division of Highways, issued a report in which he recognized the state of confusion by making the following statement (2): "Among those who use language for communication, engineers are not the most meticulous in their choice of terms, and it is at times difficult to clearly understand just what is being discussed."

Several years ago, I presented a paper (3) that listed the following as some of the causes for pavement cracking:

1. Excessive load deflections, including resilience deflections;
2. Subsidence, consolidation, slides, etc.;
3. Swell-shrink conditions of the subgrade;
4. Shrinkage cracking of the base and/or pavement caused by factors other than deflections or movements of the subgrade;
5. Frost and/or freeze-thaw action;
6. Brittleness of pavement due to aging and/or absence of traffic (includes the use of hard asphalts and their hardening due to oxidation--type of mix and/or construction procedures may contribute to oxidation); and

Figure 1. Street cross sections showing variations due to seasonal changes.



7. Thermal expansion and contraction.

These factors were discussed somewhat in detail in my earlier paper (3). From a maintenance standpoint, factors that involve slippage (lack of bond), reflection cracking (joints or old cracks coming through overlays), and tree-root damage are others that should be added to the above list. The foregoing shows why groups of engineers fail to agree as to the reasons for cracking or the proper remedial procedures to use. The mere fact that disagreement about pavement performance exists should not be embarrassing to anyone, but rather it should be considered a sign of interest that could lead to discussions pertinent to the solution of difficult paving problems.

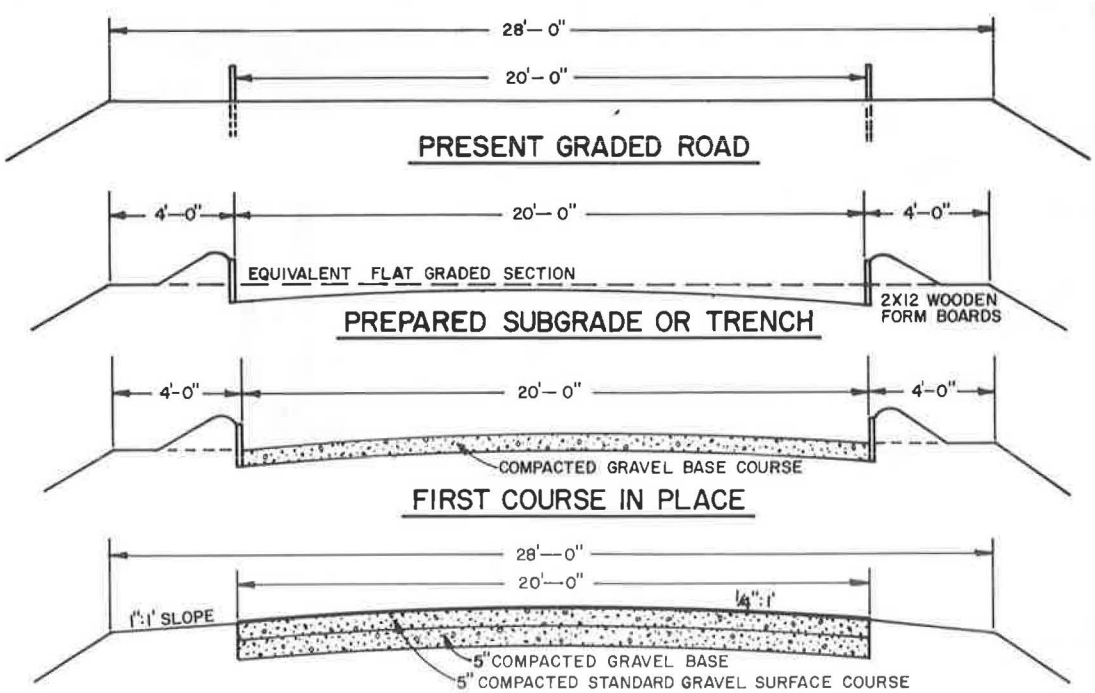
Figure 2. Cracks in pavement when soil fill and natural soil foundation had shrunk.

