Moving Load Test on Experimental Prestressed Concrete Highway Slab

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This investigation was initiated to determine the behavior of an experimental prestressed slab when subjected to moving loads over an extended period of time. Details of the design and construction of the slab and the results of static and creep load tests were reported in HRB Proceedings, Vol. 37 (1958).

The tests were conducted on a 75-ft slab that included one of the rubber expansion joints. The load was applied by a specially designed vehicle having axles spaced 20 ft apart and carrying 14 tons each. The vehicle was positioned on the slab so that the curb wheels traveled in a straight line about 6 in. from the edge of the slab. Determination of the longitudinal and transverse stresses, deflection of the slab, and settlement of the slab, were made with appropriate instrumentation. The test extended over a 2½-month period, September 19 to December 1, 1962 and comprised more than 580,000 repetitions applied at the rate of about 10,000 per day.

The performance of the slab was excellent. There was no serious damage done to either the slab or the joint. The test did indicate, however, that more attention should be directed towards the longitudinal cracks over the tendons and the elimination of pumping at the expansion joint. It is recommended that a test pavement of this type be incorporated as a part of the construction of an actual highway for further study under normal highway conditions.

•IN FEBRUARY 1957 the Jones and Laughlin Steel Corp. completed the construction of an experimental section of prestressed concrete highway pavement, 5 in. thick by 12 ft wide by 530 ft long. The project was initiated "not only to provide technical data on the strutural action of prestressed concrete highway pavements but also to provide reliable information on the feasibility of construction and the relative economics involved."

The test program was conducted in the spring and summer of 1957. Sixteen static load tests were made at three loading stations. Load deflection curves were obtained for dual wheels mounted with 10 by 20 truck tires with loads up to 40,000 lb and for a steel bearing plate with loads up to 66,000 lb. Sixteen creep speed load tests were taken for an axle load of 23,000 lb.

These tests were significant in determining the stresses and deflections of the pavement under a very limited number of load applications. They do not indicate the effect of the loss of subgrade support due to ironing effect, compaction of the subgrade, and pumping action that takes place under extended repetition of moving loads.

The pavement was designed for prestressing in the longitudinal direction only. There is no transverse reinforcing. This has raised some questions as to how the pavement would perform under normal traffic conditions.

Paper sponsored by Committee on Rigid Pavement Design.

PURPOSE AND SCOPE OF RESEARCH

The purpose of this investigation was to determine the behavior of an existing prestressed concrete highway slab when subjected to repeated applications of moving loads over an extended period of time. The project was carried out under a grant sponsored jointly by the Pennsylvania Department of Highways and the U. S. Bureau of Public Roads. The existing slab was donated by the Jones and Laughlin Steel Corp. for the purpose of this investigation.

There are five factors in this investigation that served to accelerate the test: (a) the subgrade was designed to meet the minimum standards of AASHO in order to create the least favorable, but acceptable conditions; (b) the vehicle traveled as close to the edge of the slab as practicable to produce maximum deflection at the edge of the slab; (c) each axle carried about 28,000 lb, 25 percent overload for Pennsylvania load limits; (d) the maximum speed of the vehicle was about 10 ft/sec, permitting greater deflections than would take place under normal velocities; and (e) the loads were applied at the rate of about 8 per min, so that the subgrade had little opportunity to recover after each load application. These contingencies made the tests more severe than would be expected under normal traffic conditions. On this basis it was felt that 500,000 repetitions would be adequate to evaluate the pavement.

TEST SECTION

The east end of the slab appeared to be the more logical area on which to set up the test. This end was chosen because there were no apparent cracks in the slab. It also contained an expansion joint and was removed from areas where previous testing had taken place.

A study of the oscillographs for the deflections under creep loads presented in the Jones and Laughlin report indicated that it would be desirable to place the axles of the vehicle 20 ft apart so that the deflections under one set of wheels would not affect the readings under the second set. It was also considered desirable to mount the strain gages at two cross-sections so that failure of a gage would not necessitate shutting down the operation. This permitted a degree of flexibility for the scheduling of gage replacement during fair weather and at times when the vehicle was shut down for maintenance. The dual setup would also serve as a cross-check to verify the readings.

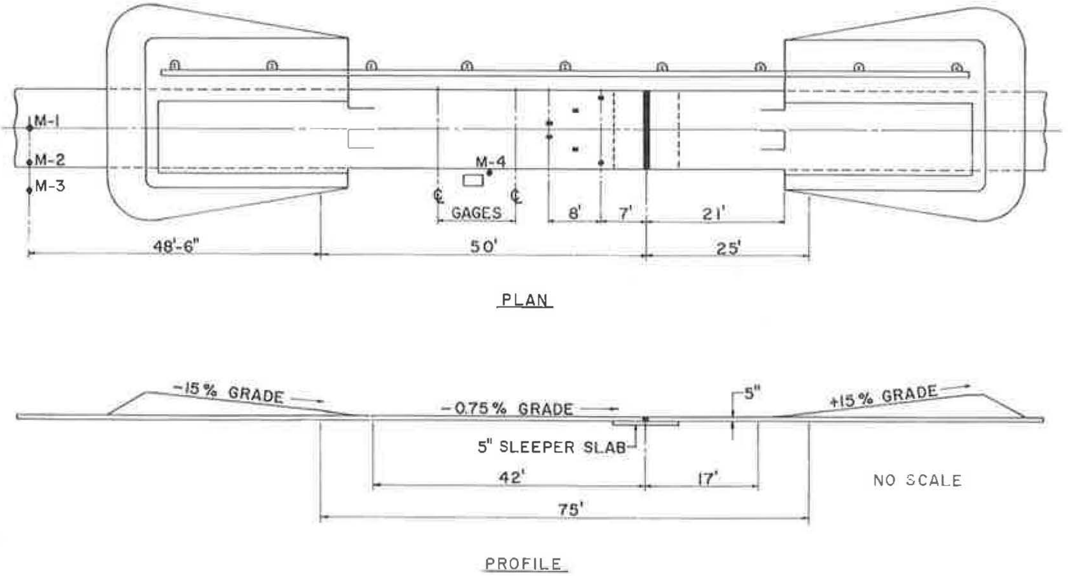


Figure 1. Test strip.

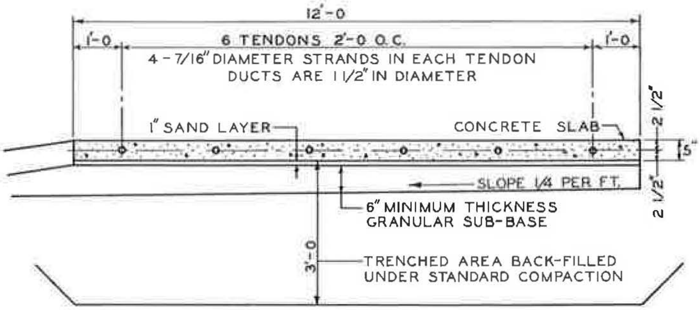


Figure 2. Typical site cross-section.

Figure 1 shows the plan and profile of the test area. The ramps were designed with a 15 percent grade to absorb the energy of the vehicle when it had attained a velocity of 10 ft/sec. The two strain gage stations were located 20 and 32 ft from the centerline of the expansion joint. The points M-1 to M-4 indicate the location of the thin-walled steel tubing that was driven into the ground for the nuclear moisture-density probe.

