

FULL SCALE CRAWLER BELT SHOE TESTS SURFACE EFFECTS

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U. S. Army Engineer Division, Ohio River
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Ohio River Division Laboratories
Cincinnati, Ohio 45227

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Technical Memorandum No. 2-64

April 1967

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John F. Kennedy Space Center, NASA

Design Engineering

Civil Engineering Division

Kennedy Space Center, Florida

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U. S. Army Engineer Division, Ohio River

Corps of Engineers

Ohio River Division Laboratories

Cincinnati, Ohio 45227

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SUMMARY

A qualitative evaluation is made of the materials and methods being considered for remedial construction of the crawler way pavements for Launch Pads A and B of Lunar Launch Complex 39 at the John F. Kennedy Space Center. The materials and surfacing are described and are evaluated through simulated loading with a full scale crawler belt shoe from the Crawler Transporter. The results of these studies have indicated the most feasible of the surfacing materials evaluated both from the standpoint of structural stability and desirable friction characteristics when used with a special lubricant. Further full scale studies of this surfacing material are recommended for tests under the operation of the fully loaded Crawler Transporter.

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P R E F A C E

The studies described in this report completes the requirements in Amendment No. 3 of NASA Defense Purchase Request Number CC-15162 dated 28 December 1966 to the U. S. Army Corps of Engineers, Ohio River Division Laboratories, Cincinnati, Ohio. Mr. J. H. Deese (MF) is the technical representative responsible for technical surveillance and coordination on behalf of the John F. Kennedy Space Center, NASA.

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The Director and Assistant Director of the Ohio River Division Laboratories during this study were Messrs. F. M. Mellinger and R. L. Hutchinson, respectively.

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FULL SCALE CRAWLER BELT SHOE TESTS

SURFACE EFFECTS

PART I: INTRODUCTION

Background

1. During the past 18 months unforeseen difficulties have come about in the operation of the Crawler Transporter (CT) at the Lunar Launch Complex 39, Kennedy Space Center, Florida. The difficulties or problems with which this study is concerned is the maneuvering of the Crawler Transporter to position the Lunar Umbilical Tower (LUT) within the Vertical Assembly Building (VAB), transporting the LUT and vehicle to the Launch Pads, and finally maneuvering the Launch Assembly into position over the supports on the launch pads.

2. The Crawler Transporter is moved and supported by tractors with twin crawler belts at each of its four corners. When the Crawler Transporter is fully loaded each tractor transmits a load of about 4.4 million pounds to the operating surface through its crawler belts. Directional steering and maneuvering is accomplished by rotating each tractor about its central axis. Although the average pressure transmitted to the pavement surface by the crawler belts is in the order of 60 psi, any unevenness of the supporting surface will increase this pressure many fold. This is due to the fact that the contact surface of the crawler belts is rigidly sprung. That is, the bogie wheels will not adjust to surface irregularities. Steering or turning the tractors is also a problem unless there is a relatively low coefficient of sliding friction between the crawler belts and pavements. More complete details on the Crawler Transporter, its loading, and operational pattern are given in Reference 1.

3. The operating surface for the Crawler Transporter in the VA Building is asphaltic concrete (AC). Protection of this AC surface and maneuvering difficulties are alleviated in this area by providing 1/4-inch thick Douglas fir plywood panels over the AC surface. The plywood is lubricated with a vegetable oil soap (Flaxoap) to provide a low coefficient of sliding friction. Operation of the Crawler Transporter under these conditions is satisfactory and results in little or no damage to the plywood panels. Anchorage of the plywood to the AC surface has not been necessary.

4. Initially the trackways for the Crawler Transporter between the VA Building and launch pads were paved with a three foot thick crushed limestone base course and seal coat. This surface was unsuitable for the operation of the Crawler Transporter. As a result three full scale test sections were installed in the trackways and evaluated under the operation of the CT. These test sections were: (a) four inches of sand, (b) four inches of crushed gravel and, (c) four inches of natural river gravel. Evaluation of these test sections indicated that the natural river gravel provided the best operational surface for the CT. Presently the trackways are overlayed with four inches of natural river gravel (maximum size one inch) on the tangents and eight inches of natural river gravel (maximum size 2.5 in.) on the curves.

5. The crawler ways on the launch pads are paved with welded grating fifteen inches deep assembled in sections 13.5 feet long and eight feet wide. The individual sections are bolted down to embedded anchor strips and filled with small aggregate concrete. Due to initial warpage of the grating sections and placement difficulties, there are offsets and irregularities in this paved surface. There are high and low points within the grating sections and offsets varying from 1/4 to one inch at junctures between the grating sections. One operational difficulty on this surface experienced by the CT was the high frictional resistance between the crawler belts and pavement. Also, the tractors tended to hang up on the high parts of the pavement and when moving off there is considerable jarring. This jarring is undesirable for the supporting structure of the launch pad and for the launch vehicle assembly being transported. At the present time, these problems are being alleviated by overlaying the crawler ways on Launch Pad A with a 2.5-in. thick course of natural river gravel having a maximum size of about 3/8 inches. While from the standpoint of operating the CT on the launch pad this overlay surface is adequate, it is undesirable because it must be removed prior to launching the vehicle.

6. A number of alternate proposals have been made for providing a suitable operating surface for the CT on the crawler ways of Launch Pad A. These are:

- a. Grind the surface level and provide a suitable lubricant.
- b. A resilient leveling course covered with a 3/16-inch steel plate surface and lubricated.
- c. A resilient leveling course alone with a lubricant.
- d. Use removable plywood panels suitably lubricated.

Any permanent surfacing used as a leveling course in addition to having suitable structural and friction characteristics must be compatible with liquid oxygen and resistant to heat in the order of 700° F for short periods of time. Any lubricants used must be LOX compatible and reasonably easy to remove.

7. Preliminary qualitative evaluations have been made in connection with the foregoing proposals. This work has been accomplished by means of sliding friction tests on the various surfaces with a small scale model of a crawler belt shoe of the Crawler Transporter. The results of these studies are reported in Reference 2. A leveling course material meeting the LOX compatibility ⁽³⁾ and heat requirements is also described and evaluated in this report on the small scale model studies.

Purpose and Scope

8. It was considered desirable to make further tests in connection with the proposed remedial surfacing for the crawler ways of Pad A prior to full scale construction and testing. This further work consists of testing the currently proposed surfaces and lubricants for structural and frictional effects with an appropriately loaded full scale crawler belt shoe of the Crawler Transporter. It is the purpose of this report to present the results of these tests and to describe as necessary the test apparatus, test procedures and materials used. Two basic surfaces (PCC and a LOX compatible resilient surfacing material) and two secondary surfaces (1/4-inch plywood and 3/16-inch steel plate) are evaluated with the full scale crawler belt shoe. Three different types of lubricants are also tested with the basic and secondary surfaces.

PART II: TEST APPARATUS

Loading Requirements

9. A full size crawler belt shoe of the Crawler Transporter was received at the Ohio River Division Laboratories from the Kennedy Space Center, NASA on 14 January 1967. The shoe weighed 2100 pounds. In plan the ground contact of the shoe is about 16 inches wide and 7 feet six inches long. (See Figure 1). Due to the rounded sides and 6-inch turn up at the ends the area of the actual ground contact surface of the shoe is about 1100 square inches. The average unit pressure under the crawler belts is 60 psi. Therefore, a vertical load of 66 kip on the shoe would provide this average pressure. However, due to wind loading and other considerations the test apparatus was designed to have a capacity for applying up to 150 kip vertically and about 100 kip in the horizontal direction to the shoe simultaneously. Another requirement is that there would be no frictional resistance in the horizontal direction other than that of the shoe contact with the test surface.

Test Set Up

10. The vertical load is applied to the center of the shoe by means of a 200 ton capacity hydraulic jack as shown in Figure 2a. The jack and gage were calibrated with a 400 kip capacity universal testing machine. Vertical loads can be read on the gage to the nearest kip. Figure 7a shows the test arrangement for measuring vertical movement as vertical loads are applied. The shoe with the steel plates and jack in the center weighs about 3000 pounds.

11. The horizontal load is applied to the shoe by means of two 60 ton capacity hydraulic rams. The points of force application and positioning of the shoe are shown schematically on Figure 1. The shoe is moved forward with no turning in the direction of the applied horizontal force. The longitudinal axis of the shoe is set at an angle of 24° with the direction of the applied force. This is about the maximum angle of attack of the leading end of a crawler belt. Horizontal movement is measured by means of dial gages and 18-inch rulers placed at each end of the shoe. The rollers at the vertical reaction point and spacing of the rods carrying the reaction beam permit a total horizontal movement of 12 inches without resetting the shoe. Calibration of the hydraulic rams gives the measurement of horizontal force to the nearest 400 pounds up to a total force of 20 kip. Beyond 20 kip measurements are to the nearest one thousand pounds. The greased roller assembly at the vertical reaction point (See Figure 2b) proved effective in obviating resistance to horizontal movement in this area.

PART III: TEST SURFACES AND MATERIALS

General

12. Three basic surfaces and two secondary surfaces were prepared and tested with the full scale crawler belt shoe. The basic surfaces are portland cement concrete, a nominal 0.5-inch thick resilient surfacing and nominal 1.5-inch thick surfacing of this same material. The secondary surfaces tested are a 3/16-inch thick steel plate and a 1/4-inch Douglas fir plywood panel. These surfaces were all tested initially without a lubricant. With the exception of the 0.5-inch resilient surfacing, each surface was also tested with a vegetable oil soap (Flaxoap) lubricant. In addition, the 3/16-inch steel plate surface was tested with a grease-like rust inhibitor (Astrol grease) used as a lubricant. The 1/4-inch plywood panel was tested with a lubricating top coating (Epocast 8444). The nominal 1.5-inch thick resilient surfacing was tested in both a wet and dry condition. This makes a total of 12 test conditions.

Portland Cement Concrete Surface

13. The concrete surface consisted of a pad 3 3/4-inches thick, 8-feet 10 inches wide by 12-feet 6 1/2-inches long. The surface was float finished to a tolerance of 1/8-inch in 12-feet. Actually this surface was an integral part of the test set up and provided the reaction for the horizontal forces applied to the shoe during the sliding friction tests. Figure 2 shows the shoe in test position on the concrete surface. Figure 4b is a close up view of a portion of the surface test area after a test.

Resilient Surface Materials

14. The composition of the Liquid Oxygen Compatible Resilient Surfacing Material consists of an aggregate mixed with a two component polymer binder, (Pro-Seal 994). The binder is a two component polyurethane material which upon being mixed in proportioned amounts will set up at room temperature. It is a proprietary product designated as "Pro-Seal 994, Expansion Joint Sealant" manufactured by the Coast Pro-Seal and Manufacturing Company, Compton, California. In this report the combined binder material and aggregate is referred to as CPS Mortar surfacing. The aggregate used is a natural sand having the following gradation:

<u>Sieve Size</u>	<u>% Passing</u>
4	100.0
8	82.7
16	57.5
30	34.4
50	10.9
100	3.5

Resilient CPS Mortar Surface Construction

15. General. Two thicknesses of the resilient surfacing or leveling course were constructed. In applying a 1.5-inch leveling course to the Pad A crawler ways, the minimum cover due to irregularities in the grating surfacing would be on the order of 0.5-inches. Therefore, it was desirable to test this thickness of surfacing first to see if this thickness would be stable under the loading of the crawler belt shoe. The 0.5-inch thick surfacing was placed on the concrete surface. After tests were completed on the 0.5-inch thick CPS Mortar surfacing, an additional 1.0-inch of the CPS Mortar was added over a rectangular area 40 x 98 inches, which was sufficient to accomodate the shoe tests on the 1.5-inch thick surfacing.