I believe that my experience as state highway soils and research engineer for more than 35 years and as a member of the Committee on Flexible Pavement Design of the Transportation Research Board for 30 years qualifies me to make further contributions on this subject. During my service in the early days, highways were constructed with, but usually without, shoulders. Some history relative to the transition from the trench to the feathered type of pavement cross sections over highly expansive soils should be of interest. Figures 1 through 9, from a report submitted to the Highway Research Board in 1938 (4) by the late Henry C. Porter, engineer of research, Texas State Highway Department, are used for illustrative purposes. Figure 1 is a graphic representation used by Porter to illustrate how the elevation of the ground surface of swelling clays fluctuates with seasonal changes. The data were obtained during the observation of the performance of a concrete pavement (probably a 9-6-9 section) that had grass shoulders and had been constructed in the early 1930s. Some observations are as follows:

1. Although the center-line elevations fluctuated, it should be noted that they moved far less than the edges did. The edges of the pavement fluctuated up and down about 2 in more than did the center line.
2. After seasonal changes for a period of one year, the pavement elevations returned to their original positions.
3. Note similar movements for the bench mark set on a tree of 6-in diameter (right-hand side of Figure 1).

The report does not tell how well or poorly this pavement performed, but cracking of such an unevenly supported pavement must have been inevitable when heavy loads were frequently applied by army trucks during World War II. Cracking of rigid pavements progresses differently from that of flexible pavements. Usually the tensile strength of narrow concrete slabs is sufficient to prevent cracking of un-

Figure 3. Typical cross section of plan for coarse-grained material to be placed in trench in clay soil.



evenly supported slabs until heavy loads are applied. During this time a few cracks may occur in a random fashion even at the center line. When wheel loads are applied to poorly supported slabs, cracking often begins halfway between the center line and the edge of the pavement (Figure 2) rather than in wheel paths as is the case for flexible pavements. The deterioration of concrete pavements laid over high-volume-change soils was reduced materially when construction of granular or stabilized shoulders was adopted as standard practice by the Texas Highway Department. This practice caused dry-weather shrinkage cracks of the supporting soil to occur farther out from the edges of the pavement.

Figures 3 through 9 from Porter's report illustrate the benefits of changing from the trench to feathered design sections for flexible pavements to be placed over high-volume-change soils. Figure 3 shows the design cross section of a crushed conglomerate base to be placed in a trench. Figures 4, 5, and 6 show the poor condition of the pavement after only five years of service. It cannot be substantiated that dry-weather shrinkage cracking aggravated the development of the distress shown, but it is most likely that it did. Figure 7 shows the cross-section design of a feathered-type crushed-stone section to be constructed on the same type of expansive subgrade that was beneath the trench-type section. Figures 8 and 9 show the condition of the pavement after three and six years, respectively, of heavy traffic. Note the absence of any dry-weather cracks in the pavement. Other photographs not shown here indicate that dry-weather cracks did occur in the shoulders but did not injure the pavement. Similar experiences noted on many other projects helped convince the Texas Highway Department that money spent for shoulders was a good investment, especially when the pavement was placed over high-volume-change soils. Additional benefits consist of increased lateral support and room for motorists who have car trouble to park off the pavement. Most other highway departments adopted the use of granular shoulders many years ago.

In recent years, the city of Austin has grown toward the east so as to require the construction of many streets over high-volume-change soils such as the Taylor Geological Formation and others. This fact, plus the extensive drying period in 1977, has caused new streets to begin cracking before they had carried any appreciable amount of traffic. Figure 10 shows shrinkage cracks that formed in 1977 only a few months after completion of paving. This street is a cul-de-sac and no homes had been constructed or lawns established at the time this photograph was taken. Figures 11 through 15 show the behavior of some older streets located on similar soils and with similar drainage conditions as those shown in Figure 10. Figures 11 and 12 show some alligator cracking, produced in part by heavy traffic loads on Montopolis Drive in east Austin. It is believed that dry-weather cracking could have occurred initially and that load cracking appeared after water had penetrated and softened the subgrade. Figure 12 shows separation of gutter from pavement, which indicates some shrinkage cracking. The pavement section for this street is the same as that shown in Figure 10 except that the base does not extend beyond the back of the curb.

Figures 13, 14, and 15 were taken on Vargas Street, which is parallel to and one block from the portion of Montopolis Drive shown in Figures 11 and 12. This street carries much less traffic than does Montopolis Drive. Figure 13 shows rather extensive cracking in the foreground, probably caused by volume changes of the subgrade for the regular curb and gutter paving section. The background of Figure 13 shows a road section that has granular shoulders that drain into ditches. Figure 14 shows a close-up of the background of Figure 13. It may be noted that few, if any, cracks appear in the roadway section. Figure 15 (same location as Figure 13) shows some separation of pavement from curb and gutter. Possibly this was reduced somewhat by maintenance of

Figure 4. Failures and patching along edges of pavement where crushed conglomerate base material was placed in trench cut in tight clay soil.