Figure 2 shows a typical cross-section of the site. The soil used in the subgrade is classified as an A-7-6 clay with a group index of 20. The T-99 unit weight of the clay varied from 90 to 95 pcf with average values of 93 pcf and an optimum moisture of 27 percent. It was compacted to within the range of 95 to 100 percent of the T-99 maximum with moisture contents at or above the optimum.

A natural sand-gravel mixture meeting the requirements of AASHO, Type 1, Grading B was used for a granular subbase. The compacted thickness of this base was 6 in. covered by a 1-in. leveling layer of washed sand and a layer of slater felt to reduce friction.

The concrete mix for the pavement was Pennsylvania Department of Highways' Class AA. The cement was air-entrained. The aggregate was stone with a maximum size of $2\frac{1}{2}$ in. Maximum water was 5.3 gal per sack. The concrete had an average cylinder strength of 4,483 psi at 28 days.

The $\frac{7}{16}$-in.-diameter strands used in the tendons were typical stress relieved prestressing strands with an average ultimate strength of 268,000 psi and an average elongation of 10 percent. The average prestress in the concrete after the release of the jacks varied from 360 to 470 psi and that of the tendons from 116,000 to 151,000 psi.

VEHICLE

The vehicle, shown diagrammatically in Figure 3, consists of a 28-ft trailer bed with the rear axle mounted on a frame that is connected to the bed with a king pin. The forward end is supported on a heavy-duty truck chassis in the same manner. The axles are 20 ft apart and carry dual wheels mounted with 10 by 20 truck tires. The tire pressure was maintained at 80 psi.

The vehicle was driven by an electric motor through the transfer case and the differential that came with the truck chassis. The maximum velocity of the vehicle was 10 ft/sec.

Forward and reverse movement of the vehicle was accomplished with a magnetic definite-time control that operated on a first come first served basis. The control was activated by staggered collector rails mounted at the side of the pavement. Current was supplied to the vehicle through similar collector rails.

The vehicle was made to travel in a straight line by means of a floating guide frame that engaged pins at each end of the frames on which the wheels were mounted. The guide frame was held in alignment with crane wheels that were mounted between two guide rails at the edge of the slab. The crane wheel housings were hinged to the guide frame by A-frames. The guide frame was moved back and forth with a pneumatic cylinder to engage the proper pins and thus guide each set of wheels in the proper direction.

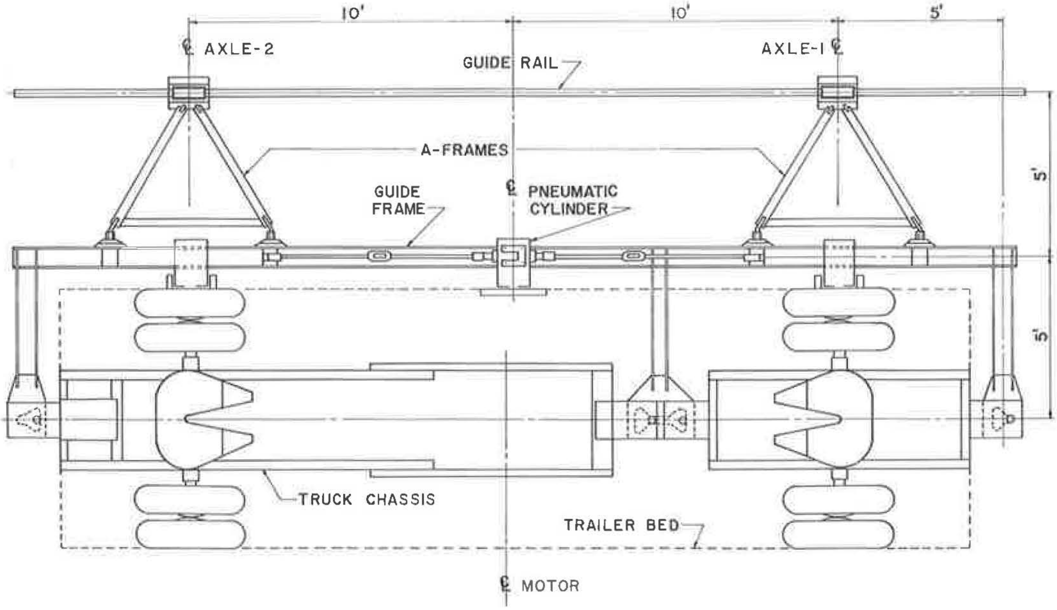


Figure 3. Test vehicle.

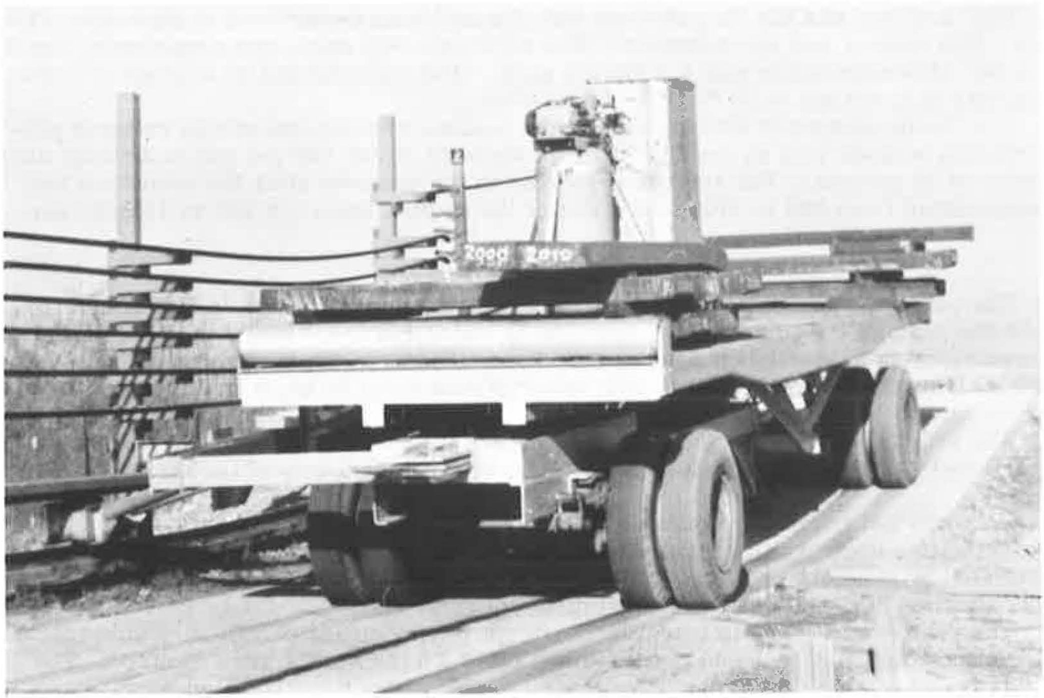


Figure 4. Assembled vehicle in operation.

A number of pressure switches, microswitches, and relays were wired into the electrical circuit to insure fail-safe operation.

The brakes were used for emergency stops. Reversing the direction of motion was accomplished on the ramps at each end of the test strip.

Figure 4 shows the assembled vehicle in operation. The vehicle is descending the east ramp. Mounted on the center of the bed is the control box with the compressor to the left of it. The compressor supplies air at 120 psi to the pneumatic cylinder and the brakes. The guide rails and collector rails are shown on the far side of the vehicle. The guide frame is shown engaging the guide pin on the near end of the chassis.