16. 0.5-Inch Thick CPS Mortar Course. Prior to the placement of this material, the concrete surface was cleaned and primed with a brush coat of Pro-Seal 977 Primer. About thirty minutes were required for the primer to dry. The CPS Mortar was mixed in a 5.5 cubic foot Muller Mortar Mixer. For this mixture four parts of dry aggregate to one part of binder by weight were combined. The mixed material was distributed over the prepared concrete surface with shovels, screeded to a 0.5-inch thickness, consolidated with a Syntron Plate Vibrator, and finished with a steel trowel. The material was difficult to screed without tearing and the thickness varied from 0.5 to 0.8 inches. The photographs of Figure 7 show the 0.5-inch surfacing in place.

17. 1.5-Inch Thick CPS Mortar Surface. This surface was created by adding a one-inch thickness of the CPS Mortar to the existing 0.5-inch thick surface. This was done after the crawler belt shoe tests had been completed on the 0.5-inch thick surface. The additional inch of surfacing differed from the base surface in that the mixture contained three parts dry aggregate to one part of the

binder material by weight instead of four parts to one. The second surface, one inch thick was bonded by coating the original surface with a troweled film of the binder material (Coast Pro-Seal 994). Similar mixing and placing procedures were followed. The reduction to three parts aggregate to one of binder improved the placing properties of the mixture. The photograph of Figure 8a shows the 1.5-inch surface in place. The total thickness after adding the final surfacing varied from 1.5 inches to 1.8 inches. For both surfaces the CPS Mortar mixtures were cured for 96 hours before testing.

Steel Test Surface

18. A steel plate (3/16-inch x 8-feet x 12-feet) was installed on the concrete base pavement as a test surface. A photograph of this installation is shown on Figure 5a. The RMS average roughness height of the steel test surface was 20 micro inches.

Plywood Test Surface

19. An A/B Douglas fir plywood panel (1/4 x 46 x 96-in.) was used for the plywood test surface. The plywood was tested over the 1.5-inch thick CPS Mortar surface. It was placed with the B grade side (unfinished) down, and with the A grade side (clear) up. Figure 10a is a photograph of the plywood panel taken after the loading tests had been completed.

Lubricants

20. Flaxoap. This is a brown vegetable oil soap of grease-like consistency, marketed by the Sherwin-Williams Company. This material is LOX compatible. It was tested as a lubricant on all of the test surfaces. It was applied at a rate of about 0.15 pounds per square foot of surface area. It can be purchased for about \$0.26 per pound in 40 pound lots.

21. Astrol Grease. This is a sprayable grease used as a rust and corrosion preventative and is marketed by the Imperial Oil and Grease Co. Inc., Los Angeles, California. The material is LOX compatible. It was used only as a lubricant for the steel surface. The rate of application to the test surface area was 0.06 pounds per square foot. Astrol (trade name) can be purchased for about \$7.50 per gallon in five gallon lots.

22. Epocast 8444. This lubricant is a slate gray topcoating material manufactured by Furane Plastics Inc. The coating is used with a primer, Epocast 516. The Epocast 8444 is a two component epoxy system with a graphite

filler. After priming the plywood panel this material was applied in two coats to the A grade surface of the plywood. This coating was cured at room temperature for 7 days prior to testing. This system can be applied to a surface at a cost of about 10 cents per square foot. A photograph of the plywood panel and coating after testing is shown in Figure 10b. The coating is not LOX compatible.

Bearing Surface of the Crawler Belt Shoe

23. The Crawler Belt Shoe as received at the laboratories, was new and was painted gray. The bearing surface of the shoe was also covered with gray paint. The paint was removed from this surface by sandblasting. Pictures of the shoe and bearing surface after sandblasting are shown on Figure 3. Prior to sliding friction tests the bearing surface had an RMS average roughness height of 250 micro inches. After the sliding friction tests were completed, the RMS average roughness height of the shoe bearing surface varied from 95 to 150 micro inches. The bearing surface of the shoe is also quite irregular varying as much as 0.10 inches over its length. Profiles of the shoe bearing surface, obtained by means of a straight edge and depth micrometer, are shown on Figure 11. These irregularities influenced the amount of surface area actually in contact with the test surface during the sliding friction tests.

PART IV: TEST PROCEDURE

General

24. The test procedure is designed to obtain sliding friction coefficients for the crawler belt shoe on the various test surfaces under a range of constant normal or vertical loads. For these tests, the horizontal force required to start movement of the shoe (breakaway) is measured as well as the horizontal force necessary for continuing movement of the shoe (sliding). The sliding friction coefficient determined is the ratio of the horizontal force necessary for continuous movement of the shoe to the applied vertical load. In addition, observations are made of the effects of the shoe on the stability of the test surface and the actual area of the shoe in contact with the test surface.

Vertical Loads

25. Generally sliding friction tests were made using vertical loads of 50, 100, 110, and 137 kip. As indicated previously, the shoe with the vertical load jack and steel plates beneath the jack weighs a total of about 3.0 kip. Some of the sliding friction tests were also made at this loading. The possible contact area of the shoe is about 1100 square inches. Therefore, under the range of vertical loads indicated average contact pressures would range from about 2.7 to 125 psi. Measurements of vertical deformation were made for each vertical load on the 0.5-inch thick CPS mortar surface, the 1.5-inch thick mortar surface and with the 1/4-inch plywood panel on the 1.5-inch CPS mortar surface.

Horizontal Loading

26. At each normal load the horizontal force required to initiate movement of the shoe and the force required for continuous sliding of the shoe on the test surface was measured. The procedure was to start at the lowest normal load and apply increasing increments of normal load. Measurements of the horizontal forces and movement were made for each increment of vertical load applied. After the final increment (137 kip) the vertical load was released and the sequence repeated. In this manner three measurements of sliding friction were obtained for each normal load used for most of the test surfaces. The range of horizontal movement for a given vertical load varied from 0.5 to 4.0 inches.

Observations and Measurements

27. After the sliding friction tests on each test surface, a photographic record of the condition of the test surface was obtained along with quantitative measurements where applicable. In addition, a determination of the actual area of the shoe in contact with the test surface was made. As indicated by Figure 11, the

bearing surface of the shoe is quite irregular and on a hard, flat surface such as the concrete or the steel plate, very little of the shoe surface would be in contact. However, on the resilient surfaces such as the plywood or CPS mortar, the shoe would have a greater actual contact area. The area of the shoe in bearing was determined in two ways: First, by measuring the area on the shoe after a test to which particles of the test surface adhered, see Figure 4a. Second, by crayoning a one inch grid on the shoe surface prior to testing, and then after the test, counting the squares not obliterated, see Figure 9a. It should be pointed out, however, that for the resilient surfaces such as the CPS mortar and plywood, the contact area measured applies only to the maximum normal load (137 kip). At the lower normal loads the actual contact area would be less.

PART V: TEST RESULTS

Portland Cement Concrete Surface

28. General. This was the first surface tested. Two test conditions were evaluated: the plain concrete surface, and the concrete surface with the Flaxoap lubricant. The results of the sliding friction tests are given in Table 1 for the plain concrete and in Table 2 for the concrete surface lubricated with Flaxoap. These tables give all normal loads at which the tests were made along with the breakaway and sliding horizontal load, the amount of horizontal movement for each load and the computed coefficient of sliding friction. Observations of these tests indicated that only about 8% of the bearing area of the shoe was in contact with the test surface (See Figure 4a.).

29. Plain Concrete Surface. As may be seen from Table 1, the breakaway force is essentially the same as the sliding force, and the coefficient of sliding friction varies from 0.6 to 0.8. When movement started on the concrete surface there was no jerking. That is, the buildup was gradual with no increase or decrease in horizontal force. The only effect on the concrete surface was some scuffing or abrasion where the shoe made contact. (See Figure 4b).

30. Concrete Surface Lubricated with Flaxoap. As may be seen from Table 2, the coefficient of sliding friction is about 0.2 for this test condition. However, there was quite a buildup of horizontal force under each normal load before sliding occurred at an appreciably reduced horizontal force. The breakaway movement occurred suddenly. For example, Table 2 indicates that for the 137 kip normal load the breakaway force was about 15 kip greater than the force necessary to maintain sliding. Also, this difference tends to decrease as the normal load is decreased. However, once movement starts the coefficient of sliding friction is consistently in the neighborhood of 0.2 for all normal loads.

31. Discussion

a. Plain Concrete Surface. This was the first test made with the shoe, and its contact surface had no wear other than the initial sandblasting. It has also been indicated that the RMS value for the shoe bearing surface was reduced from about 250 to 150 during the test program (See Paragraph 23). Therefore, it is likely that the coefficients of sliding friction given in Table 1 are high, and a worn shoe might yield coefficients in the range of 0.5 to 0.6. However, these values are still too high for satisfactory maneuvering of the Crawler Transporter and a reduction would be necessary through the application of a satisfactory lubricant.

b. Concrete Surface With Flaxoap Lubricant. The Flaxoap lubricant reduced the coefficient of sliding friction on the concrete very appreciably from about 0.7 to 0.2. However, the buildup of horizontal force and its sudden reduction when sliding started would be an undesirable feature in operating the Crawler Transporter on a concrete surface with this lubricant. This stick slip phenomenon can be likened to what occurs in metals when they are extruded with a lubricant under high pressures. In this case the severity is dependent on the magnitude of the pressure and the time the pressure is applied before movement takes place. In the case of metal extrusion the use of lubricants with higher melting points has provided a solution. With only 8% of the shoe in contact with the test surface the contact pressures for the normal loads used could range from 500 to 1500 psi. Further, the severity of the stick slip action did increase with an increase in normal load. Therefore, if at any time it is planned to lubricate a concrete surface for the operation of the Crawler Transporter, a lubricant that performs better than Flaxoap under these conditions will be required. Possible high melting point lubricants that could be investigated are combinations of zinc and lithium stearates in both the powdered form and dispersed in water.

Steel Surface, 3/16-Inch Plate

32. The results of the sliding friction tests with the steel plate supported by the concrete surface are given in Tables 3, 4 and 5 for the shoe on the plain steel surface, the steel surface lubricated with Flaxoap, and with the Astrol grease lubricant respectively. The coefficient of sliding friction for the plain surface is about 0.3. The two lubricants were equally effective, reducing the friction coefficient to about 0.2. Figure 5 shows the steel surface and that of the shoe after the test without a lubricant. A more detailed view of the shoe surface is given in Figure 6b. Only about 6% of the shoe bearing area was in contact with the steel plate for these tests. Although this would produce slightly higher contact pressures than was the case with the lubricated concrete surface, the stick slip phenomenon did not occur with the lubricants on the steel surface. The only movement of the plate during the sliding friction tests was due to the plate leveling out as the loaded shoe moved on the surface. There was no sliding of the steel plate as it transmitted the horizontal forces to the concrete surface.

