# Effect of Pavement Breaker Rolling on Crack Reflectance in Bituminous Overlays

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THIS STUDY was conducted on S.P. 6511-10 and S.P. 6512-01 (T.H. 212) located etween Bird Island and Stewart. The project was a typical widening and bituminous esurfacing project, in which the bituminous mixtures were placed directly on the old oncrete pavement.

The 1931 concrete pavement, like a number of the older pavements in Minnesota, ad warped panels, cracks, and faulted joints to the extent that the riding qualities had ecome somewhat objectionable, especially for trucks. Experience on other bituminous esurfacing projects indicated that many of these objectionable features will eventually e reflected in the bituminous overlay surface. Usually the joints and cracks in the d pavement cause cracks in the new surface within a very short time. Then longi-dinal cracks appear at the edges of the old pavement and many times at centerline; nd, ultimately, slab movements cause recurrence of general roughness. Maintenance osts go up, and the serviceability of the surface is reduced.

In the past, one solution has been to provide lifts of granular material over rough d pavements before placing the bituminous surface. The added thickness retarded e reflectance of cracks and roughness; and, when thick enough, lifts actually elimina-d most of the effects of the old pavement defects. However, this type of construc-on was costly because of the large quantities of granular materials needed and because the additional grade widening usually required. It also might be considered extrava-nt, in that the full potential of the old pavement as a base course was not used and be-use it consumed such large volumes of good base aggregate—an undesirable feature any case, but especially so in areas of gravel scarcity.

A different solution to the problem of crack and roughness reflection from old pave-ents; namely, pavement breaker rolling, was tried experimentally on this project. he experiment was limited to a 1½-mi section (Sta. 950 to 1025) located about 1 mi est of Stewart. This section was rolled with a 59-ton roller to break the old pave-ent, and was constructed to three different design sections. The variables were: -in. leveling course, 3-in. bituminous base and 6-in. bituminous base, as compared a 1½-in. leveling course on the rest of the project. These variables were coupled th a 1½-in. binder course, a 1½-in. wearing course and a standard widening section complete the reconstruction.

To assist in the study, four comparison sections were selected as follows: Sta. 0 to 130, one of the roughest portions of the old pavement; Sta. 800 to 810, an area typical roughness; Sta. 925 to 950, immediately adjacent to the beginning of the ex-rimental section; and Sta. 1025 to 1033, immediately adjacent to the end of the ex-rimental section. (The comparative value of this last section was partially lost be-use rolling was extended to Sta. 1029.)

This report includes the results of the evaluation studies made during construction 1959 and subsequently to April 1960, a period of six months after completion of the tuminous surfacing. Information is included on such items as the design of the old vement, the immediate effects of the rolling on the old pavement, typical sections, sts of the reconstruction and the performance of the project to date.

## SUMMARY OF FINDINGS

The project is not old enough to draw positive conclusions regarding the effects of e pavement breaker rolling and the performance of the various design sections. owever, a number of interesting facts and observations are disclosed by the study to date. These findings, discussed in detail in this paper, are summarized as follows

Pavement Breaker Rolling

1. Contact tire pressure was 83.5 psi based on the gross contact area of the 18.00 x 25, 24-ply tires.
2. Vertical slab movements at joints were variable, ranging from $\frac{1}{8}$ to $\frac{1}{2}$ in. and averaging about $\frac{1}{4}$ to $\frac{3}{8}$ in.
3. Ten passes of the 59-ton roller provided optimum cracking on this project. An additional ten passes increased the number of cracks only slightly.
4. After rolling, all cracks (new plus old) averaged 16.4 per station in each lane. When the joints are included with the cracks, the total openings averaged 19.1 per station in each lane—an average spacing of 5.2 ft.
5. Cracking in 20-ft panels was comparable to cracking in 40-ft panels; however, the 20-ft panels had 4.9 more openings per station, mostly on account of more joints.
6. Pavement breaker rolling caused only minor permanent changes in the profile of the concrete pavement. Generally, the pavement was permanently depressed from 0.01 to 0.05 ft over most of its length. Some portions of the pavement were unchange some were raised slightly and some were depressed greater amounts, up to 0.13 ft (about $1\frac{1}{2}$ in.).
7. Pavement breaker rolling caused only a slight decrease in roughness in one lan (160 to 154 in. per mile) and no change in the other lane (154 in. per mile) as measur by the road roughness recorder.
8. Pavement breaker rolling cost $271.44 per mile for 10 passes of the roller ov the 20-ft pavement.

Typical Sections and Costs

9. Resurfacing sections included a $1\frac{1}{2}$-in. wearing course, a $1\frac{1}{2}$-in. binder cours and widening plus the following variables, all at the total indicated costs per mile:

| | |
|---|---|
| $1\frac{1}{2}$-in. leveling course (std. sec. for project) | $ 38,340 |
| 2-in. leveling course (sta. 1000 to 1025) | 39,908 |
| 3-in. bituminous base (sta. 950 to 975) | 40,427 |
| 6-in. bituminous base (sta. 975 to 1000) | 45,001 |

The latter three sections include pavement breaker rolling.

Performance

10. Sections subjected to pavement breaker rolling have had less cracking in the bituminous surface to date than unrolled sections. Where rolled, 5 to 42 percent of the transverse joints and two cracks were reflected as compared to 48 to 100 percent of the transverse joints and one crack reflected where not rolled.
11. Reflectance cracking occurred over the 1-in. expansion joints sooner than ove contraction joints on both the rolled and unrolled sections.
12. No cracking over the edge of the old pavement has occurred on the rolled sec- tions, whereas from 2 ft to 364 ft has occurred on unrolled comparison sections.
13. Cracking over the centerline of the old pavement has occurred on all sections except the 6-in. bituminous base section (rolled) which showed very little cracking of any kind. Some of this centerline cracking may have been associated with frost actio
14. Frost heaving occurred on all the sections, with the maximum measured heav being 2.4 in.
15. Differential heaving, though slight in many cases, was noticeable at a conside able number of cracks. Where every joint was cracked, such as between Sta. 120 an Sta. 130, the heaving at cracks caused a slight warped panel effect.
16. Roughness on the rolled sections was 50 in. per mile after construction and 56 in. per mile in April 1960. Project averages were 56 and 60 in. per mile at these same times.
17. No rutting or displacement of the bituminous mixtures in the wheel tracks has occurred on this project to date.