INSTRUMENTATION

Strain gage and deflectometer locations are shown in Figure 5. The gages were SR-4, Type A-9. Gages 1, 3, 4, 6, 8, and 9 were mounted at right angles to the longitudinal axis of the slab. Gages 2 and 7 were originally installed as transverse gages located 5 ft from the south edge of the pavement. They were rendered inoperative due to a longitudinal crack which developed through their position and were remounted as longitudinal gages 6 ft from the edge of the slab. Temperature-compensating gages 11, 12, and 13 were mounted on an unstressed block of concrete formed at the time the pavement was poured. The readings for the strain gages were recorded on a two-channel oscillograph.

Vertical deflections due to the passage of wheel loads were recorded at the edge of the slab. Deflectometers U-1 through U-5 were fastened at mid-depth to the side of the pavement. Deflectometers L-3, L-4 and L-5 were fastened to the side of the sleeper slab. Maximum readings were taken with a dial indicator. Readings were also recorded on the oscillograph with a cantilever-beam deflectometer.

Figure 6 shows the grid that was established on the slab for determining changes in elevation. Elevation of these points was taken periodically with a wye level and recorded to the nearest 0.001 ft. Line A was along the loaded edge of the pavement and Line D was along the unloaded edge.

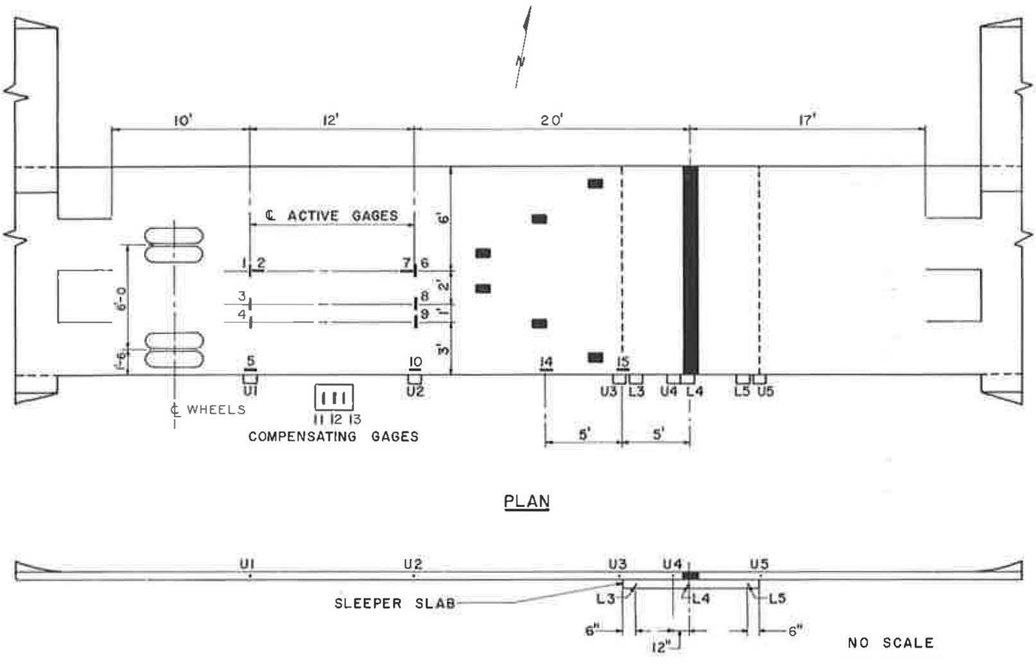


Figure 5. Location of instrumentation.

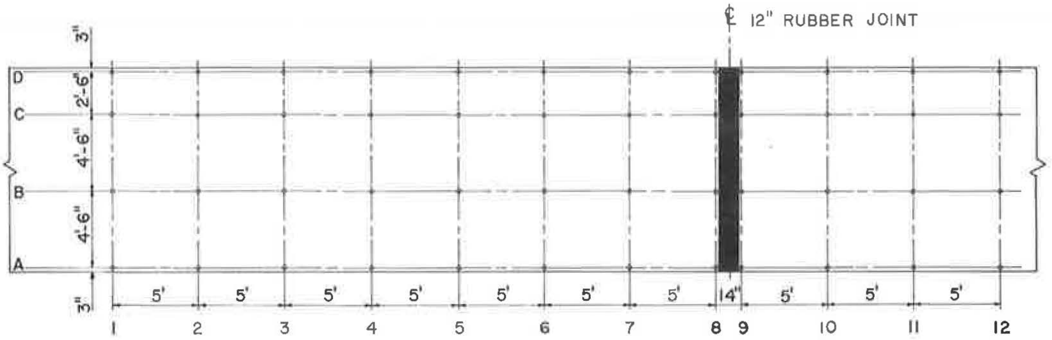


Figure 6. Stations for elevations.

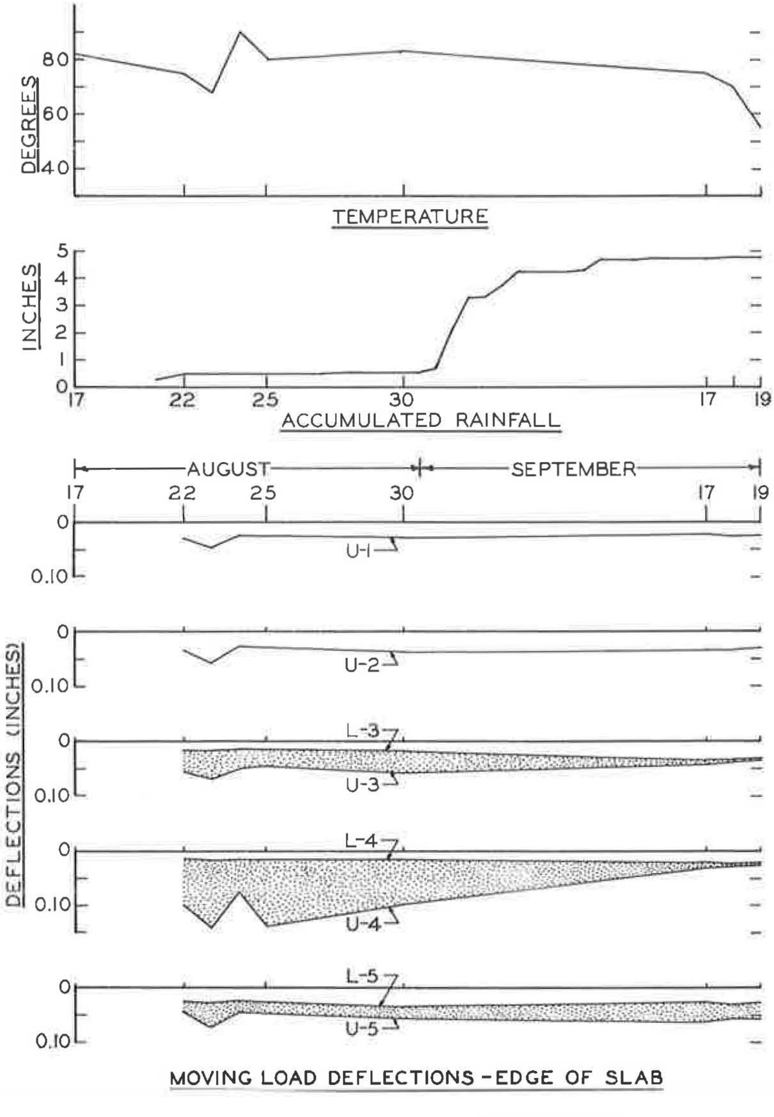


Figure 7. Pretest data for deflectometers.