33. Discussion. The coefficient of sliding friction on the plain surface of the steel plate may be reduced by additional wear on the shoe. There is also some possibility that this would be true for the lubricated surfaces. If a suitable lubricant is found for the concrete surface, that is one that would eliminate the stick slip phenomenon, there is a good indication that operation of the Crawler

Transporter would be similar on either a lubricated steel or concrete surface. If steel plates are used on any type of surface, one of the problems, if an anchoring system is necessary, will be to provide for movement as the steel surface levels under the loading of the Crawler Transporter.

0.5-Inch CPS Mortar Surface

34. The results of the sliding friction tests on this surface are given in Tables 6 and 7. These are duplicate tests. The results reported in Table 6 are those for the first run. That is the shoe was moved continuously under the series of normal loads indicated in Column 1 of the table. After this series the shoe was removed, the surface cleaned of loose particles, and the shoe reset in its initial position. Table 7 gives the results of the repeat loading. Both sets of results indicate a sliding friction coefficient of about 0.4. The breakaway and sliding loads were generally the same throughout the tests. A maximum of about 70% of the shoe bearing area was in contact with the test surface. No tearing or breakdown of the test surface occurred. Granulation of the test surface to about a 1/8-inch depth took place under the protruding lugs of the shoe. There was also some stripping or scouring of the binder material from the aggregate where the shoe was in direct contact with the test surface (See Figure 7b.) In addition to the sliding friction tests, the deflection or vertical movement of the shoe was measured under the 50, 100, 110, and 137 kip normal loads. The results of these tests are plotted in the lower curve of Figure 13. For all loads, the deflection was less than 0.01 inch. No tests were made with lubricants on this surface, since their after effects could interfere with bonding the additional inch of material for creating the 1.5 inch thick test surface.

35. Discussion. The significant result of this test is that the resilient surfacing material remained quite stable under the test conditions when placed in thickness of 0.5 to 0.8 inches, even with a frictional coefficient that is higher than will occur if a lubricant is used. This would indicate that the use of a nominal 1.5-inch thick surface of this material on the crawler ways of Launch Pad A should be stable under the operation of the Crawler Transporter. As indicated previously, surface irregularities on the crawler ways can produce minimum thicknesses of about 0.5-inches when a 1.5-inch thick leveling course is applied.

1.5 Inch CPS Mortar Surface

36. General. Four sliding friction tests were made on the 1.5 inch thick CPS mortar surface. These were tests on the surface wet (with water), and dry, and two tests with the Flaxoap lubricant. The results of these tests are

given in Tables 10, 11, 12 and 14. In addition, vertical deformations were measured for the four applied normal loads. The results of these measurements are given by the upper curve of Figure 13 in which vertical movement is plotted versus load for both increasing and decreasing normal loading. These curves indicate a maximum vertical movement of about 0.074 inches for the 137 kip load. They further indicate complete recovery of the surfacing when loading was reduced from 137 kip to zero. That is, there was no permanent deformation.

37. Surface Wet and Dry. The coefficient of sliding friction was of the same order of magnitude (about 0.4) for both the wet and dry surface condition. About 71% of the shoe bearing surface was in contact for the wet condition. In both cases there was an indication of a slight buildup of the breakaway force. However, this had no effect on the continuity of the horizontal movement. That is, there was no jerking or irregularities. For both tests the surface was abraided to a depth of less than 1/8-inch where the shoe made contact. Photographs of the surface after test (dry) and of the abraided materials are shown on Figure 8. Microscopic examination of the abraided materials indicated that they consisted of the larger aggregate sizes and the binder material with fine sand as a matrix. Some of the large aggregate pieces were scored.

38. Flaxoap Lubricated Surfaces. Two tests were made for this condition in that after the first test was run the shoe was removed and the surface cleaned. Then for the second test the surface was lubricated with a fresh application of Flaxoap. Coefficients of sliding friction were the same for both tests (about 0.1). The results of the sliding friction tests shown on Tables 12 and 14 indicate that the breakaway force was usually less than the sliding force and that there was a slight increase in the coefficient of sliding friction with increasing horizontal movement. Surface abrasion was considerably less with the lubricant than for the wet and dry untreated surface conditions.

39. Discussion. The increase in vertical deformation for the 1.5-inch thick surface over that of the 0.5-inch thick surface (See Figure 13) can be attributed to: (a.) the increase in thickness of one inch and (b.) the binder content of the added inch of material was greater than that of the base material (See Paragraph 17). This material is more resilient and since no tearing of the surface took place under the shoe tests, the three part sand to one part of binder mixture is preferable.

40. The Flaxoap lubricant reduced the coefficient of sliding friction of the CPS mortar surface from about 0.4 to 0.1.

41. The 1.5-inch thick CPS mortar surface was structurally adequate under the full scale shoe loadings, and subsequent coring of the surface materials

indicated that there was no impairment of bond between the 0.5 and 1.0-inch surfaces. As a matter of record, this bonded interface was stronger than the adjoining materials.

42. The increase in the coefficient of sliding friction as the horizontal movement increased for the tests with the Flaxoap lubricant could be attributable to a reduction in the amount of lubricant at the contact areas as the shoe moved horizontally. This may also be the reason why the horizontal sliding force was slightly greater than the breakaway force.

1/4-Inch Plywood Panel Surface

43. General. Three surface conditions were evaluated: (a) the plain plywood surface, (b) the plywood surface lubricated with the Epocast coating and (c) the plywood surface lubricated with Flaxoap. The results of the sliding friction tests for these three conditions are given in Tables 8, 9, and 13. In all cases the plywood panels were supported by the 1.5-inch thick CPS mortar surface. The results of the vertical deformation measurements under the four normal loads are given by the curves of Figure 12. There was no movement of the plywood panels horizontally for any of the three test conditions.

44. Plain Plywood Surface. The coefficient of sliding friction for this test condition was about 0.3 and about 55% of the bearing area of the shoe was in contact with the test surface. There was some abrasion of the surface in the form of sawdust, but no other apparent damage occurred to the plywood panel. The vertical deformation tests (See Figure 12) indicated greater deformation than those for the 1.5-inch CPS mortar surface alone (See Figure 13).

45. Plywood Panel with Epocast Coating. The coefficient of sliding friction indicated for this condition was about 0.2 (See Table 9). The horizontal breakaway force was generally greater than the sliding force. In this case, the shoe stuck slightly before breaking away and the horizontal movement was jerky. When the shoe bearing surface was examined after the test, there was a considerable amount of graphite on it. A photograph of the coated panel after testing is shown on Figure 10b.

46. Plywood Panel with Flaxoap Lubricant. The coefficient of sliding friction for this condition was about 0.1 (See Table 13). The phenomenon of the breakaway force being less than the sliding force also occurs as it did for the CPS mortar surface lubricated with Flaxoap.

47. Discussion. The vertical deformation measurements for the 1/4-inch plywood panel on the 1.5-inch CPS mortar surface (See Figure 12) are greater than those measured for the CPS mortar surface alone. This would indicate a maximum deformation of about 0.011 inches in the plywood alone. With the plywood, recovery was not complete. Since complete recovery was indicated for the CPS mortar surface, this would indicate a permanent deformation of the plywood surfacing of about 0.005 inches.

48. The Flaxoap proved to be a more effective lubricant than the Epocast coating since it reduced the coefficient of sliding friction from 0.3 to 0.1 while the Epocast only achieved a reduction to 0.2. The Epocast coating also had the undesirable effect of causing the shoe to stick slightly before movement started.

49. The plywood surface, even though supported by a 1.5-inch thickness of CPS mortar was not as resilient as the mortar. This is evidenced by the fact that for the tests on the plywood surface only about 55% of the shoe bearing area made contact with the test surface while on the 1.5-inch CPS mortar surface the shoe contact was about 83%.

PART VI: SUMMARY AND DISCUSSION

Test Surfaces

50. In Reference 2, small scale model studies are described, wherein about a 1/20 scale model of the crawler belt shoe was tested on surfaces identical to those on which the prototype shoe has been tested. In the model studies the contact surface of the model shoe was machined and uniform. The maximum contact pressure for the model sliding friction tests was 200 psi. There were also some differences in RMS values as may be seen from the following tabulation:

Table A

Surface Characteristics (Metal)

Contact Surface	RMS in Micro Inches	
	Initial	After Tests
Prototype Shoe	250	95-150
Model Shoe	16	16
Prototype Steel Plate	20	20
Model Steel Plate	20	20

51. A further difference in contact surfaces is brought about by the very irregular surface of the prototype shoe indicated by the profiles of Figure 11. This resulted in quite high contact pressures for the 137 kip normal load of the prototype tests. This condition is summarized for the various test surfaces by the following tabulation:

Table B

Prototype Shoe Contact Areas and Pressures

Test Surface	Contact Area		Max Pressure psi 137 kip Normal Load
	% Total	In. ²	
PC Concrete	8	88	1560
3/16" Steel Plate	6	66	2060
1/4" Plywood	55	605	226
0.5" CPS Mortar	70	770	178
1.5" CPS Mortar	83	913	150

52. As indicated previously, the total possible contact area for the crawler belt shoe is about 1100 square inches. The above tabulation shows as would be expected that the more resilient the test surface the better it will accommodate the irregularities in the bearing surface of the shoe.

53. Even with the above conditions the prototype determinations of sliding friction coefficients were very consistent and reproducible for a wide range of normal loads. This is indicated by the detailed tabulation of test results on Tables 1 through 14.

Sliding Friction Coefficients

54. The following tabulation summarizes the coefficients of sliding friction obtained from the prototype and model shoe tests. The coefficients are rounded off to the nearest tenth.

Table C

Summary of Sliding Friction Coefficients

Type of Surface	Condition							
	Plain		Flaxoap Lubricant		Astrol Lubricant		Epocast Coating	
	P	M	P	M	P	M	P	M
PC Concrete	0.7	0.3	0.2	0.1		0.1		
0.5" CPS Mortar	0.4							
1.5" CPS Mortar	0.4	0.2	0.1	0.1		0.1		
1/4" Plywood	0.3	0.2	0.1	0.1		0.1	0.2	0.1
3/16" Steel Plate	0.3	0.2	0.2	0.1	0.2	0.1		

P - Prototype Determinations

M - Model Determinations

55. Both the prototype and model studies indicate that the CPS mortar surface and the plywood surface lubricated with Flaxoap have the best friction characteristics for the operation of the Crawler Transporter. There is also every indication that the Astrol grease would work equally well as a lubricant on these surfaces. The model studies did not give any indication of the sticking phenomenon that was observed for the tests on the concrete surface lubricated with the Flaxoap and the plywood panel coated with Epocast.