18. It appears from all the data, that pavement breaker rolling has had a beneficial ffect in retarding reflectance cracking during the first six-months performance of this roject.

## OLD PAVEMENT

The old concrete pavement was constructed in 1931. The slab was 20 ft wide, 9 in. iick at the edges and tapered to 7 in. thick 4 ft from the edges, a typical 9-7-9 section. 'anels were generally 40 ft 4 in. long, with every other joint being an expansion joint. 'he 1-in. expansion joints had 3/4-in. dowels with steel sockets on one end. The dum-iy-type contraction joints had 3/4-in. dowels which were greased on one end. Slab einforcement consisted of two 5/8-in. bars along each edge and one along each side of enterline, one 5/8-in. bar along each side of the joints, and 1/2-in. by 4-ft tie bars cross centerline. The pavement design is shown in more detail in Figure 1.

In minor portions of the project, the pavement was modified to 20-ft panels. Some these shorter panels occur in the experimental and comparison sections.

Just prior to construction, in April of 1959, the road roughness recorder showed an verage roughness of 138 in. per mile, with 163 in. being the roughest mile recorded id 121 in. being the smoothest mile recorded. This roughness, combined with the arped panels, caused very unsatisfactory riding qualities on a considerable length of e project.

## PAVEMENT BREAKER ROLLING

The pavement breaker rolling was performed July 23 and 24, 1959 on the 1 1/2-mi perimental section near the east end of this project, Sta. 950 to Sta. 1025. The ecial Provisions required that each 10-ft lane be covered by 10 passes of a 59-ton ller having four wheels on one transverse axle and tire air pressure of 90 psi. These ovisions were followed, except that 20 passes of the roller were made in the west-und lane between Sta. 949 and 964+13, and with the further exception that the rolling as extended beyond Sta. 1025 to an entrance at Sta. 1029 to facilitate turning the roller.

ire Contact Pressure

The roller was a Bros Compactor loaded to 118,000 lb (59 tons) and fitted with four,

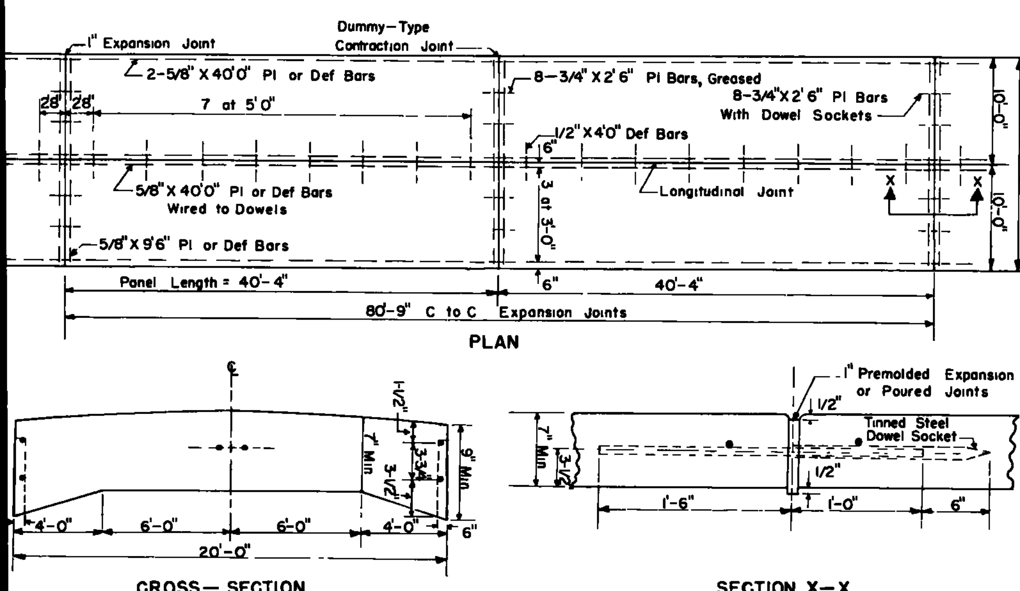


Figure 1. Concrete pavement details.

18.00 x 25, 24-ply, diamond tread tires inflated to 90-psi air pressure. The rolling width, measured from outside to outside of tire contact, was 8 ft 8 in. An Internationa TD 24 tractor was used to pull the roller and did an excellent job of controlling it at all times. The roller-tractor combination is shown in Figure 2.

To measure the tire contact areas, a length of 30-in. wide paper was placed across a clean portion of pavement slab, and the roller was pulled forward until the tires wer on the paper. Then using pressurized cans, paint was sprayed completely around the contact periphery of each tire, being sure to cover the tire and the paper at all places. When the roller was moved ahead, the four contact areas were outlined on the paper a shown in Figure 3. Later, these were measured as follows:

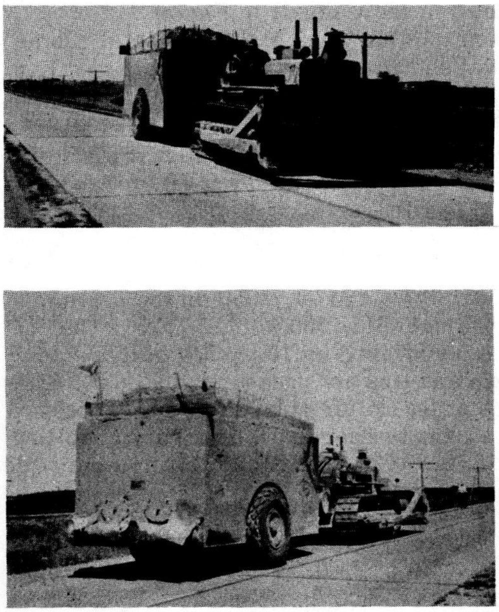

Figure 2. Fifty-nine-ton pavement breaker roller.

| Tire | Gross Contact Area (sq in.) |
|---|---|
| Left outside | 354.3 |
| Left inside | 344.7 |
| Right inside | 384.8[a] |
| Right outside | 329.3[b] |
| Total | 1,413.1 sq in. |

[a]Noticeably larger. [b]Noticeably smaller.