Figure 5. Rainwater in rut in shoulder soil.

Figure 6. Rainwater in traffic depression caused by movement of underlying clay soil previously overly wetted.

Figure 7. Typical cross section of crowned clay soil with coarse-grained material placed as blanket across crown.

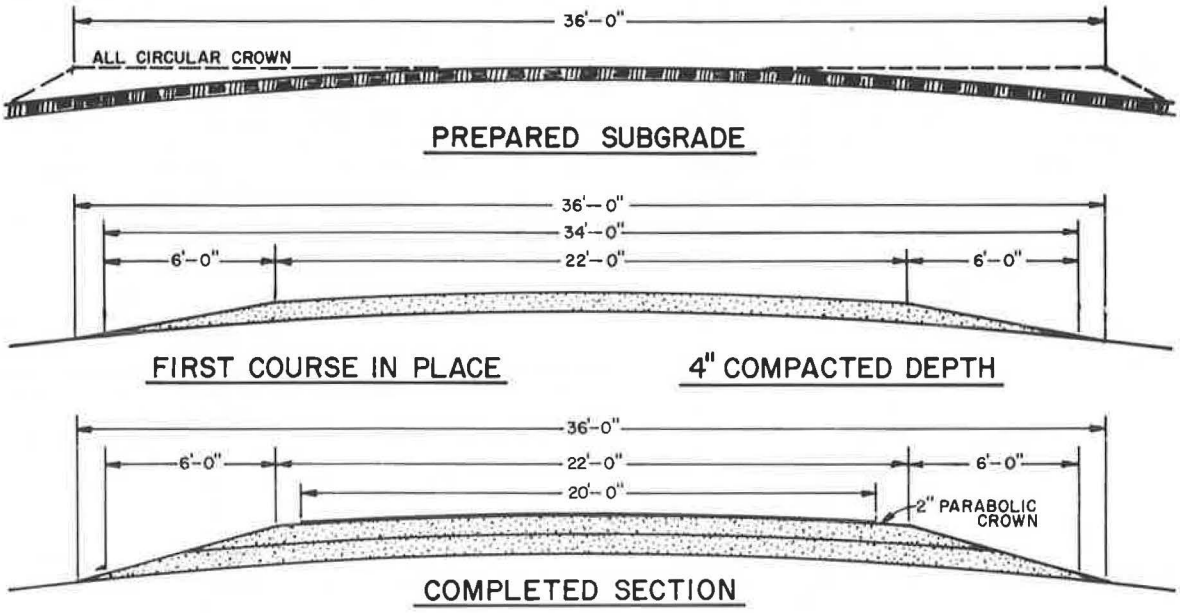


Figure 8. Riding surface after three years of heavy traffic where rain or gravity water moved from base material to ditches.

Figure 9. Same section of highway as in Figure 8 after six years.

Figure 10. Dry-weather shrinkage cracks on Galen Court, cul-de-sac street in southeast Austin.

Figure 11. Alligator cracking on Montopolis Drive in east Austin.

Figure 12. Alligator cracking and possibly some shrinkage cracking on Montopolis Drive.

Figure 13. Extensive cracking of pavement on Vargas Street (parallel to and one block from Montopolis Drive).

Figure 14. Closeup of background in Figure 13.

Figure 15. Left curb shown in Figure 13.

moisture under the sidewalk. The pavement section for this street is somewhat similar to that shown for Figure 10 except that the subgrade was not stabilized with lime and the flexible base was not extended beyond the back of the curb.