Structural Adequacy of Test Surfaces

56. The question of structural adequacy involves only the application of a 1.5-inch thick CPS leveling course for the crawler ways of Pad A. This question is concerned with the magnitude of the deformation of the surfacing under the operation of the fully loaded crawler transporter, the amount of recovery when the load is removed, and whether it would be stable for a 0.5-inch minimum thickness. Insofar as can be determined from the prototype shoe tests, transient deflections will be less than 0.1 inches, recovery will be complete after the load is removed, and there will be some attrition or powdering of the surface over the contact area of the crawler belts. This last will be reduced if a lubricant is used. Although not simulated in these tests some additional attrition of the surface will be caused by the lugs of the shoes of the crawler belts at initial lay down. Surface irregularities will increase the severity of this attrition.

PART VII: CONCLUSIONS AND RECOMMENDATIONS

57. On the basis of the test results obtained from the sliding friction tests with the full scale crawler belt shoe it is recommended:

a. That full scale tests with the Crawler Transporter be made on a 1.5-inch thick CPS mortar leveling course for the crawler ways of Launch Pad A, and that both Flaxoap and Astrol grease be tried as a lubricant (See Paragraphs 54-56).

b. That further shoe tests be made for the selection of a suitable lubricant for the operation of the Crawler Transporter on a portland cement concrete surface. (See Paragraph 30.)

c. That the test procedures and apparatus developed in this study be used in the initial evaluation and selection of surfacing materials for full scale tests with the pavements involved in the operations of the Crawler Transporter.

REFERENCES

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2. Mellinger, F. M., Nickles, J. M., Potts, A. P., "Friction Characteristics of Crawler Belt Shoe on Various Types of Surface by Means of Small Scale Models", Ohio River Division Laboratories, Technical Memorandum No. 2-59, Jan. 1967
3. Luvall, B. U., "Compatibility of Joint Sealers with Liquid Oxygen", Ohio River Division Laboratories, Technical Memorandum No. 2-44, Aug. 1965

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 1

Test Results of Shoe on Plain Concrete Surface

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	30	30	2.50	0.60
50	--	35	0.50	0.70
50	--	35	0.50	0.70
100	70	70	0.50	0.70
100	--	75	0.15	0.75
110	80	80	0.50	0.73
110	--	88	0.20	0.80
110	--	88	0.10	0.80
137	92	92	0.50	0.67
137	--	100	0.70	0.73
137	--	100	0.30	0.73

8% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 2

Test Results of Shoe on Concrete
Surface Lubricated With Flaxoap

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	9.8	7.5	0.70	0.15
50	9.8	7.5	0.94	0.15
100	25.0	21.0	0.50	0.21
100	27.0	21.0	0.70	0.21
100	23.5	18.0	0.91	0.18
110	35.0	23.5	0.82	0.21
110	27.0	23.5	0.66	0.21
110	27.0	19.5	--	0.18
137	47.0	31.4	0.70	0.23
137	47.0	31.4	0.32	0.23

8% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 3

Test Results of Shoe on 3/16-inch Thick
Plain Steel Plate Surface

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	12.0	12.0	4.0	0.26
100	26.6	26.6	4.0	0.27
110	33.0	31.8	4.0	0.30
137	39.3	39.0	4.0	0.30
137	39.3	39.0	0.4	0.30

6% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 4

Test Results of Shoe on 3/16-inch Thick Steel
Plate Surface Lubricated With Flaxoap

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	9.2	7.4	2	0.15
50	8.8	8.8	-	0.18
100	16.6	16.4	2	0.16
100	22.0	16.6	1	0.17
110	18.6	18.6	4	0.17
110	16.6	16.0	2	0.15
110	17.6	17.5	2	0.16
137	21.6	21.4	4	0.16
137	21.4	--	1	--

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 5

Test Results of Shoe on 3/16-inch Thick Steel
Plate Surface Lubricated with Astrol Grease

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	8.3	7.4	--	0.15
50	9.3	8.0	--	0.16
100	17.4	15.6	--	0.16
100	13.8	13.8	--	0.14
100	17.8	17.0	--	0.17
100	--	17.4	--	0.17
110	15.9	--	--	--
110	15.9	15.9	--	0.14
110	19.0	19.0	--	0.17
110	--	21.2	--	0.19
137	21.8	21.6	--	0.16
137	20.0	20.0	--	0.15
137	21.4	21.4	--	0.16

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 6

Test Results of Shoe on Nominal
0.5-inch Thick CPS Mortar Surface

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	23.6	23.6	2.0	0.47
50	23.6	23.6	1.1	0.47
50	28.0	--	0.5	--
100	40.0	40.0	--	0.40
100	42.0	42.0	1.6	0.42
100	45.8	45.8	0.7	0.46
110	45.5	45.5	--	0.41
110	45.5	45.5	--	0.41
110	47.3	47.3	2.1	0.43
110	51.0	51.0	1.4	0.46
137	53.0	53.0	--	0.39
137	57.1	55.3	2.5	0.40
137	63.0	63.0	1.7	0.46

70% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 7

Test Results of Shoe on Nominal
0.5-inch Thick CPS Mortar Surface*

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	23.0	23.0	0.7	0.46
50	24.8	23.8	0.7	0.48
100	42.0	42.0	1.5	0.42
100	42.0	42.0	1.0	0.42
110	47.0	47.0	1.7	0.43
110	46.7	46.7	1.5	0.42
137	58.0	56.0	2.2	0.41
137	58.0	58.0	2.0	0.42

* Test similar to that tabulated in Table 6, except that the shoe was moved over the mastic surface a second time.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 8

Test Results of Shoe on Plain 1/4-inch Plywood
Over Nominal 1.5-inch CPS Mortar Surface

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
3	0.92	0.92	0.5	0.31
3	0.92	0.92	0.5	0.31
3	1.11	1.11	0.5	0.37
50	--	12.3	1.0	0.25
50	11.9	11.9	0.5	0.24
50	13.0	13.0	0.5	0.26
100	24.8	24.8	1.0	0.25
100	23.8	23.8	1.0	0.24
100	24.8	24.8	0.5	0.25
110	28.6	26.7	1.0	0.24
110	26.7	26.7	1.0	0.24
110	28.6	28.6	1.0	0.26
137	32.4	32.4	1.0	0.24
137	34.3	34.3	1.0	0.25
137	35.2	35.3	1.0	0.26

55% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 9

Test Results of Shoe on 1/4-inch Plywood Coated With
Epocast 8444 Over Nominal 1.5-inch CPS Mortar Surface

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
3	1.11	0.92	1.0	0.31
3	0.92	0.74	0.5	0.25
3	0.92	0.92	0.5	0.31
50	12.9	11.5	1.0	0.23
50	11.5	11.1	1.0	0.22
50	11.5	11.1	0.5	0.22
100	25.7	21.1	1.0	0.21
100	19.4	19.4	0.5	0.19
100	19.4	19.4	1.0	0.19
110	25.7	22.8	1.0	0.21
110	22.8	22.8	1.0	0.21
110	24.8	22.8	1.0	0.21
137	28.6	27.6	1.0	0.20
137	30.5	29.6	1.0	0.22
137	30.5	30.5	1.0	0.22

56% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 10

Test Results of Shoe on Nominal 1.5-inch CPS
Mortar Surface Lubricated With Water

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
3	1.48	1.48	0.5	0.49
3	1.67	1.48	0.5	0.49
3	1.67	1.48	0.5	0.49
50	18.5	18.5	0.5	0.37
50	18.7	18.1	1.0	0.36
50	19.2	18.9	1.0	0.39
100	36.2	36.2	1.0	0.36
100	36.2	35.2	1.0	0.35
100	35.2	35.2	1.0	0.35
110	39.0	39.0	1.0	0.35
110	40.0	38.1	1.0	0.35
110	40.0	39.0	1.0	0.35
137	47.6	46.7	1.0	0.34
137	48.8	47.6	1.0	0.34
137	49.5	48.8	1.0	0.35

71% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 11

Test Results of Shoe on Nominal 1.5-inch Thick
CPS Mortar Surface (dry)

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
3	1.30	1.30	0.5	0.43
50	15.7	15.4	1.0	0.31
100	39.1	38.1	1.0	0.38
110	40.0	40.0	0.5	0.36
137	49.5	48.6	0.5	0.35
3	1.66	1.48	0.5	0.49
50	18.7	18.3	1.0	0.37
100	36.2	36.2	0.5	0.36
110	41.0	40.0	0.5	0.36
137	50.5	50.5	0.5	0.38
3	1.66	1.48	0.5	0.49
50	20.4	20.0	1.0	0.40
100	38.1	38.1	0.5	0.38
110	42.9	41.9	1.0	0.38
137	54.3	53.4	1.0	0.39

83% of Shoe Surface in Contact

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 12

Test Results of Shoe on Nominal 1.5-inch Thick
CPS Mortar Surface With Flaxoap Lubricant

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	--	1.1	1.0	0.02
100	--	3.0	1.0	0.03
110	--	4.1	1.0	0.04
137	--	6.5	1.0	0.05
50	--	2.6	1.0	0.05
100	--	6.5	1.0	0.07
110	--	7.8	1.0	0.07
137	9.4	10.2	1.0	0.07
50	5.6	6.5	1.0	0.13
100	9.4	10.7	1.0	0.11
110	11.7	12.6	1.0	0.11
137	13.7	14.6	1.0	0.11
50	6.5	7.0	0.5	0.14
100	11.1	12.4	0.5	0.12
110	13.1	14.1	0.5	0.13
137	15.7	16.3	0.5	0.12

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

Table 13

Test Results of Shoe on 1/4-inch Thick Plywood

Lubricated With Flaxoap

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	0.5	0.5	1.0	0.01
100	1.8	3.9	1.0	0.04
110	4.8	5.0	1.0	0.05
137	6.7	6.8	1.0	0.05
50	4.6	4.6	1.0	0.09
100	6.7	6.8	1.0	0.07
110	9.4	9.4	1.0	0.09
137	12.0	13.2	1.0	0.10
50	6.1	6.7	1.0	0.13
100	12.0	12.2	1.0	0.12
110	14.8	15.2	1.0	0.14
137	19.4	19.4	1.0	0.14

Note: Plywood supported on nominal 1.5-inch thick
CPS Mortar Surface.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