Using this total area the average conta pressure was computed as 83.5 psi.

## Vertical Slab Movements

From visual observations, it was note that there was considerable variation in slab movement at joints from panel to panel and place to place. It seemed that the slab ends at expansion joints moved more when the roller passed than they di at contraction joints. This seemed logic considering that some aggregate interloc was still effective in resisting vertical movement at the contraction joints. How ever, the few actual measurements taken do not bear this out.

Four joints were checked for vertical movement as follows:

| | | Vertical Movement (in ft) | | | |
|---|---|---|---|---|---|
| | | At Centerline | | At Left Edge | |
| Station | Joint Type | Panel 1 | Panel 2 | Panel 1 | Panel 2 |
| 959+00 | Expansion | 0.015 | 0.030 | 0.025 | 0.030 |
| 959+41 | Contraction | 0.010 | 0.030 | 0.025 | 0.025 |
| 959+82 | Expansion | 0.030 | 0.015 | 0.040 | 0.020 |
| 960+22 | Contraction | 0.020 | 0.025 | 0.025 | 0.010 |

These measurements seem typical of the movements observed—varying from abou $1/8$ to $1/2$ in. with most approximately $1/4$ to $3/8$ in. However, the measured movements were not significantly larger at the expansion joints.

## Cracking

Visual cracking of the pavement slab did not occur until after several passes of th


Figure 3. Tire contact areas, 59-ton pavement breaker roller.

oller, and cracks became more visible as rolling continued. When they first occurred, racks were extremely fine and difficult to observe. As rolling progressed, the top dges spalled slightly, and the cracks became more visible. It was also observed that raffic caused a similar spalling of the cracks. Much of this spalling was very minute, eing just enough to show whitish dots along the path of the crack, although a few spalls ltimately were an inch or more in diameter. Practically all cracks, new and old, vere transverse cracks with the exception of some diagonal cracks in frost heave areas.

Prior to rolling, there were 368 cracks in the left (W.B.) lane and 339 cracks in ne right (E.B.) lane. Rolling caused 933 and 935 new cracks in the respective lanes. Vhen 420 half-width joints were added to the cracks, there were a total of 2,995 openngs in the two lanes.

Converting these figures to cracks or openings per station, the following comparisons an be made:

| | Left | Right | Both Lanes |
|---|---|---|---|
| ld cracks per Sta. | 4.7 | 4.3 | 9.0 |
| ew cracks per Sta. | 11.9 | 11.9 | 23.8 |
| otal cracks per Sta. | 16.6 | 16.3 | 32.9 |
| otal openings per Sta. (including joints) | 19.3 | 18.9 | 38.2 |
| verage spacing between cracks and joints (ft) | 5.2 | 5.3 | - |

Between Sta. 949+00 and Sta. 964+13, there were 10 passes of the roller in the ight lane and 20 passes of the roller in the left lane. The difference in cracking was s follows:

| | Left | Right |
|---|---|---|
| | 20 Passes | 10 Passes |
| umber of old cracks | 77 | 67 |
| umber of new cracks | 207 | 184 |
| otal No. of cracks | 284 | 251 |
| otal No. of openings (including joints) | 322 | 289 |
| ld cracks per Sta. | 5.1 | 4.4 |
| ew cracks per Sta. | 13.7 | 12.2 |
| otal cracks per Sta. | 18.8 | 16.6 |
| otal openings per Sta. (including joints) | 21.3 | 19.1 |

The 20 passes on the left lane caused only 23 more new cracks than the 10 passes on the right lane. This small increase in cracking indicates that, for this project, 10 passes of the roller were sufficient to develop the optimum amount of cracking.

On this project, the standard joint spacing was 40 ft. However, there was a 580-ft section of 20-ft panels in the rolled area. Therefore, a comparison of cracking can b made between these two joint spacings as follows:

| | Cracks in Both Lanes | |
|---|---|---|
| | 20-ft Panels | 40-ft Panel |
| Old cracks per Sta. | 10.9 | 8.9 |
| New cracks per Sta. | 22.2 | 24.0 |
| Total cracks per Sta. | 33.1 | 32.9 |
| Total openings per Sta. (including joints) | 42.8 | 37.9 |

The new cracking caused by the rolling was slightly greater for the 40-ft panels, though not a significant amount when you consider that there were more old cracks in the 20-ft panels. Combining the new and old, the 20-ft panels had slightly more total cracks after rolling. When the joints are added, the 20-ft panel section averages 4.9 openings more per station that the 40-ft panel section, a significant difference.

## Permanent Slab Deflections and Roughness

Profiles were taken 8 ft right and left of centerline on the old concrete pavement before and after the pavement breaker rolling at three locations. The results were generally as follows:

Sta. 950 to 955.—There were only minor changes in the profile of the old pavemen In a few places, the pavement was higher by 0.01 to 0.04 ft after rolling. In other places, there was no measurable change in elevation. However, in a majority of plac the rolling depressed the old slab from 0.01 to 0.06 ft.

Sta. 980 to 990.—Through most of this section the profile after rolling was within 0.02 ft of the original profile. Generally, the rolling depressed the slab, but not at all places. The old pavement was depressed more than 0.02 ft only in isolated areas

Sta. 1010 to 1025.—Rolling caused a somewhat more consistent lowering of the pa ment by 0.02 to 0.05 ft through this section. However, there were areas of little or no change and areas where the slab was slightly higher after rolling. At one point, at a crack, the slab was depressed 0.13 ft. This was the maximum permanent deflec tion caused by rolling as measured by the profiles.

Roughometer readings before and after rolling show a slight decrease in average roughness in the westbound lane and no change in the eastbound lane. The westbound lane averaged 160 in. per mile in April prior to rolling and 154 in. per mile in July after rolling. The eastbound lane averaged 154 in. per mile at both times.