PREPARATION FOR TESTS

Three thousand repetitions were applied to the slab while the vehicle and the instrumentation were being adjusted. During this time, the deflectometers indicated a separation between the sleeper slab and the main slab. This amounted to about 0.123 in. on the west side of the joint and 0.043 in. on the east side. It was decided to bring the main slab in contact with the sleeper slab on the west side of the joint by grouting the separation.

The pretest data for the deflectometers are shown in Figure 7. The separation between the two slabs is illustrated by the shaded area between U-3, L-3; U-4, L-4; and U-5, L-5. The readings for September 17 show the effect of the grouting operation. The relative movement between the main slab and the sleeper slab is negligible. The temperature and rainfall data shown at the top of the graph are of importance only to indicate the weather conditions which preceded the tests.

DEFLECTIONS AT EDGE OF SLAB

Figure 8 shows the range in temperature for each day and the accumulated rainfall during the test period that extended from September 19, 1962 to December 1, 1962, and resulted in approximately 580,000 passes of the axle loads over the slab. The bar graph at the bottom of Figure 8 shows the periods when the vehicle was shut down for repair or adjustment.

The majority of the deflections were recorded from 4 to 5 P.M. The oscillographs shown in Figures 9 and 10 are typical for the deflections at points U-1, U-2, U-3, and L-3. The variation in the width of the peaks was caused by a variation in the velocity. This also accounts for the somewhat higher readings at the broad peaks because lower velocity would cause a greater deflection.

The graphs in Figure 11 are a plot of the maximum peaks on the oscillographs. In a few cases these readings were supplemented with values obtained from the maximum reading deflectometers. In all but a couple of cases the two instruments agreed reasonably well with each other. It can be seen that the deflections of the slab at U-1, U-2, U-3, and L-3 were relatively consistent and amounted to about 0.030 in.

At points U-4, L-4, U-5, and L-5, the effect of the loss of subgrade support can be seen. The shaded area is representative of the separation between the main slab and the sleeper slab. The live load deflection of the sleeper slab averaged about 0.02 in. at L-4 and varied from 0.02 to 0.04 in. at L-5. The deflection of the main slab varied from 0.02 to 0.04 in. at U-4 and from 0.03 to 0.074 in. at U-5. The last readings, taken on December 1, 1962, indicated theat the separation was becoming less as pumping reduced the support under the east ramp.

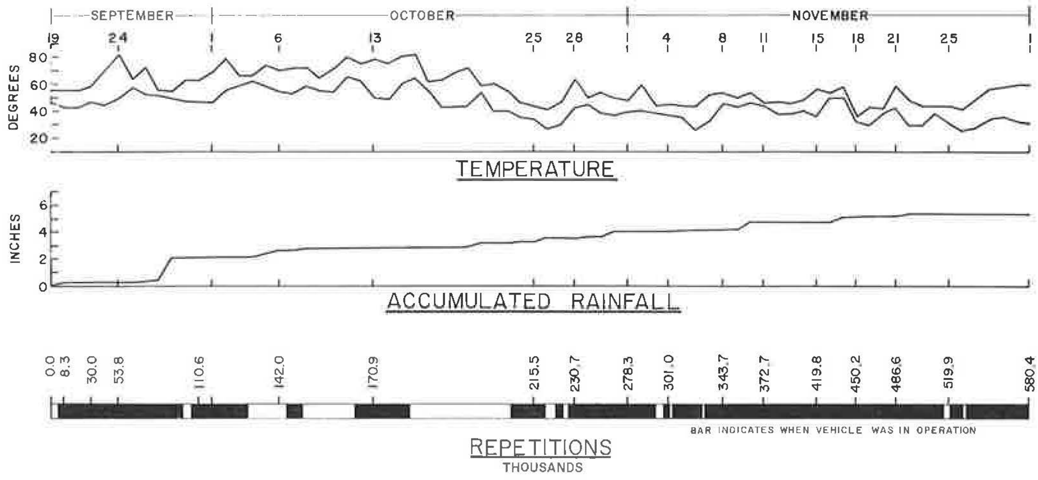


Figure 8. Weather data and vehicle operation.

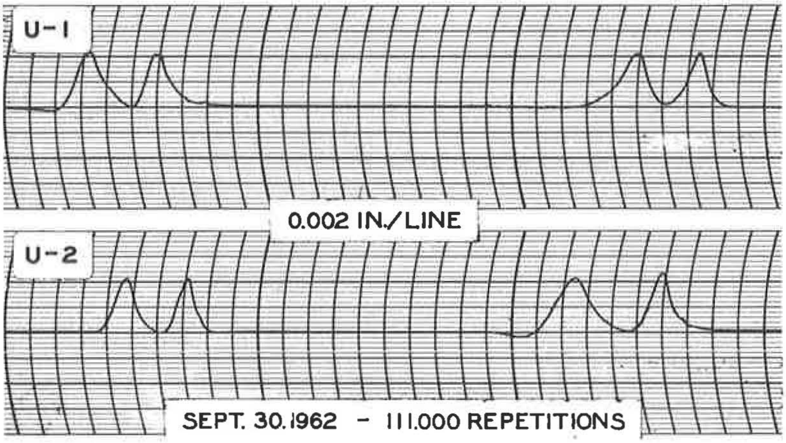


Figure 9. Typical deflections as recorded by oscillographs at U-1 and U-2.

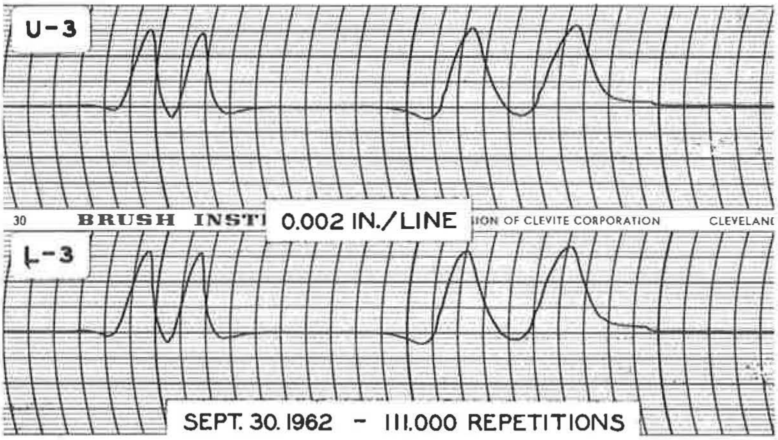


Figure 10. Typical deflections as recorded by oscillographs at U-3 and L-3.