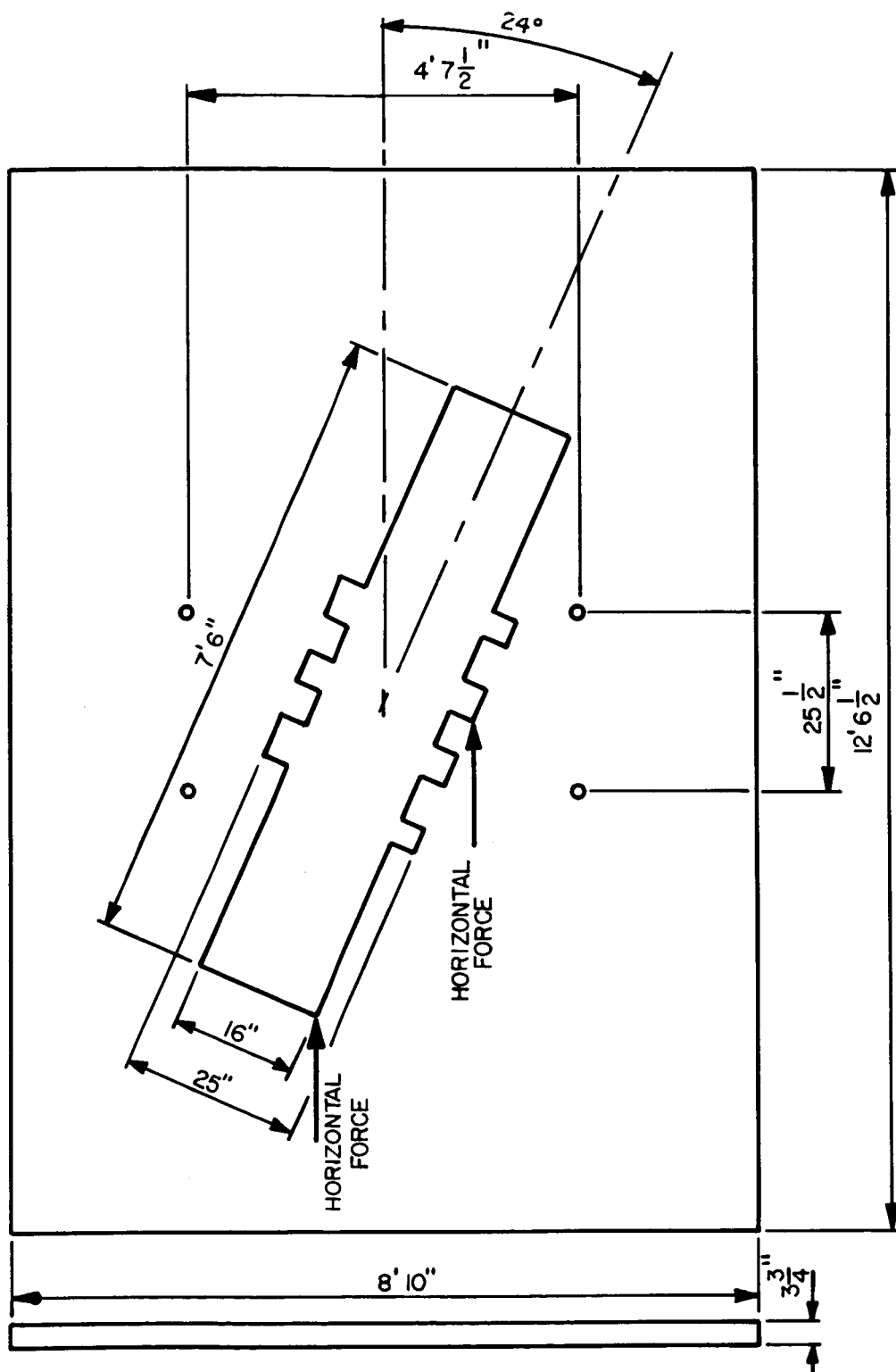
Table 14

Test Results of Shoe on Nominal 1.5-inch Thick
CPS Mortar Surface With Flaxoap Lubricant

Normal Load, Kip	Horizontal Load, Kip		Horizontal Movement, Inch	Coefficient of Sliding Friction
	Breakaway	Sliding		
50	0.6	0.9	1.0	0.02
100	2.6	4.1	1.0	0.04
110	4.3	4.6	1.0	0.04
137	5.0	5.5	1.0	0.04
50	1.5	3.0	1.0	0.06
100	4.1	5.7	1.0	0.06
110	5.9	7.0	1.0	0.06
137	8.0	10.0	1.0	0.07
50	3.7	6.1	1.0	0.12
100	8.5	9.2	1.0	0.09
110	9.8	9.8	1.0	0.09
137	11.1	11.8	1.0	0.09

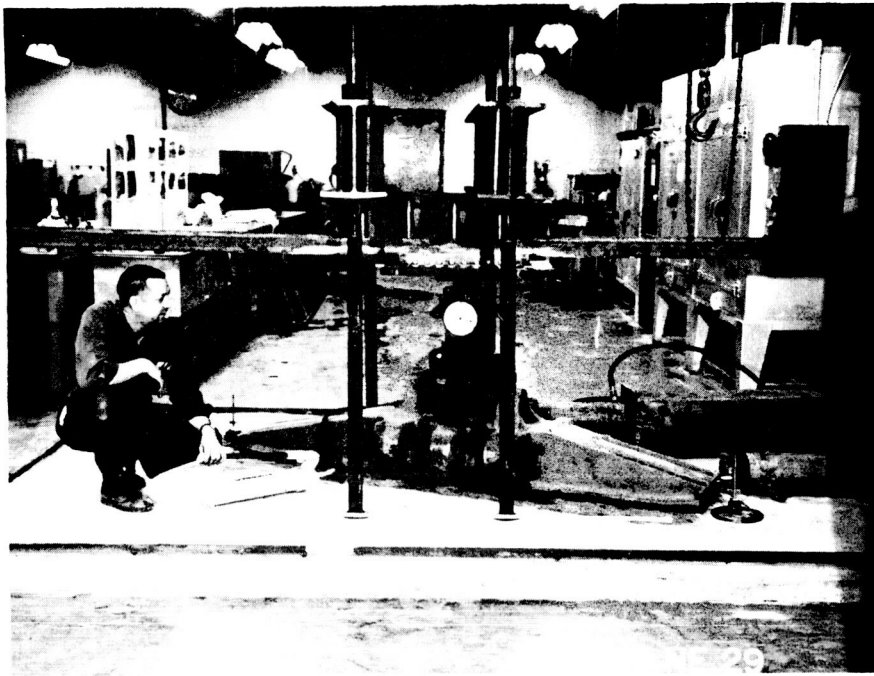
Note: This is a rerun of the test results reported in Table 12. The test surface was cleaned and relubricated with the Flaxoap for this test.

SCALE: 1"=2'

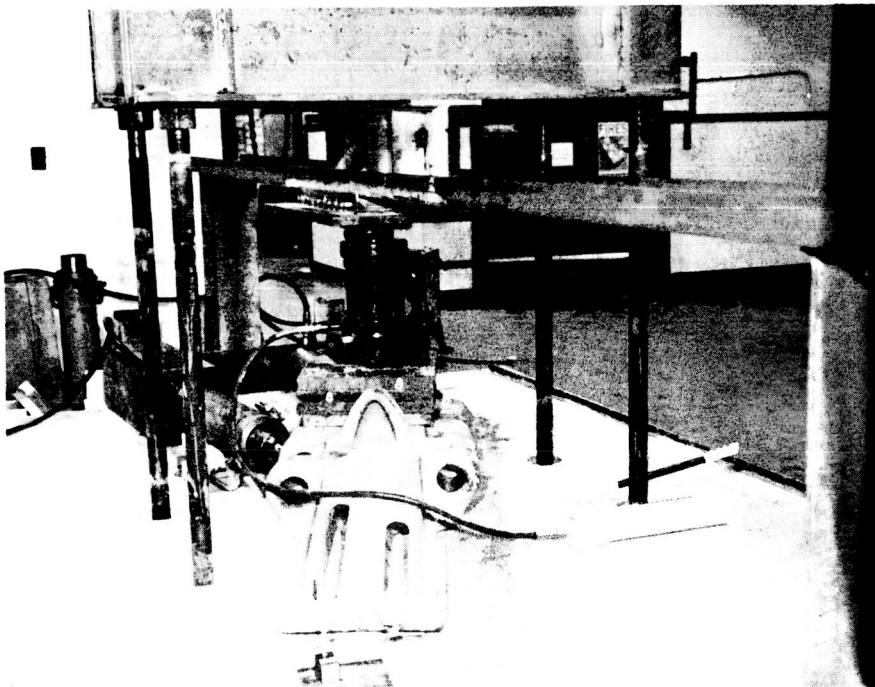


SCHEMATIC ARRANGEMENT OF CRAWLER BELT SHOE ON TEST SURFACE

FULL SCALE CRAWLER BELT SHOE TESTS SURFACE EFFECTS

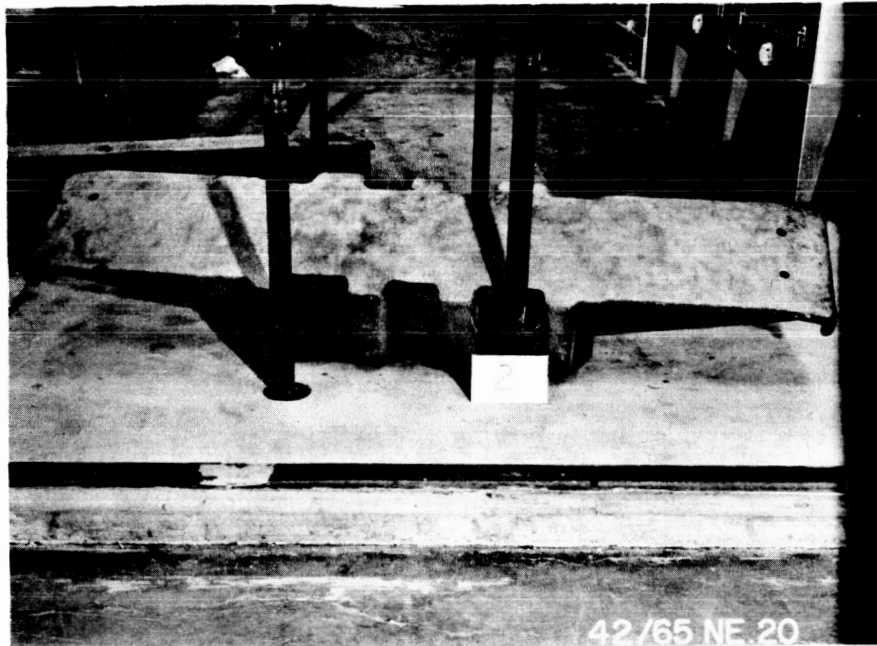


- a. General view of test setup for applying vertical and horizontal loading to the crawler belt shoe.

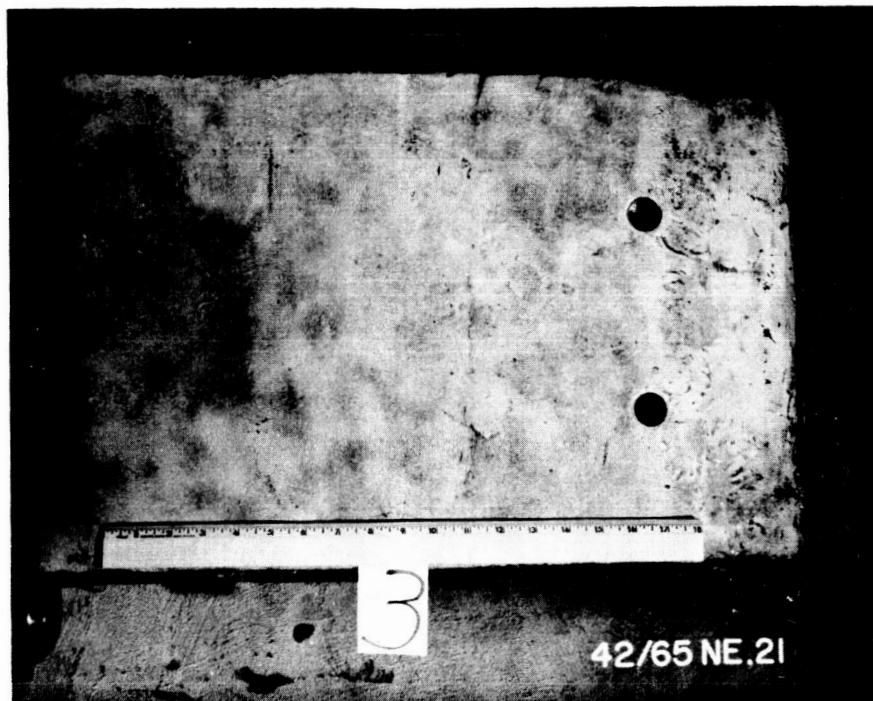


- b. Similar to a. Shoe is oriented 24° to direction of horizontal thrust. Note rollers in guide at normal load reaction point for elimination of friction in the horizontal direction.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS



- a. Overall view of concrete test surface and shoe bearing surface. Possible contact area of shoe is about 1100 sq. ins. Concrete surface is constructed to a tolerance of 1/8-in. in 12 ft.