## RESURFACING SECTIONS AND COSTS

The typical resurfacing section for the project consisted of a 1½-in. leveling cour a 1½-in. binder course and a 1½-in. wearing course over the old concrete pavement This section was varied over the rolled experimental portion of the project to provid for a 2-in. leveling course, a 3-in. bituminous base and a 6-in. bituminous base as alternates to the 1½-in. leveling course on the standard section. These features plu the widening designs are shown in detail in Figure 4.

Costs of the various sections constructed on this project were computed on the ba of average job data. All items pertaining to the construction from shoulder to should including the excavation for the widening, were taken into account. Items such as cu vert extensions, subgrade treatments, sodding and seeding were not included. On th basis, the costs of the various sections are given in Table 1. The cost of the standa section (1½-in. leveling course) was $38,340 per mile. The costs of the other secti

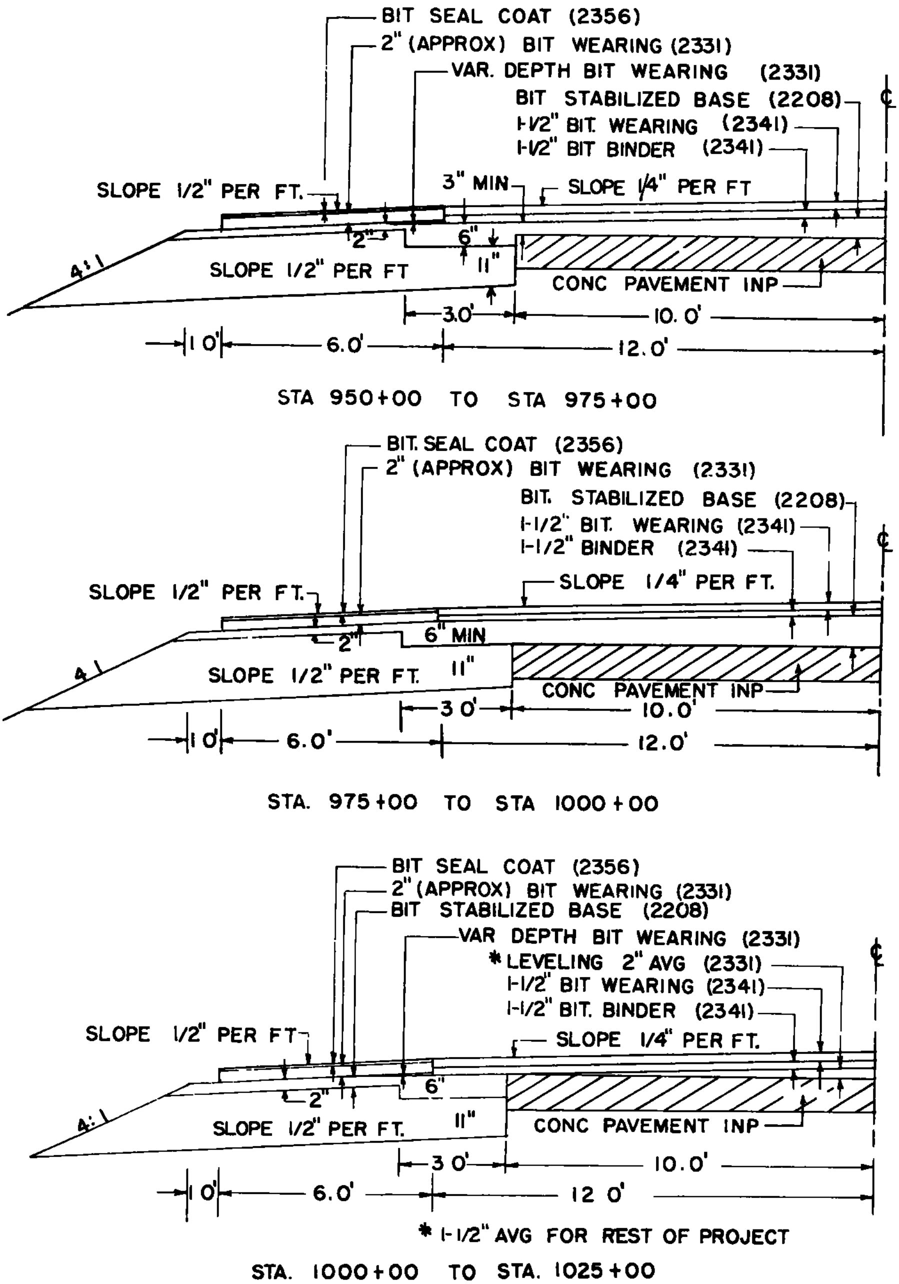


Figure 4. Typical sections.

re increasingly greater as the thickness of bituminous mixture was increased: the n. leveling course section being $39,908; the 3-in. base section being $40,427; and 6-in. base section being $45,001. These latter costs include $271.44 per mile for pavement breaker rolling.

## PERFORMANCE OF THE PROJECT

The performance of the bituminous resurfacing has been evaluated and compared in

TABLE 1

RELATIVE COSTS OF RESURFACING SECTIONS

| Station | Wearing Course (in.) | Binder Course (in.) | Leveling Course (in.) | Bituminous Base (in.) | Pvt. Breaker Rolling[a] | Cost per Mile[b] ($) | Date Surface Complete |
|---|---|---|---|---|---|---|---|
| 950-975 | 1.5 | 1.5 | - | 3.0 | Yes | 40,427 | 9/28/59 |
| 975-1000 | 1.5 | 1.5 | - | 6.0 | Yes | 45,001 | 9/28/59 |
| 1000-1025 | 1.5 | 1.5 | Av. 2.0 | - | Yes | 39,908 | 9/28/59 |
| Rem. of Project | 1.5 | 1.5 | Av. 1.5 | - | No | 38,340 | 10/9/59[c] |

[a]$271.44 per mile for 10 passes.
[b]Complete section including widening.
[c]Based on Sta. 925 to 950 as a comparable area.

several ways. Crack surveys have been made before rolling, after rolling, and seve times after completion of the surfacing. Profiles were taken before and after rolling after completion of the surfacing, and in February 1960, to show the effects of frost heaving. Detailed cross-sections of the bituminous surface have been taken to detect rutting in the wheel tracks. And, as previously mentioned, several comparison sections were selected with which the performance of the experimental sections could be compared and evaluated.