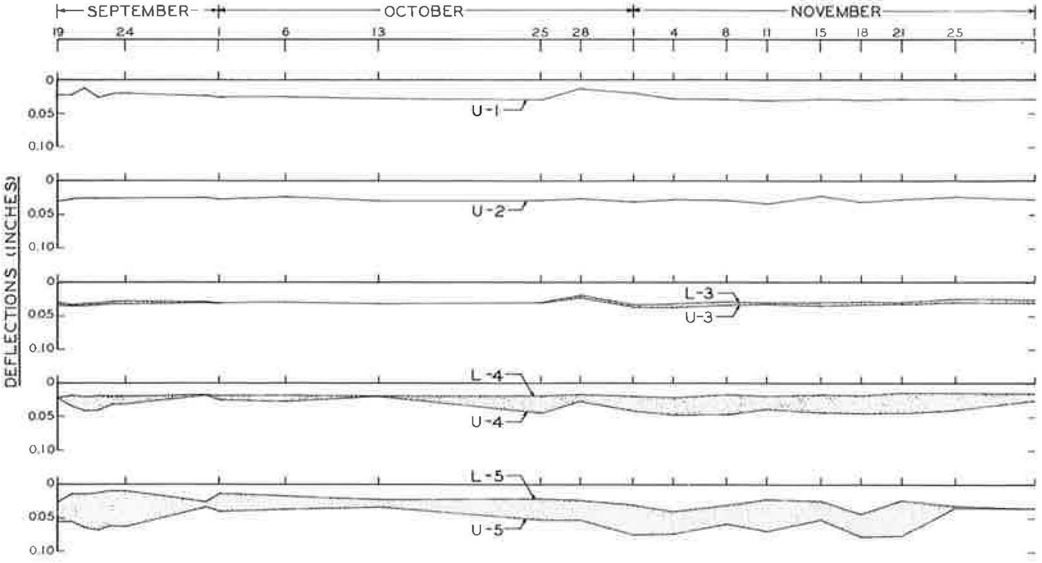


Figure 11. Moving load deflections—edge of slab.

Figure 12. Pumping at U-5, L-5—Oct. 30, 1962.

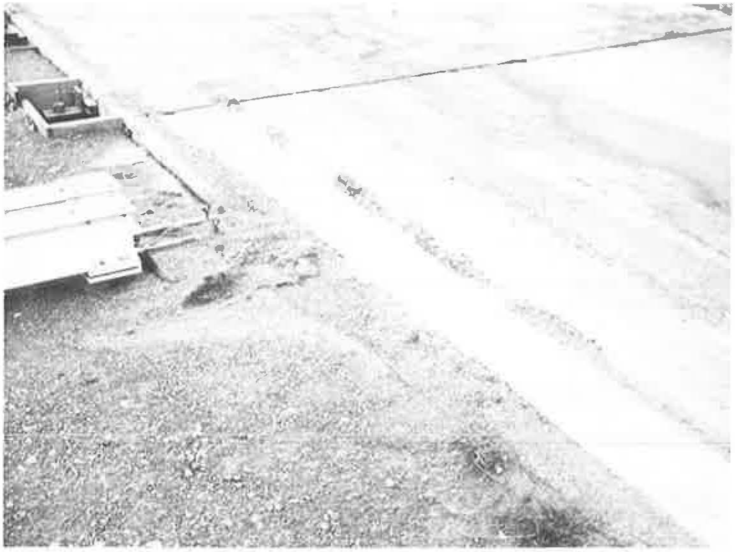
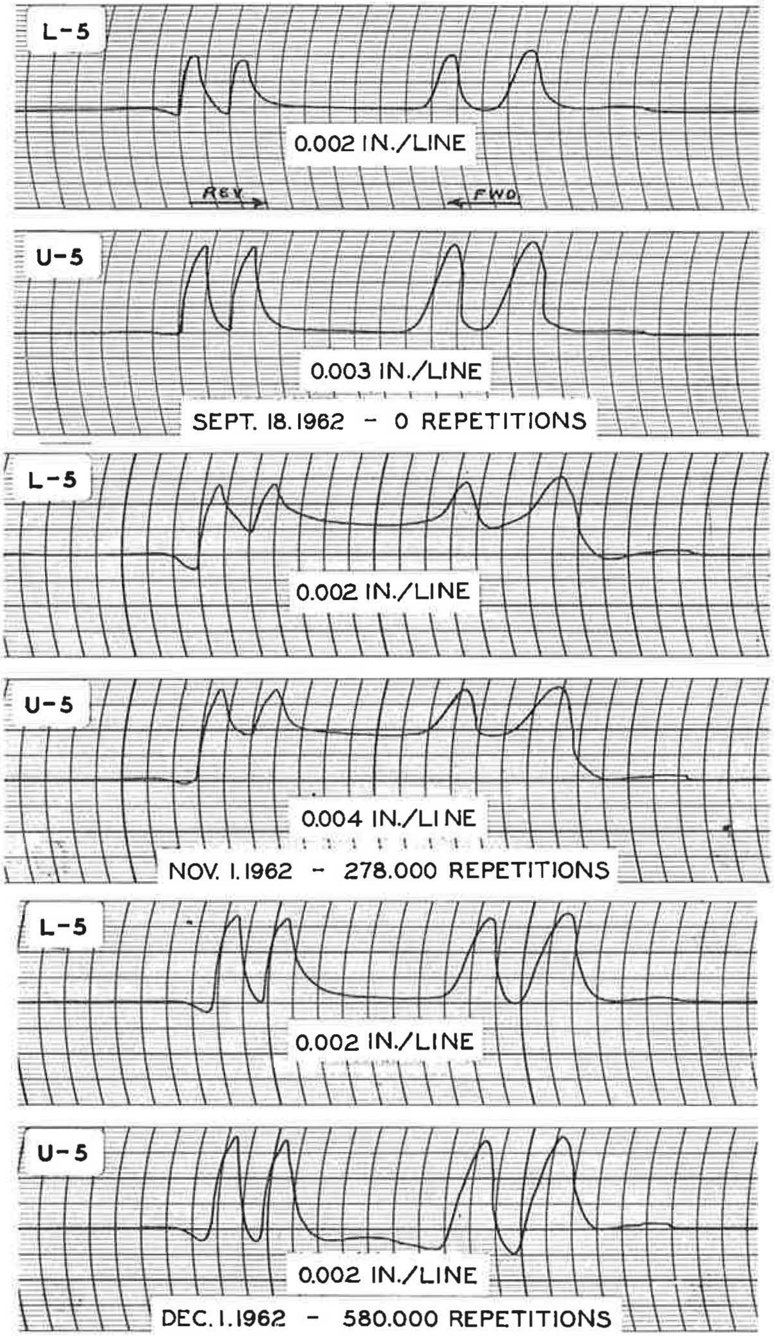


Figure 13. Pumping at U-5, L-5--Nov. 10, 1962.

Figure 14. Pumping at bottom of east ramp—Nov. 10, 1962.



SEPT. 18.1962 - 0 REPETITIONS

NOV. 1.1962 - 278.000 REPETITIONS

DEC. 1.1962 - 580.000 REPETITIONS

Figure 15. Oscillographs at U-5 and L-5.