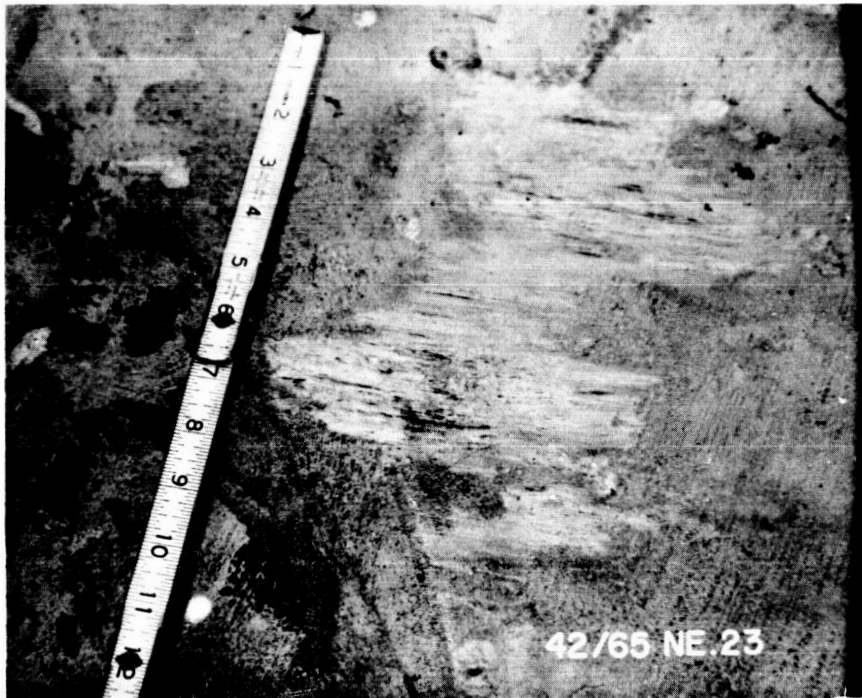
- b. Close up of shoe bearing surface. RMS average roughness height of surface is 250 micro inches.

Figure 3

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

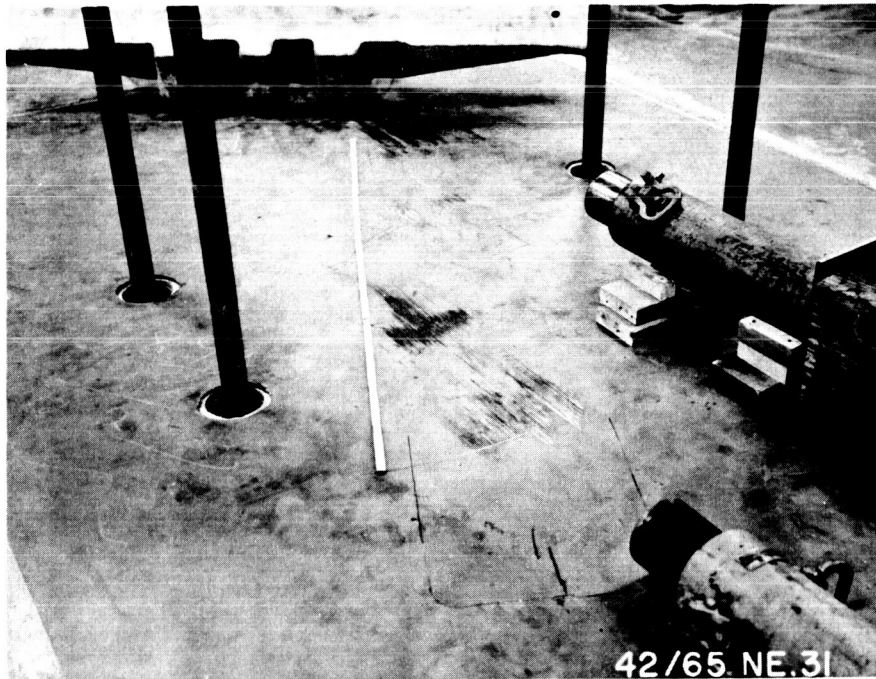


- a. Scuff marks on shoe after test on concrete surface. Area measurements indicate that about 8% of possible contact area was bearing on concrete surface. Maximum normal load 137 kip.

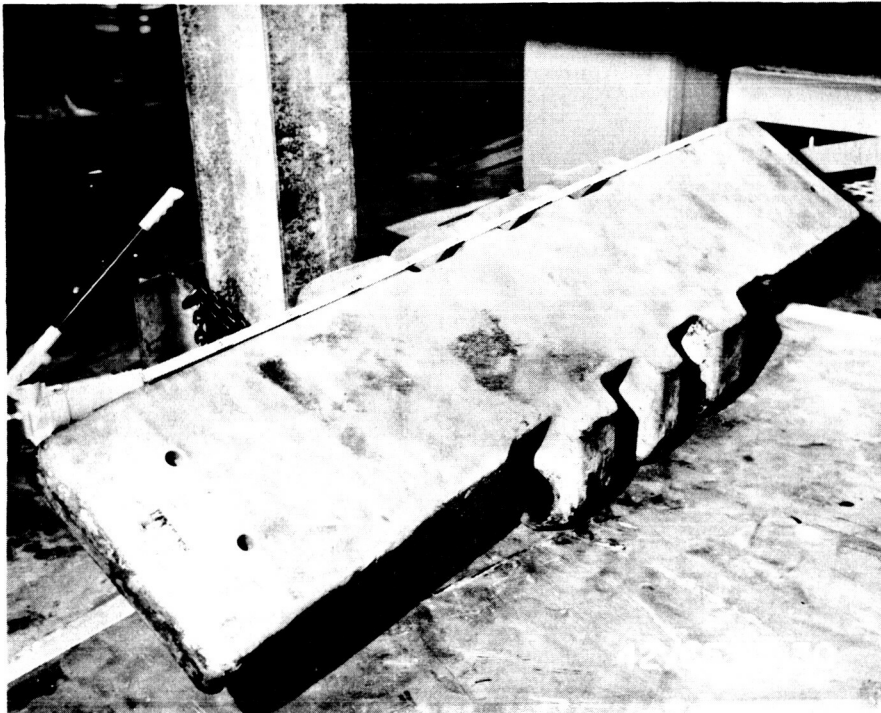


- b. Close up view of scuff marks on concrete surface. Maximum normal load 137 kip.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS



- a. Three-sixteenth inch (3/16") steel plate on concrete surface. Note scuff marks on steel plate after shoe tests on this surface. Maximum normal load 137 kip. RMS avg. roughness height of surface is 20 micro inches.

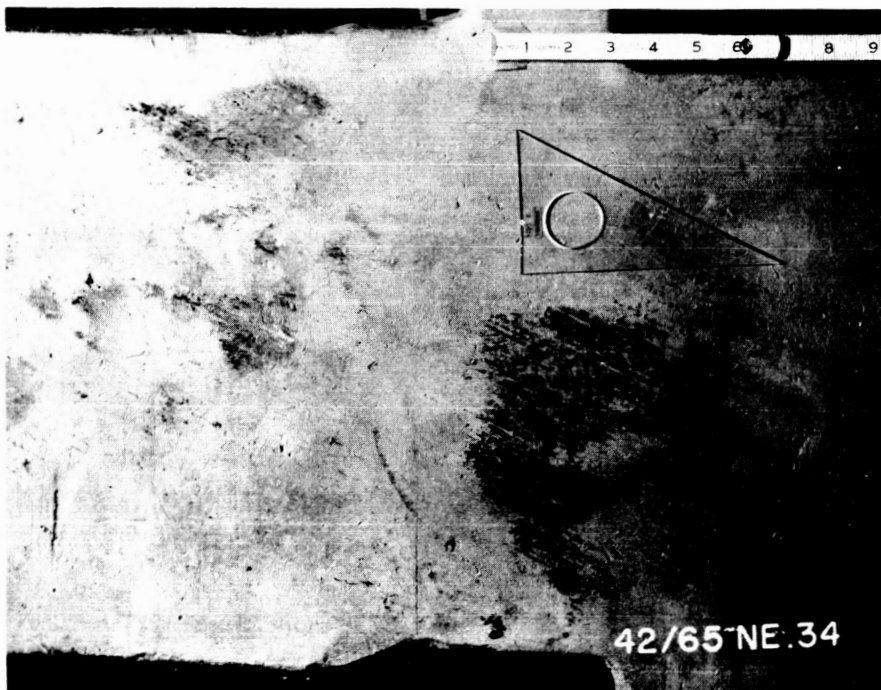


- b. Scuff marks on bearing surface of shoe after tests on steel plate. Only about 6% of possible contact area was in direct bearing with steel plate.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS



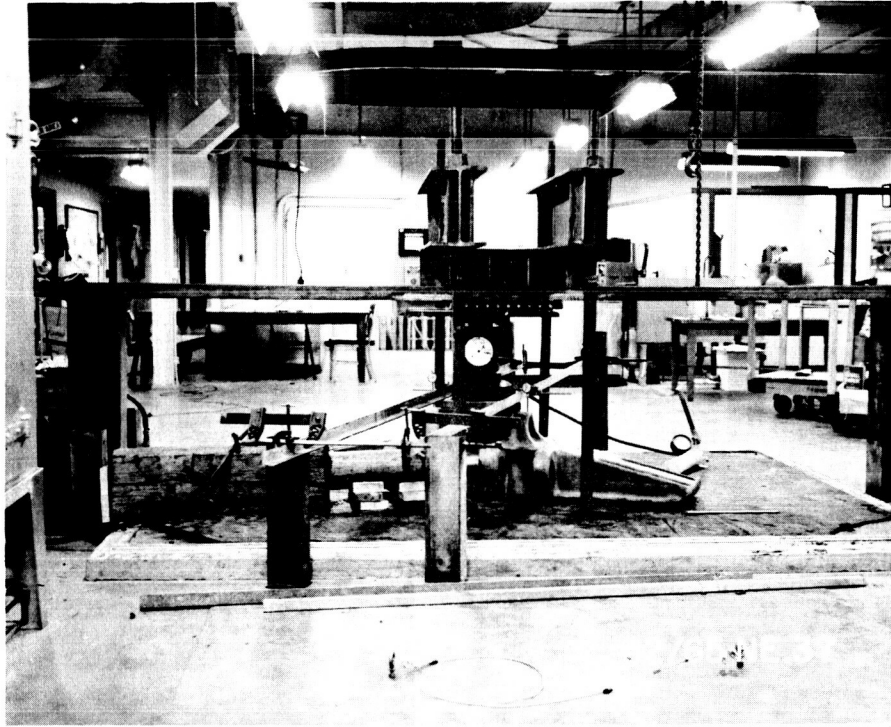
a. Close up view of shoe bearing surface after tests on concrete. Maximum normal load 137 kip.