The information on cracking, profiles, and roughness before and after rolling have already been discussed in relation to the rolling. This data will not be repeated here but it must be pointed out that the condition of the pavement after rolling is the condition which will influence the performance of the surfacing in the experimental section

## Reflectance Cracking

The results of crack surveys on each of the sections, comparison and experimenta are discussed separately, covering the sequence and amount of cracking. This information is also summarized in Table 2, where it will be noticed that the rolled sections have less cracking than the comparison sections. The rolled section between St 975 and Sta. 1000 with the 6-in. bituminous base is the least cracked.

Sta. 120 to 130.—This section is located 2.5 mi east of Bird Island and was selected for study because it represented one of the roughest portions of old pavement o the project. The average roughometer reading was 166 in. per mile on this section.

The surfacing was completed during July, and, according to reports from field personnel, cracking started a day or two after the mat was laid. Earlier cracking ha also been reported in the binder course before the wearing course was placed. It is probable that this cracking—which occurred over much of the project completed durin July and early August—was caused by excessive joint movements due to high tempera tures during this period.

In September, when the first condition survey was made on this section, 100 perce of the transverse joints were reflected as cracks in the new surface, and there were

TABLE 2

SUMMARY OF REFLECTANCE CRACKING

| | | | | | Condition Surveys | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Cracks | | | | | | | | | | | | | | |
| | | | | | | | 11/19/59 | | | | 2/9/60 | | | | 4/14/60 | | | | Length (ft) | | |
| | | | | | No. Sts. | | No. | | % | | No. | | % | | No. | | % | | | | |
| Station | Treatment | Pvt. Rolling | Const. Cost ($/mi) | Date Surf. Compl. | L | R | L | R | L | R | L | R | L | R | L | R | L | R | Left Edge | Right Edge | Cent line |
| 120-130 | Std. Sec. | No | 38,340 | July | 35 | 35 | 34 | 35 | 97 | 100 | 34 | 35 | 97 | 100 | 34 | 35 | 97 | 100 | 230 | 134 | 446 |
| 800-810 | Std. Sec. | No | 38,340 | Oct. 1 | 25 | 25 | 2 | 7 | 8 | 28 | 12 | 12 | 48 | 48 | 12 | 12 | 48 | 48 | 0 | 2 | 20 |
| 925-950 | Std. Sec. | No | 38,340 | Oct. 9 | 63 | 63 | 25 | 6 | 40 | 10 | 32 | 30 | 51 | 48 | 34[a] | 30 | 52 | 48 | 38 | 22 | 10 |
| 950-975 | 3-in. Bit. Base | Yes | 40,427 | Sept. 28 | 59 | 59 | 0 | 0 | 0 | 0 | 15 | 17 | 25 | 29 | 25[a] | 27[b] | 41 | 42 | 0 | 0 | 80 |
| 975-1000 | 6-in. Bit. Base | Yes | 45,001 | Sept. 28 | 64 | 64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 4 | 5 | 6 | 0 | 0 | 0 |
| 1000-1025 | 2-in. Bit. Level | Yes | 39,908 | Sept. 28 | 73 | 73 | 0 | 0 | 0 | 0 | 9 | 7 | 12 | 10 | 19 | 21 | 26 | 29 | 0 | 0 | 30 |

[a]Includes one crack over crack in old pavement.
[b]Includes two cracks over cracks in old pavement.

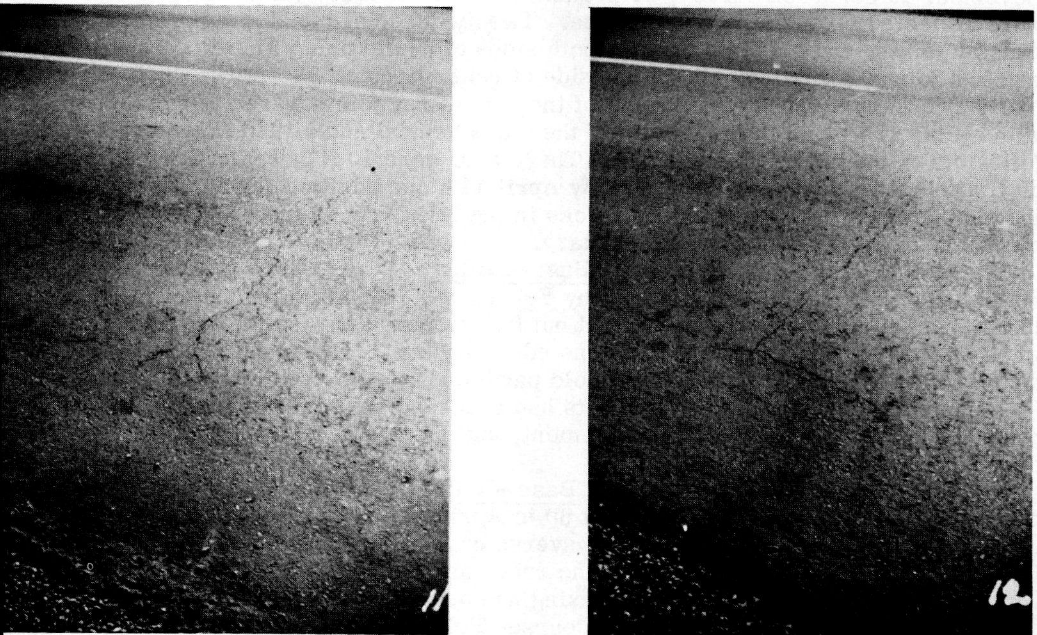

Figure 5. Typical transverse and widening cracks, Sta. 120 to 130.

er 200 ft of longitudinal cracking on centerline. Widening cracks along the edge of e old slab extended up to 5 ft from many of the transverse cracks. Figure 5 shows pical examples of this cracking.