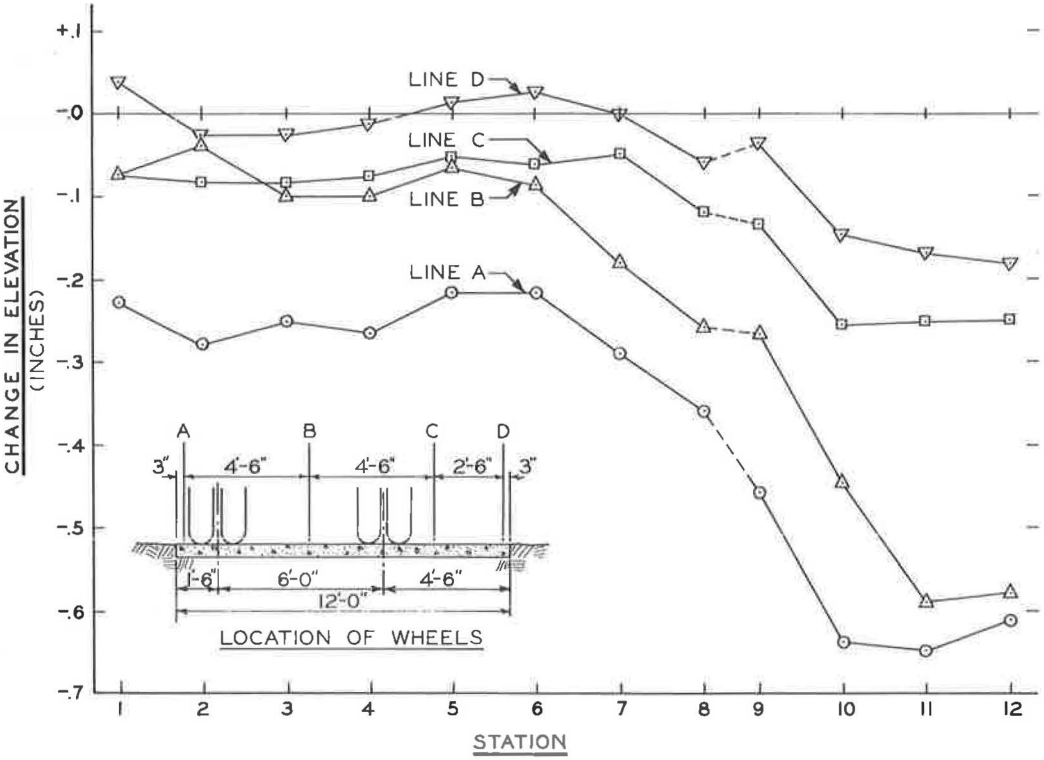


Figure 16. Change in elevation, 580,000 repetitions.

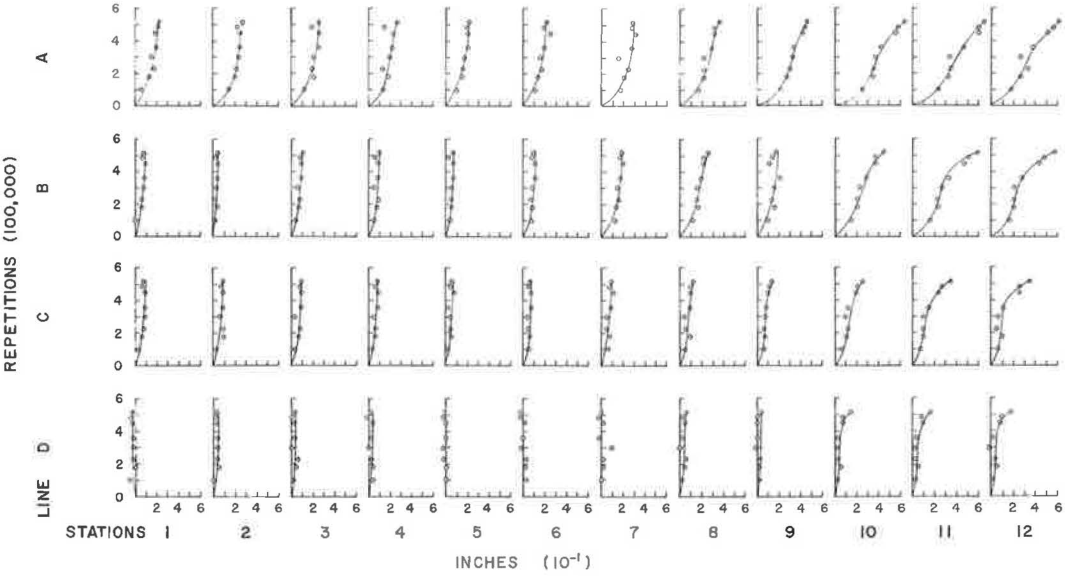


Figure 17. Change in elevations.

PUMPING

The first evidence of pumping was witnessed about 7 P.M. September 27, and it continued until about 10 A.M. the following morning. Two cubic feet of well-graded sand was pumped out at U-5, L-5. On October 30 about 1.5 cu ft of sand was pumped at U-5, L-5 (Fig. 12). In both cases there was no evidence of pumping at any other location.

On November 9 and 10 there was heavy pumping at the edge of the slab from the U-5, L-5 position to the bottom of the east ramp (Figs. 13 and 14). There was a substantial amount of fines pumped into the U-4, L-4 position and a somewhat lesser amount at U-3, L-3. The only other evidence of pumping was a slight trace of fine sand under the counter hose about 5 ft east of the west ramp.

On both November 17 and 21 pumping occurred along the edge of the slab from the expansion joint to the east ramp with fines accumulating at both U-3 L-3 and U-4 L-4. No pumping was found elsewhere. During the November 21 rain, water was seen pumping through the cracks that had developed in the slab east of the expansion joint.

The oscillograph charts shown in Figure 15 graphically illustrate what had occurred at U-5, L-5 due to the pumping action. The September 18, 1962 chart shows the deflections as the vehicle passes over the points and ascends the ramp, then reverses itself and returns across the point to the main slab. While the vehicle was up on the ramp, the deflections at U-5, L-5 returned to zero.

The November 1, 1962 chart was taken after 278,000 repetitions and a considerable amount of pumping. Here the slab appeared to be acting as a supported cantilever that maintained a reaction on the sleeper slab while the vehicle was on the ramp.

On December 1, 1962, after 580,000 repetitions and additional pumping, the slab appeared to have settled to the subgrade again because the deflections had nearly returned to zero while the vehicle was on the ramp. Figure 16 tends to reinforce this line of reasoning. The graph shows the change in elevation of the points shown in Figure 6, after 580,000 repetitions. The sketch in the lower left of the figure shows the relative location of the wheels and the points. The change in elevation between stations 1 and 7 is relatively consistent. Line A at the loaded edge of the slab has moved downward about 0.25 in. while line D on the opposite edge shows little change in elevation. Station 7 marks the west edge of the sleeper slab. Stations 8 and 9 are on the west and east sides of the rubber joint, respectively, and station 10 is at the east edge of the sleeper slab.

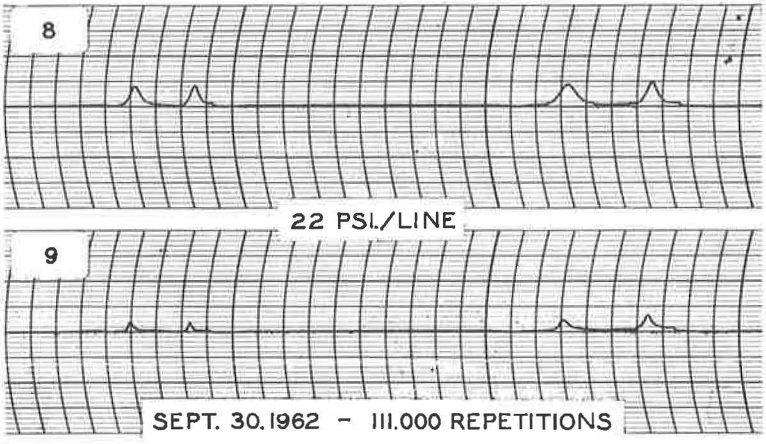
The pavement at the east edge of the sleeper slab has settled about 0.64 in. on line A and about 0.14 in. on line D. The pavement between the sleeper slab and the bottom of the ramp has settled about 0.65 in. on line A and 0.18 in. on line D.

Figure 17 shows the graphs for each point at which a record of the elevations was made. The graphs were plotted with repetitions on the ordinates and deflections on the abscissas; the effects of the pumping from Station 8, just to the west of the expansion joint, to Station 12 can be seen.