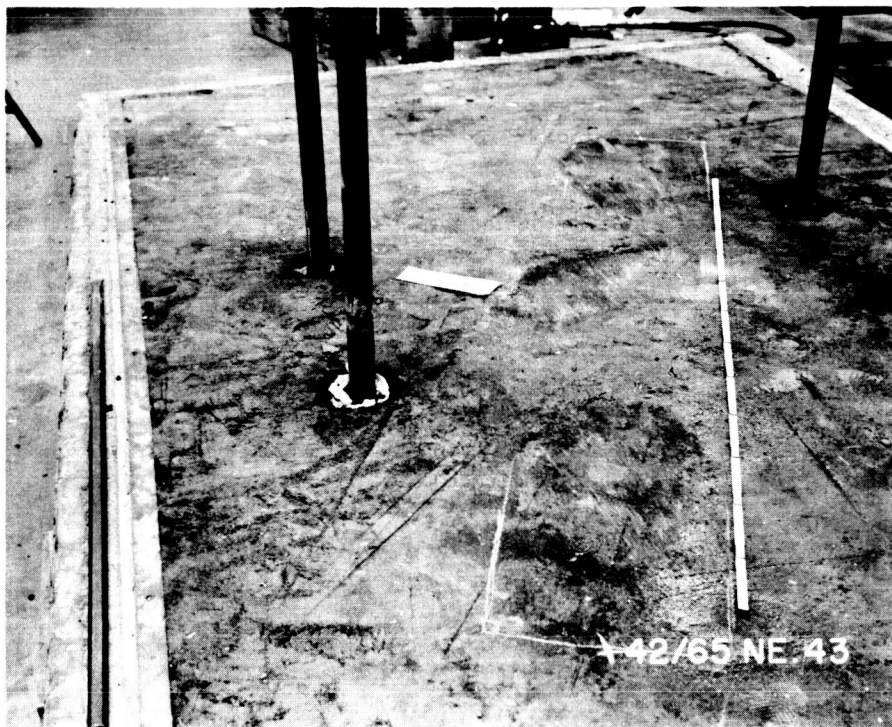
b. Close up view of shoe bearing surface after tests on 3/16-inch steel plate. Maximum normal load 137 kip.

Figure 6

FULL SCALE CRAWLER BELT SHOE TESTS SURFACE EFFECTS

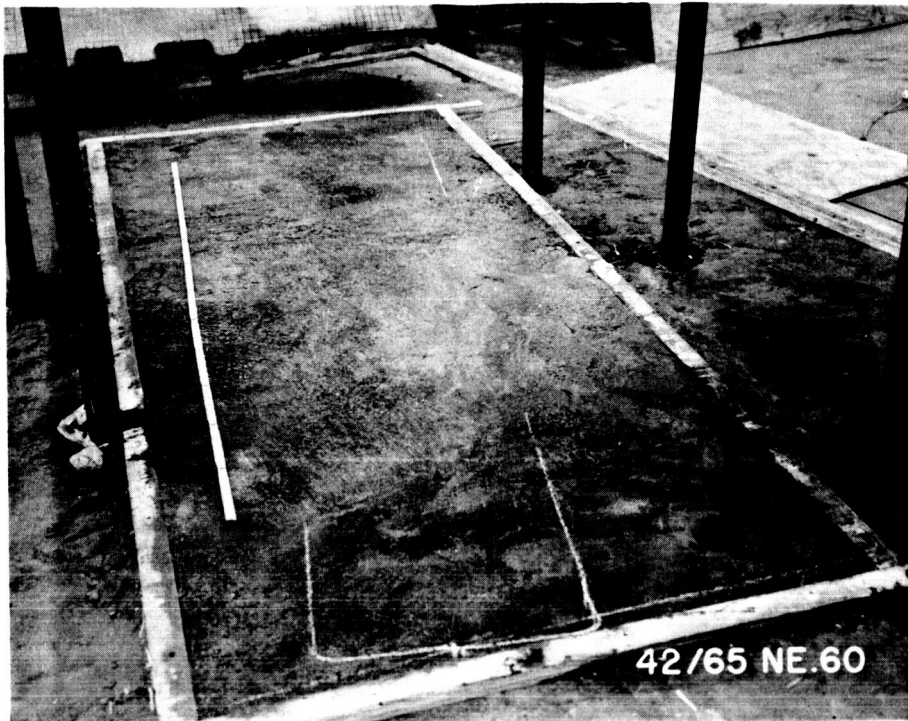


- a. Shoe setup on nominal 0.5-inch CPS mortar surface. Note gages in contact with upright boss on shoe for measuring vertical deflections under normal loads.



- b. Nominal 0.5-inch thick CPS mortar surfacing after shoe loading (max. normal load 137 kip). Arrow points to area where protruding lugs dug into surfacing material.

FULL SCALE CRAWLER BELT SHOE TESTS
SURFACE EFFECTS

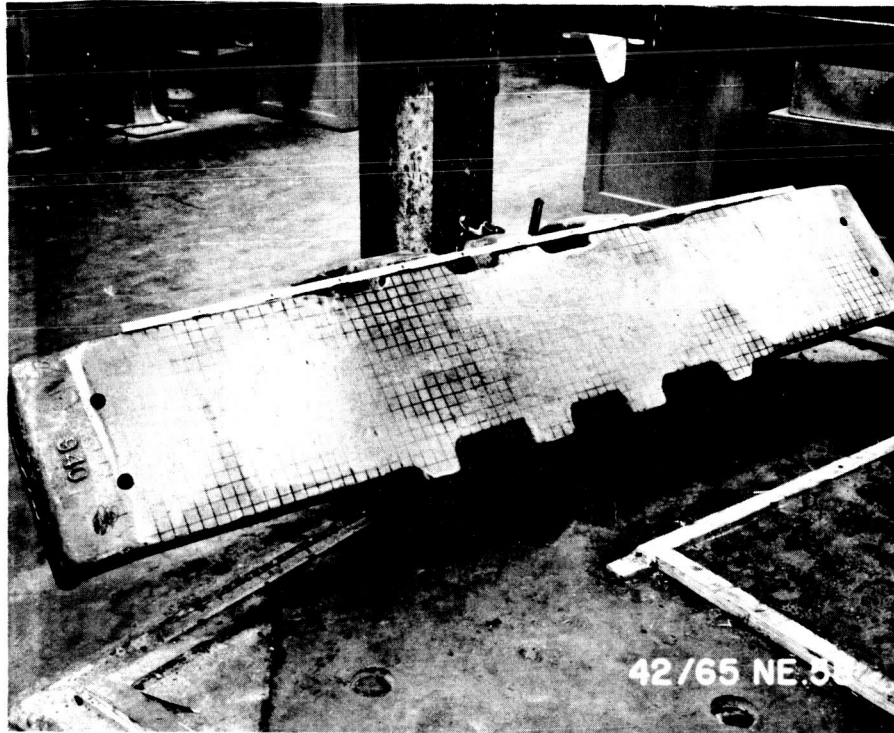


- a. Nominal 1.5-inch thick CPS mortar surface after shoe test (max. normal load 137 kip.) Loose material is visible on loaded area. The surface was dry for this test.

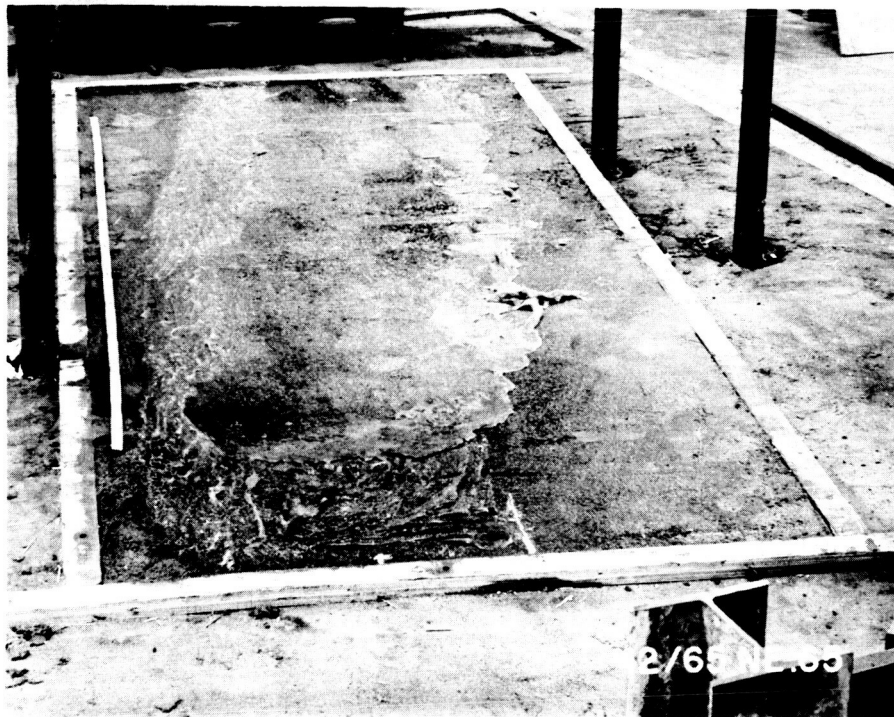


- b. Abraded material consisting of shredded rubber-like particles and sand grains collected from 1.5-inch CPS mortar surface after shoe test. Note cleaned surface on each side of paper.

FULL SCALE CRAWLER BELT SHOE TEST
SURFACE EFFECTS



- a. Surface of shoe after test on nominal 1.5-inch thick CPS mortar (dry). Actual area in contact is about 916 square inches out of a possible 1100 square inches.



- b. Nominal 1.5-inch thick CPS mortar surface after shoe test with Flaxoap lubricant. About 2.5 lbs. of Flaxoap was used for an area of about 17 square feet.