By November 19 two transverse cracks had faulted significantly, 20 percent of the ansverse cracks had extended across the widening, and the centerline and widening ngitudinal cracks had extended slightly. Cracking progressed so that on February 9, 60, 57 percent of the cracks extended across the widening. This increased to 66 rcent by April 14th. All transverse cracks were over the pavement joints except e which occurred at a construction joint in the bituminous surface in the left lane. wever, by April 14 the longitudinal cracking had progressed to the point where there re 446 ft on centerline, 230 ft over the left edge and 134 ft over the right edge of the l pavement. This section has cracked more than any of the other sections studied detail.

Sta. 800-810.—This section is located about 1 mi east of Buffalo Lake and repre- nts old pavement of average roughness, 150 in. per mile. The binder course was d on September 15, and the wearing course was completed on October 6, 1959. On ptember 22 there were no cracks in the binder course. However, on November 19 e-third of the transverse joints were showing as cracks in the wearing course. Some these cracks were only on one-half of the road, and none extended into the widening. is quite certain, although not verified, that all of these cracks are over expansion nts.

By February 9, 1960, 48 percent of the joints had reflected as cracks in the bi- ninous surface. All of these were the full width of the old pavement and many ex- ded into the widening. There was no change in the number of cracks up to April h except that nearly all the transverse cracks had progressed into the widening. ere were only four instances where the cracks did not extend into the widening on one e.

Sta. 925 to 950.—This section is located adjacent to the beginning of the experimental lled) section and was selected for comparison purposes. The binder course was npleted on September 17, and the wearing course on October 9. At the time of the

November 19 condition survey, 39 percent of the transverse joints in the old pavemen were reflected through the new surface. Twenty-three of the 25 cracks were over ex- pansion joints, and only six were on both sides of centerline. The two cracks over co traction joints were also only on one side of centerline.

By February 9, 1960, 51 percent of the transverse joints were reflected as cracks with all but two being the full width of the old pavement and all but three extending the full width of the bituminous surface. There also were 10 ft of centerline cracking and 60 ft of edge cracking at this time. By April 14th one additional joint and one crack i the old pavement had reflected as cracks in the left (W.B.) lane. Otherwise, there w no change from the condition in February.

Sta. 950 to 975 (3-In. Bituminous Base—Rolled). —There were no cracks in this section on November 19, 1959; but, by February 9, 1960, 29 percent of the transver joints had reflected as cracks, and all but five extended across the widening. There were 80 ft of centerline cracking and no edge cracking. One short crack in the bitum nous surface was over a crack in the old pavement.

By April 14, 46 percent of the joints had cracked, one more crack appeared which probably was over a crack in the pavement, and there was no change in the centerline or edge cracking.

Sta. 975 to 1000 (6-In. Bituminous Base—Rolled). —This rolled section with the 6- bituminous base has cracked the least up to April 14, 1960. No cracking had occurre up to February 9th, and only four transverse cracks occurred over joints by April 14 One of these was only on one-half of the road, and none of the cracks extended into th widening. No centerline or edge cracking had occurred up to this date.

Sta. 1000 to 1025 (2-In. Leveling Course—Rolled). —At the time of the February 9, 1960 condition survey, 13 percent of the transverse joints had reflected as cracks in the bituminous surface. Of the 10 cracks occurring, six covered the width of the con crete slab, and only 3 extended into the widening. Approximately 30 ft of centerline cracking had occurred in a frost heave area and there was no edge cracking.

By April 14, 28 percent of the transverse joints and one crack had reflected throu the bituminous surface. Only four cracks had extended into the widening on one or b sides. There was no longitudinal cracking over the edges of the old slab, and there no increase in the longitudinal cracking on centerline since February.

## Profiles and Frost Action

On all experimental and comparison sections profiles were taken 8 ft right and 8 ft left of centerline for the purpose of evaluating roughness and distortion of the new bituminous surface with age. The first profiles of the new surface were taken shortl after placement. The second set were taken on February 18 and 24, 1960, to show t effects of frost. It is planned to take more profiles to follow the progression of dis- tortion.

The February profiles showed that frost heaving was occurring in most of the are The maximum measured heaving amounted to 0.20 ft or 2.4 in. Most of the heaving was quite uniform, however, differential heaving at some of the transverse cracks o joints occurred to various degrees. The conditions on each section were as follows:

Sta. 120 to Sta. 130 (Comparison Section). —Heaving was more pronounced on the portion between Sta. 124+60 and Sta. 130 than on the westerly 460 ft of this section. However, nearly every cracked joint was raised by heaving, particularly where pane were 40 ft long rather than 20 ft. These raised joints were as much as 0.06 ft highe than the center of the 40-ft panels. Where the panels were 20 ft long, the differentia was on the order of 0.02 to 0.04 ft. Because practically every joint was cracked on section, the differential heaving at the joints was creating a slight although noticeabl reflection of the severe warping that existed in the old pavement prior to resurfacing

Sta. 800 to Sta. 810 (Comparison Section). —The heaving on this section was gene ly slight except for a few spots where it approached 0.05 to 0.08 ft. Here again, the cracks over joints showed a slight differential heave in many cases, but not to the de gree found on the previously discussed section. Cracks were further apart so the warped panel effect was not noticeable at this time.

Sta. 945 to Sta. 950 (Comparison Section). —The heaving on this section averaged om 0.02 to 0.06 ft except for an old heave area at Sta. 948+10 where the maximum eave amounted to 0.16 ft. This heaving has caused the reflection of diagonal cracking the new surface. Heaving at cracks over joints was not noticeable in this area.

Sta. 950 to Sta. 955 (Rolled Section—3-In. Bituminous Base). —Heaving was general- 0.02 to 0.06 ft through this area with no major differentials. Four out of six cracks er joints showed slight differential heaving, but this was only minor at this time.

Sta. 980 to Sta. 990 (Rolled Section—6-In. Bituminous Base). —Between Sta. 980 d 987+40 heaving was generally less than 0.04 ft and quite uniform. There were no acks in this section in February. From Sta. 987+40 almost to Sta. 990, heaving was ore pronounced and not as uniform. The maximum rise was about 0.12 ft. Diagonal acking in the old pavement indicated this to be a potential heave area. One transverse ack over a joint was found in this area in April 1960, and could have resulted from e frost effects.