The principal cause of pumping was poor subbase drainage. Moisture tests indicated that the moisture content of the base material was about 24 percent. Rain had little effect on these readings. Water appeared to collect in the sand layer and during the early storms was forced in and out of the separation between the pavement and the sleeper slab. Much of the water and sand was forced out of the separation into the hole along the edge of the slab at deflectometers U-5, L-5. As the volume of sand under the slab was reduced, the pumping extended along the edge of the slab—first to the bottom of the east ramp and then back to the U-4, L-4 position at the rubber joint.

STRESSES

Most of the strain readings were recorded from 5 to 6 P.M. The transverse stresses are of questionable value because of the longitudinal cracks that developed through the strain gage stations. Typical oscillographs for the transverse stresses are shown in Figure 18. The maximum readings from these charts were plotted against repetitions to develop the graphs in Figure 19. The maximum transverse stress recorded was 105 psi at gage 8. This was based on an elastic modulus of 4,400,000 psi.



STRESS

Figure 18. Oscillographs for transverse gages 8 and 9.

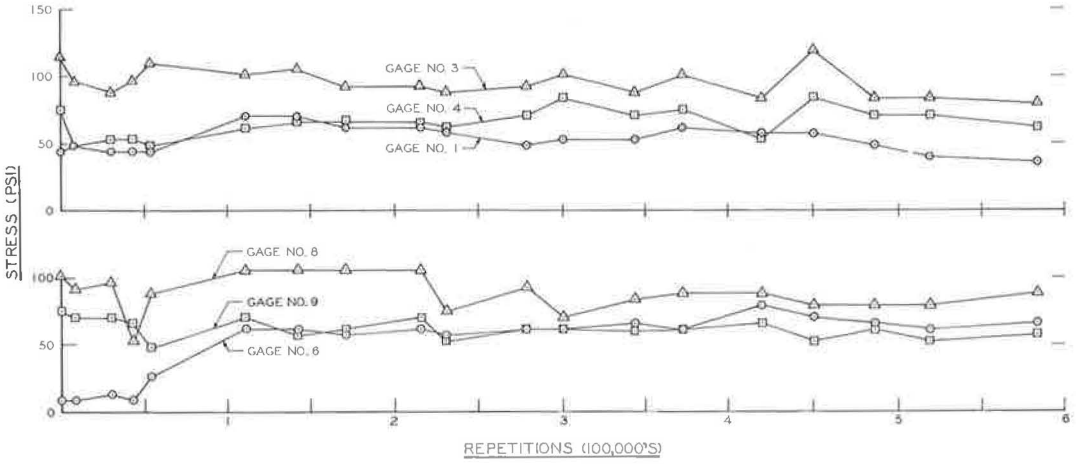


Figure 19. Transverse stresses.

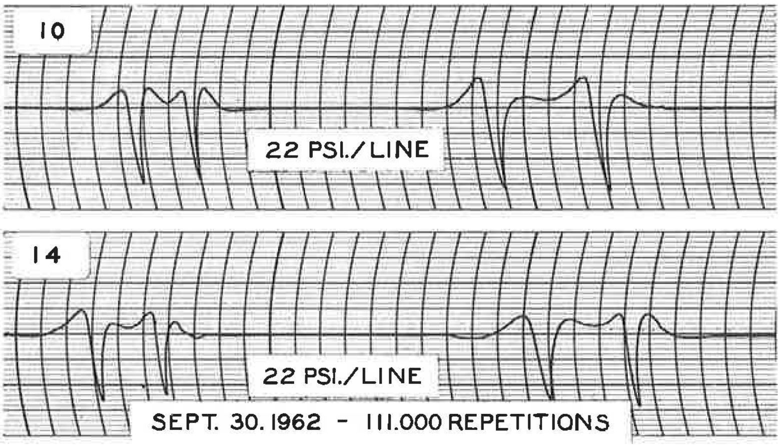


Figure 20. Oscillographs for longitudinal gages 10 and 14.

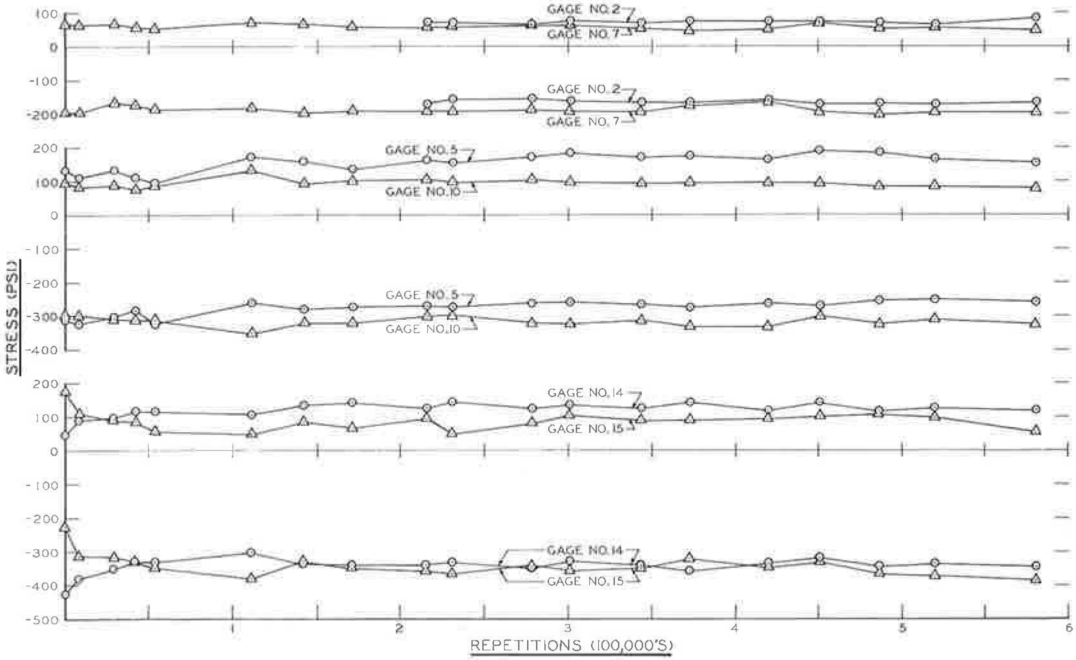


Figure 21. Longitudinal stresses.

The oscillographs shown in Figure 20 for gages 10 and 14 are typical for the longitudinal gages. Figure 21 shows the maximum stresses recorded for the longitudinal gages. Gages 2 and 7 were located 6 ft from the edge of the slab and recorded a maximum tensile stress of 70 psi and a maximum compressive stress of 190 psi. The longitudinal gages along the edge of the slab show a maximum tension of 125 psi for gage 14 located 5 ft west of the edge of the sleeper slab and a maximum compression of 350 psi for gage 15 located at the west edge of the sleeper slab.

CRACKS

Longitudinal cracks were first discovered on August 22, 1962 during the initial compaction runs. These cracks are shown in Figure 22 and represent the condition that existed at the beginning of the test. They are located over the prestressing tendons. The relative position of the wheels is shown in the figure.