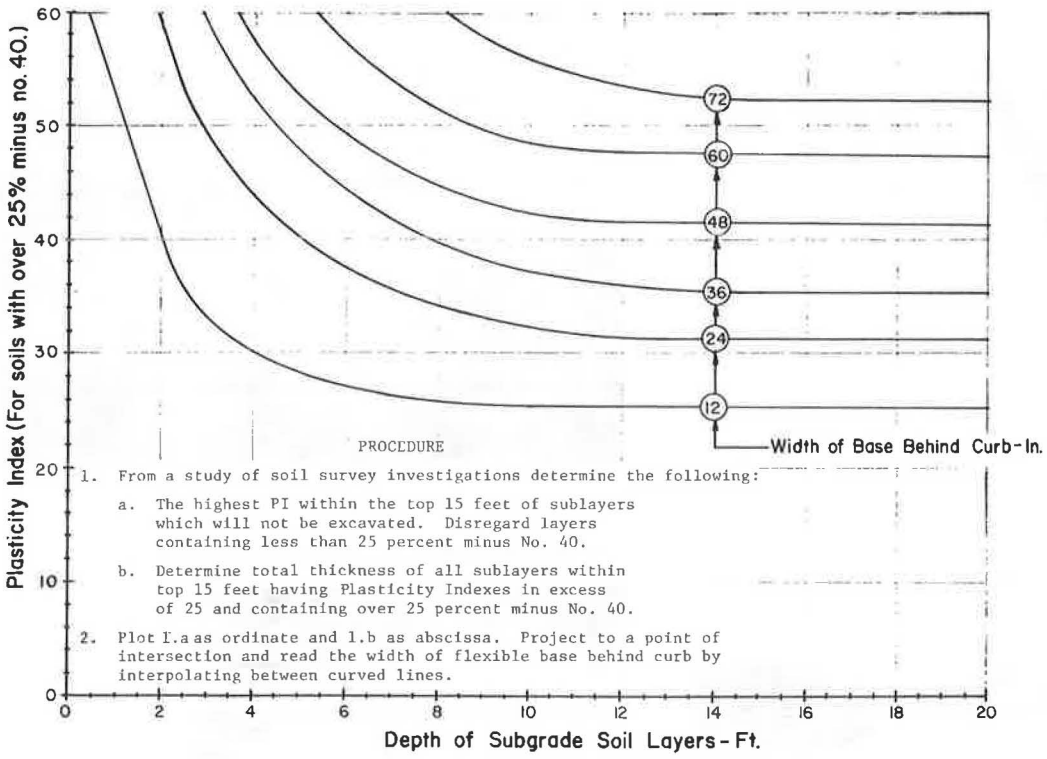
Figures 1 through 15 show the tremendous effect that change in the volume of the subgrade has on the life and performance of pavements. Others may have had experiences that differ from those presented here. It is possible that roads or streets constructed on identical soil conditions as those given in this paper, where preconstructed lawns are watered frequently, may not show any abnormal pavement distress. It is also possible that the use of the old "stand-up" curbs, which penetrated to a considerable depth into the subgrade, could have performed differently from that indicated in this paper. Sometimes cracking may not occur for several years or until a radical cycle in the weather has taken place.

In order to diminish the cracking of pavements constructed over subgrades of high-volume-change soil, I propose that a layer (4-6 in) of subbase or base be extended in back of the curb as indicated in Figure 16. The presence of well-watered lawns and existing sidewalks should be considered as exceptions in that the suggested widening shown in Figure 16 may not be necessary. The position and shape of the curves shown in Figure 16 are based somewhat on observations and considerably on the volume-change characteristics of the subgrade soil in terms of its potential-vertical-rise (PVR) computations (5). The following PVRs are shown:

Curve (in)	PVR (in)
24	0.5
36	1.0
48	1.5
60	2.0

Calculations of PVR values were based on the presence of a thick layer of subgrade soil with average subgrade moisture conditions. Calculations of PVR were made in accordance with the THD-test method Tex-125-E. There are probably other methods of protecting subgrade moisture, such as the use of plastic sheeting or asphalt- and/or tar-treated paper, but chances of their proper replacement after utility excavations are questionable. Vertical trenches filled with granular material may also serve the purpose, but when they interrupt the natural flow of moisture, results can be very unsatisfactory.

Figure 16. Width of base behind curb.



It is believed that use of the widening curves given in Figure 16 will materially reduce pavement cracking of streets in the city of Austin, but its use will not prevent cracking altogether. There will still be pavement cracking due to overloading, settling, and heaving.

Pertinent references have been used to show the complexity of the pavement-cracking problem. Fifteen figures have been presented that indicate pavement damage caused by subgrade-volume change. Some of these figures indicate how the use of granular shoulder materials reduced the severity of the problem. A new figure shows proposed widths of the base behind the curbs, which, if used, would reduce the severity of pavement cracking (Figure 16). If attention is not directed to this problem on highly plastic subgrades, extensive cracking will continue to increase until corrective maintenance is performed.

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