Sta. 1010 to 1025 (Rolled Section—2-In. Leveling). —Between Sta. 1010 and Sta. 19+80 the heaving was minor ranging from practically nothing to 0.04 ft. There was e crack over a joint in this area which was raised slightly. From Sta. 1019+80 to a. 1025 the profiles show an area of differential heaving which was also indicated by agonal cracks in the old pavement. This heaving ranged up to 0.20 ft. In the area of eatest heave (Sta. 1023+80), cracking was found on centerline in February. Oddly, transverse cracking was found in this heave area in April as might have been ex- cted.

ughness

Roughness measurements were made with the road roughness recorder shortly after e surface was completed in October 1959, and again in April 1960. The average re- lts obtained on the entire project and on the various sections are given in Table 3.

TABLE 3

SUMMARY OF ROAD ROUGHNESS READINGS

| Section | Roughness (in./mi) October 1959 | Roughness (in./mi) April 1960 |
|---|---|---|
| oject average | 56 | 60 |
| a. 120 to 130 | 54 | 62 |
| a. 800 to 810 | 53 | 58 |
| a. 950 to 1025[a] | 50 | 56 |

avement breaker rolling on this section.

These figures show an average increase of 4 in. per mile for the project as a whole om October to April. The individual sections show slightly more increase in rough- ss than the average, but the differences are still so small that they are not very gnificant.

rface Cross-Sections

Cross-sections of the bituminous surface were taken to determine distortion of the own in the wheel tracks. Such distortion (wheel tracking) has occurred on other pro- cts due to vertical and lateral displacement or movement of the bituminous mixture. cause various thicknesses of mixtures were used on this project, these cross-sections re taken and will continue to be taken as a measure of the stability of the mix under ical highway traffic.

The cross-sections were taken at established locations on the various sections three nes, October 1959, and February and April 1960. To date, no rutting was found to exist. This was more or less expected, because the weather has been cold during thi time, and most displacement of the bituminous mixture would occur during warm wea ther. The plots of the February cross-sections did show the frost heaving. These cross-sections were taken with a leveled straight-edge and scale and were measured to 0.01 in.

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## *Discussion*

J.L. STACKHOUSE, Maintenance Engineer, Washington State Department of Highwa —This discussion was requested by V.G. Gould, Chairman of HRB Committee on Sal vaging Old Pavements by Resurfacing, and H.E. Diers, Chairman, HRB Department of Maintenance, primarily because this paper is closely associated with the work reviewed by the writer in a paper reported in the 1959 HRB Proceedings describing a similar type of construction performed on a Washington highway.

Mr. Velz is to be congratulated on the excellence of his paper generally and the presentation of details of the preliminary work performed with the variable load com pactor on the old cement concrete. The paper presents each step undertaken on all sections of the experimental construction on Minnesota highways and evaluates the re sults.

The writer was keenly interested to note, after reviewing this paper, the similari of results of rolling old concrete pavement with a variable load compactor with near identical loads of 59 tons gross weight on both projects; also, the agreement of othe items noted in the report from the sections in Minnesota and Washington. The write recently had the unexpected opportunity to consult with Mr. Wade Faulk, Resident Engineer on the Ethel to Salkum project in Washington. Mr. Faulk and the writer concur on the following comparison of results as noted in this paper:

Pavement Breaker Rolling.—The vertical slab movements noted on the Washingto project agree with that found by Mr. Velz. The maximum number of passes with the compactor to produce optimum cracking was found to be from 8 to 10 which substant agrees with the author's findings. The crack pattern of the old concrete pavement a ter rolling, as noted in this paper, was about the same as observed by Mr. Faulk an some portions of the pavement remained unchanged, whereas other portions were raised and others subsided from 1½ to 2 in., which concurs with the Minnesota findings.

It is noted that slightly greater compaction of the old pavement slab occurred at centerline rather than at the edge on the Minnesota project, whereas the edges of the slabs were compacted or subsided slightly more, generally, than the center area on the Washington section. Some areas were not compacted from their original profile However, there seemed to be no uniformity in compaction as to slabs or locations as reported by Mr. Faulk.

The delay of small cracks appearing after the start of rolling until several passes with the compactor had been made, as reported by Mr. Velz, checks closely with th action noted by Mr. Faulk. As the rolling progressed the cracks became more visib accompanied by a crushing, grinding sound in the slab as the compactor passed over the pavement.

Old Pavement.—Inasmuch as the age of the old pavements is not the same (the Mi esota pavement was constructed in 1931 and Washington's section in 1924), and the pavement on which Mr. Velz reports was reinforced with two bars at the edges and each side of the center longitudinal joint of each 10-ft slab and the Washington sectio was unreinforced with the exception of dowel bars tying the two 9-ft slabs together a nterline, it is significant to note that the results of the variable load compactor were milar as previously noted. The Minnesota section was slightly thicker in cross-secon. It is indicated the compactor was heavy enough to overcome this difference in nstruction design and to break down bridging of the pavement on the subgrade.

Performance. —It is interesting to note the radical reduction of percentage of transrse reflection cracks, reported by Mr. Velz, that appeared in the asphalt concrete rface which was laid on the concrete pavement rolled by the compactor as compared the control sections which were not rolled. This observation was made after six onths of use by traffic. The findings of Mr. Velz that less reflective cracks appeared the section constructed with the 6-in. leveling base course checks with the experience Washington's resurfacing projects the past 20 years where old cement concrete paveents have been widened and resurfaced. It is axiomatic with the writer and engineers this department's Construction Division that the thicker the asphalt concrete pavement nstructed, the less reflective cracks will develop and the longer it will take them to pear.