A record of the final cracks, after 580,000 repetitions, was made on December 2, 1962. These are shown in Figure 23. West of the joint the cracks at F-1 and F-4 increased in length only a few inches. Fifty thousand repetitions of the load caused an

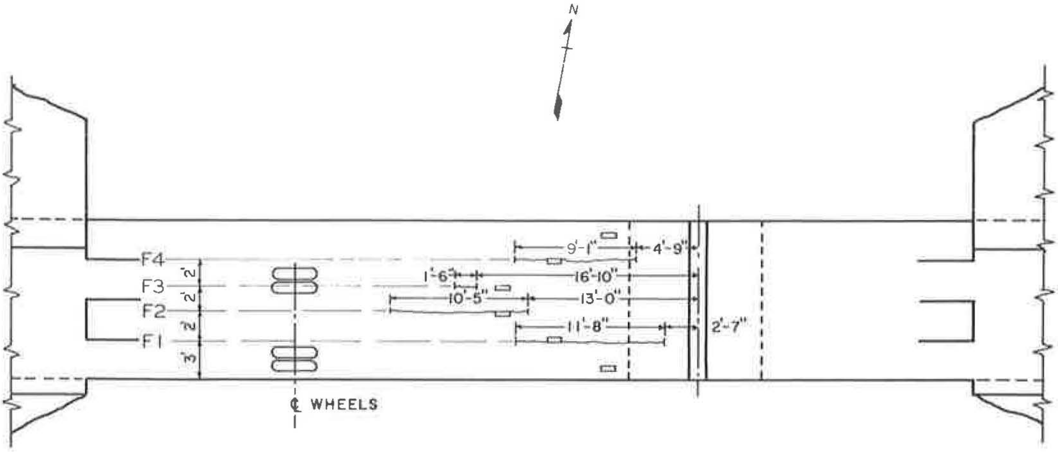


Figure 22. Longitudinal cracks, Aug. 22, 1962.

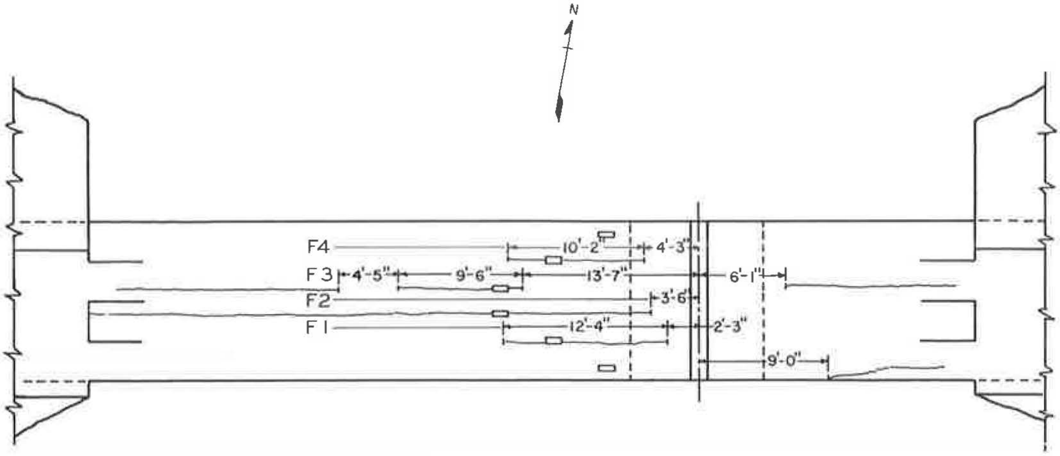


Figure 23. Longitudinal cracks, Dec. 2, 1962.

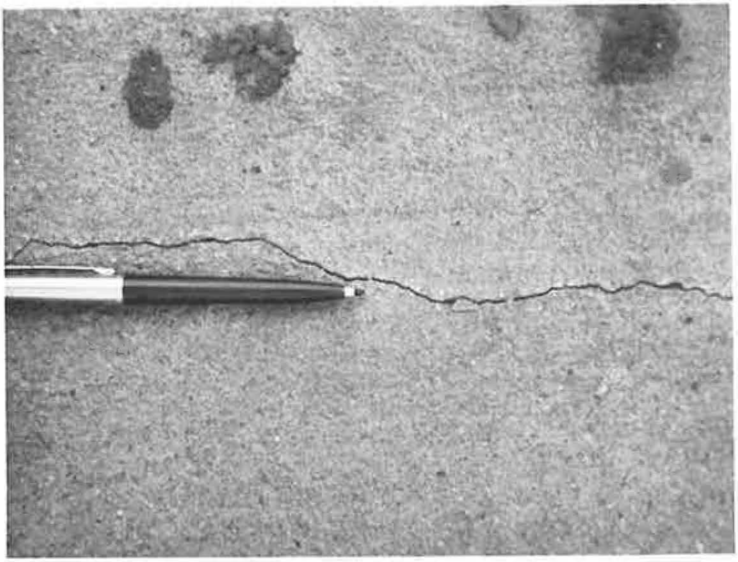


Figure 24. Longitudinal crack at F-2.

extension of the crack F-2 from the west ramp to within 5 ft of the rubber joint. At the same time, a crack 8 ft long was found extending from the west ramp in line with F-3. Three hundred fifty thousand repetitions brought these two cracks on line F-3 within 7 ft of each other.

The cracks east of the joint developed during the rain on November 9 at 350,000 repetitions. When they were originally discovered, the crack along F-4 was within 8.5 ft of the expansion joint, and the crack at the edge of the pavement was 12.75 ft from the joint.

Toward the end of the tests, the edge of the slab was exposed for about 12 ft extending west from the west edge of the sleeper slab.

This was painted with whitewash to determine whether or not transverse cracks had developed on the bottom of the slab. After 25,000 repetitions an inspection was made and no evidence of cracks was found.

An examination of the test site in the summer of 1963 revealed that the crack at F-3 had extended the entire length of the slab to a point 3.5 ft west of the expansion joint. All the other cracks remained essentially the same as they were at the end of the tests.

A close-up of the crack at F-2 is shown in Figure 24. The picture was taken at what appears to be the widest crack in the test section. At this point it was 0.043 in. wide.

CONCLUSIONS

Wheel loads were applied to the slab at the rate of 500 repetitions per hr. Except for breakdowns, maintenance, and reading of the instruments this was a 24-hr operation. The 580,000 repetitions were accomplished in two and one-half month period from September 19, 1962 to December 1, 1962. During this time, the vehicle was shut down for maintenance and repairs or due to malfunction of the controls for a total of 21 days.

During the test the downward movement of the slab west of the joint increased to 0.25 in. at the loaded edge. In spite of this, the stresses shown in Figures 19 and 21 and the moving load deflections shown in Figure 11 were nearly constant for the pavement. The longitudinal stresses were well below the cracking stress and an investigation of the loaded edge of the slab revealed no transverse cracks.

The downward movement east of the joint was considerably greater. The loaded edge of the slab subsided about 0.65 in. This was caused by the excessive pumping in this area.

The project was initiated as a test of the prestressed slab. The data accumulated on the subgrade condition developed as a part of the investigation. It should be emphasized that in spite of the adverse foundation conditions the components of the pavement performed remarkably well. There was no serious damage done to either the slab or the rubber joint. The structural performance was excellent. Longitudinal cracks were evident over the tendons and should be considered in future designs. The appearance of similar cracks after grouting the tendons during slab construction, leads to the belief that these cracks were not entirely a result of the moving loads. The reduction of the cross-section due to the tendons was also a contributing factor.

While this test indicates the fine performance of the pavement under relatively extreme conditions, it is felt that further testing under normal highway conditions is necessary. It is recommended that a test pavement of this type be incorporated as a part of the construction of an actual highway. Particular attention should be given to the design and drainage of the subgrade, the placing of the slab on the sleeper slab, and the reduction or elimination of the longitudinal cracks by redistributing the prestressing strands, and, if practicable, the inclusion of transverse reinforcement.

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