The performance of the Ethel to Salkum section in Washington has been excellent. ter a visual inspection made on December 8, 1960, or 3½ years after the pavement s opened to traffic, no transverse or longitudinal reflective cracks were observed ile walking and driving slowly over the pavement. Credit for the absence of reflecn cracks in the wearing surface of the Washington pavement is only partially given to e action of the compactor roller and the major part of this lack of cracks is believed be due to the 4-in. average thickness of base course and 2-in. thickness of top course rfacing material that was used to level up the old cement concrete pavement after mpaction. In the construction of these uncemented, crushed gravel surfacing courses processing with a motor patrol blade, wetting and rolling with both steel-tired and eumatic rollers, some fine particles of the aggregate were worked down into the rger cracks of the old pavement, thereby firmly wedging the broken slab pieces in ace and precluding any possibility of further rocking under loads. It is believed the anular material is the greatest deterrent to crack prevention in insulating the wearing rface from the contracting and expanding stresses of the underlying concrete pavement d eliminating any possible chance of such stresses being transmitted to the asphalt vement. The subject sections in Minnesota and Washington are not comparable in sign in this respect, inasmuch as the Minnesota pavement under discussion did not ve a crushed gravel or rock layer between the concrete pavement and the asphalt veling and wearing surface. It is also possible that the foregoing comments are inngrous in view of the policy of the Minnesota Highway Department as to design and ent and therefore the comparison may not be valid. The policy of the Plans and ntracts Division of the Washington Highway Department is that when traffic volumes dicate a design standard of the ultimate width of wearing surface, shoulder and ditch-, providing funds are available, the old roadway will be reconstructed similar to the bject section in Washington. Likewise if it is the intention to improve the old highway a tolerable standard with future long-range plans to reconstruct the roadway to the imate design standard, then the old pavement is usually widened to 22 or 24 ft when s resurfaced and less than standard shoulders provided. No improvement is made areas outside the shoulders. The thickness of asphalt concrete leveling and wearing rface is usually a total of 3 in. with the expectation that reflective cracks will apr within a year in the new wearing surface. It is the present policy in Washington, en reconstructing a highway with existing concrete pavement, to break the pavement h a compactor and place leveling courses of base and top course surfacing materials er the concrete before constructing the asphalt cement pavement as described in the shington report.

Comment is made on the third paragraph of Mr. Velz' paper in discussion of the rmer use of granular materials to overlay rough old pavements and particularly, also might be considered extravagant, in that the full potential of the old pavement a base course was not used and because it consumed such large volumes of good se aggregate—an undesirable feature in any case, but especially so in areas of gravel rcity."

The quantities of base aggregate to which Mr. Velz refers are not known; however, if the thickness of the overlay aggregates did not exceed 12 in., it would not seem extravagant, to the writer, if the added thickness would provide more than adequate fou tion or more than the bare needs of the wearing surface to resist forces of heavy traf fic using the highway. In the past, designers of highway foundation sections have pro vided thicknesses of materials that theoretically would develop the full potential of th base without providing for any factor of safety to allow for extremely wet conditions, frost heaves, or unusual conditions. It is common practice for designers of portland cement concrete highway structures to provide at least a factor of safety of 2½ in the structures to insure against failure. Then why is it not economical to construct foun tions under pavements that are more than just adequate to carry the current maximu loads under all conditions? Prior to 1947 the foundations on several projects in Wasl ington state were designed on the apparent theory of "cutting the suit pattern to fit th cloth" because of shortage of funds. The end result was that after the first winter th wearing surface failed; after much criticism and many complaints the project was re surfaced and the wearing surface was replaced. The blame for the failure, in these cases, was placed on the wearing surface by most of the uninformed citizens affecte whereas the real cause of the failure was the inadequate foundation which would not support the loads using the highway.

Attention is called to the fact that where it is indicated, leveling an old pavement require more than 6 to 7 in. average thickness of material, including 3 to 4 in. of as phalt pavement. A saving can be obtained by using granular material (such as ⅝-in. or smaller top course) for the first 3 in. As an example, the unit contract cost on the subject Washington project was $6.65 per ton for asphalt concrete leveling and wearing course and $1.95 per ton for crushed gravel surfacing or a saving of 3.4 ti the cost of asphalt concrete for the purpose of leveling.

Costs. —The comparison of cost of use of the variable load compactor of both projects indicates the rolling, as stated in Mr. Velz' paper, was computed to be $271.4 per mile for a 20-ft pavement width. This compares with $331.28 per mile for rolli an 18-ft wide concrete pavement. A comparison cost of the asphalt pavement of all courses of the two sections cannot be fairly made because of the difference of metho of leveling up the old pavement; however, Mr. Velz reports the total cost per mile f a 1½-in. wearing course over a 1½-in. binder course and the 1½-in. leveling cours was $38,340 per mile. Comparable costs on the Washington project for a 1¾-in. le ing course under a 1¼-in. course wearing surface was $17,705.53 per mile. The width of both wearing surfaces was 24 ft. Although the plan for the total thickness o the Washington project is shown to be 3 in., the thickness of this pavement was actu approximately 4½ in., due to the fact that the quantities were computed on an avera specific gravity for aggregate and the aggregates used in the mixture were slightly less. The total quantities of tons of mixtures set up under the contract were used, which resulted in a larger volume of mixture and consequently a thicker layer. Although Mr. Velz reports that a 1½-in. leveling course was used, it is believed that the average thickness in leveling up the old concrete pavement was greater than this figure.

Comments. —It is of interest to note that on one 4.2-in. contract completed in 19 in eastern Washington, where a compactor was specified to break down the old conc pavement constructed about 1932 with a 9-in. uniform slab thickness, the compacto was unable to break the slabs and eliminate the bridging effect of the pavement. Aft a trial with the 59-ton compactor, which had no crushing effect on the pavement, a 20-cu yd Euclid scraper unit was loaded to full capacity and operated over the old pa ment at a speed of from 15-20 mph. The bouncing effect of the approximately 50-to load accomplished the desired effect of breaking the slabs that were rocking under t compactor.

As a result of the experience gained on Washington highways during the past five years, it has been concluded that where a highway is to be reconstructed to ultimate standards and the existing pavement is a portland cement concrete type, the most su cessful method for obtaining an asphalt pavement wearing surface that will remain f of reflection cracks and maintain a uniform profile grade is by the use of a variable load compactor to first break down the old concrete pavement to eliminate void area and level up with a granular material.