FULL SCALE CRAWLER BELT SHOE TESTS SURFACE EFFECTS

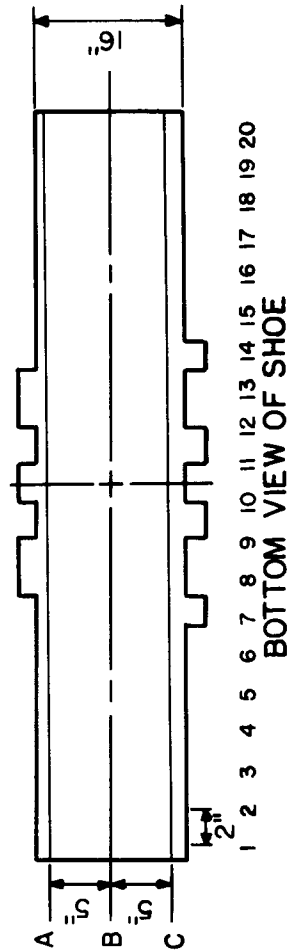
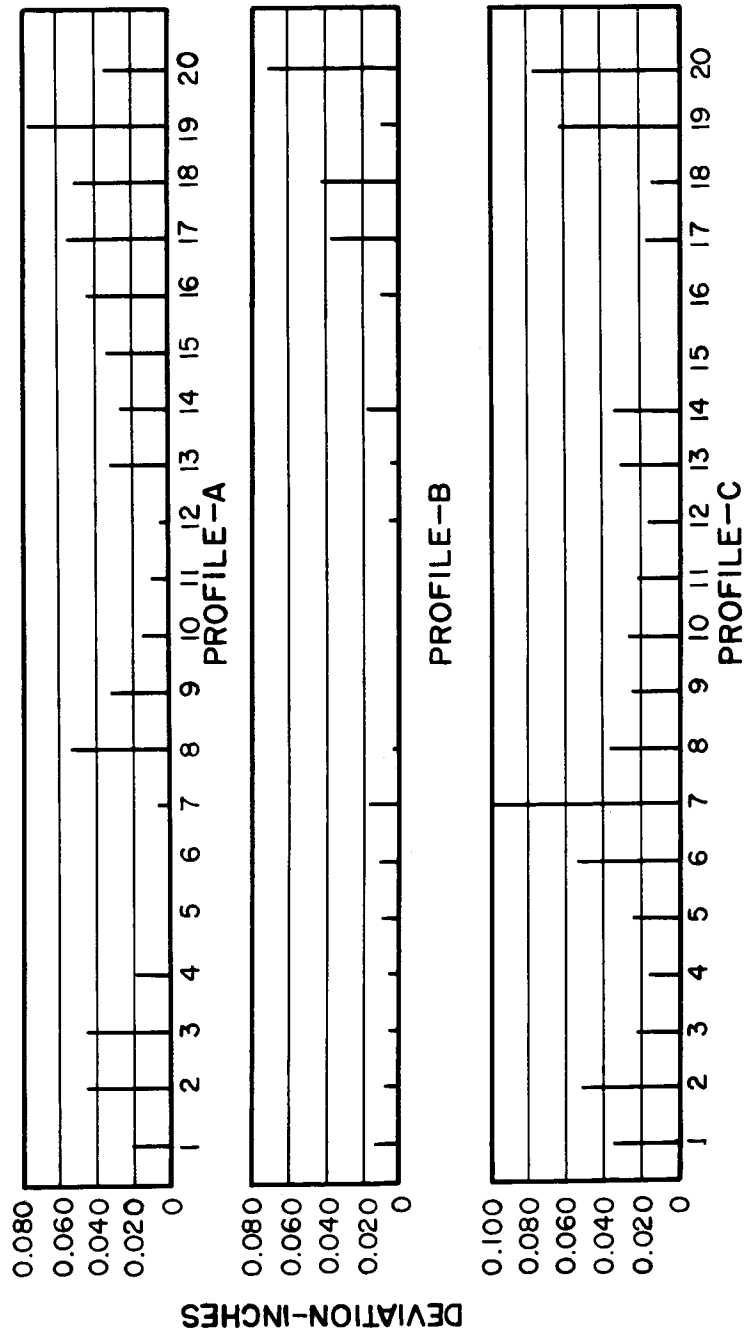


- a. 1/4-inch thick Douglas fir plywood surfacing after shoe tests. Plywood was supported on nominal 1.5-inch thick CPS mortar course.

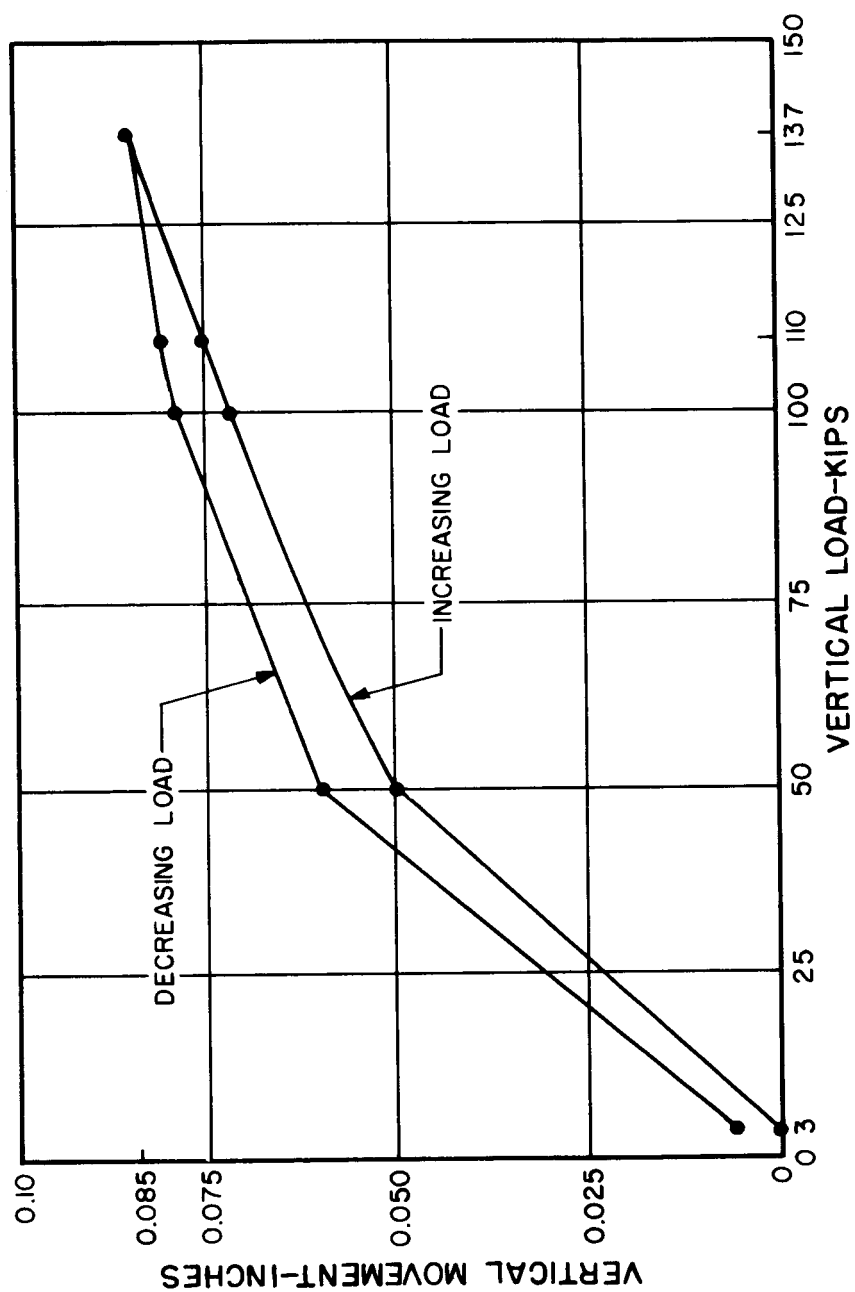


- b. 1/4-inch thick plywood with Epocast coating after shoe test.

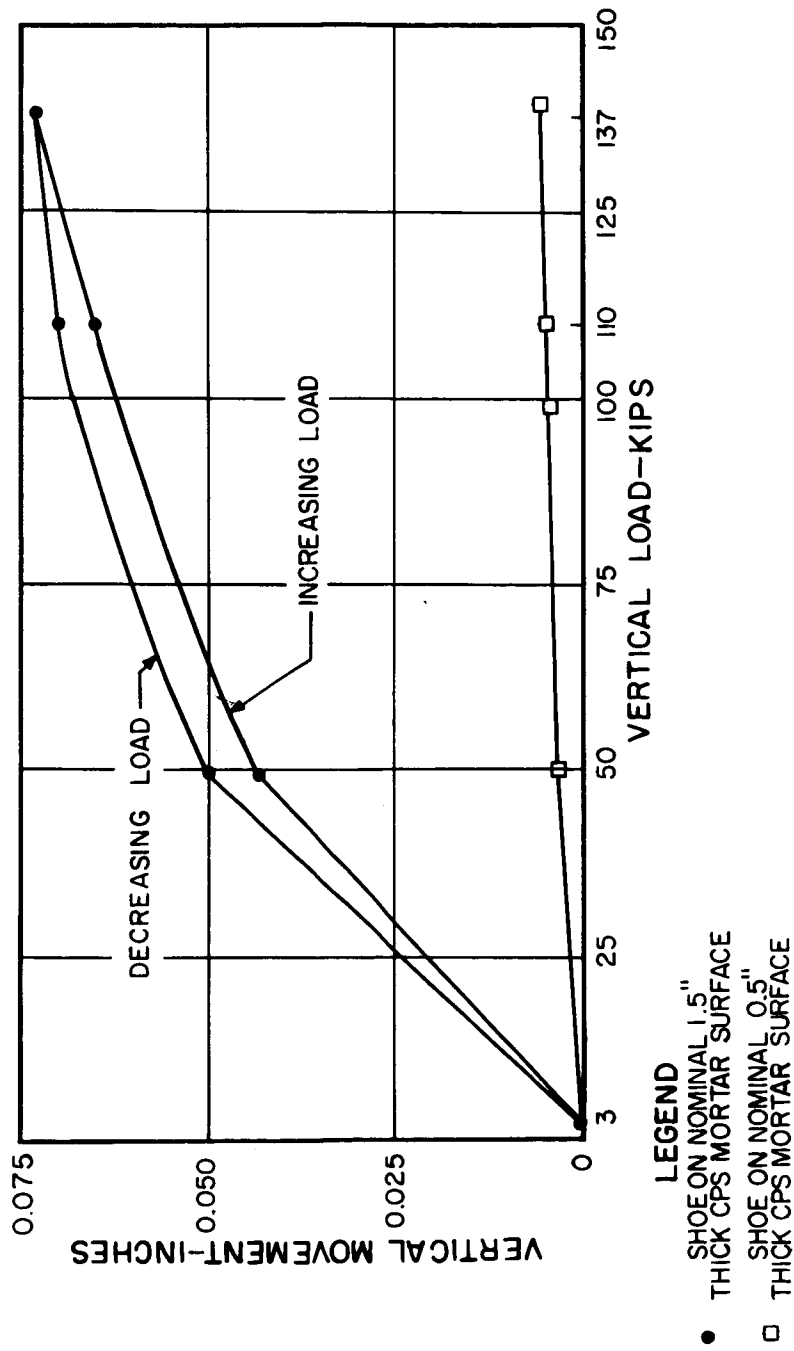
Figure 10



**PROFILES OF DEPTH GAGE MEASUREMENTS
ON BEARING SURFACE OF CRAWLER BELT SHOE**



LOAD DEFORMATION CURVE FOR CRAWLER
BELT SHOE ON $\frac{1}{4}$ INCH PLYWOOD WITH
NOMINAL 1.5" THICK CPS MOTAR SURFACING



LOAD DEFORMATION CURVES FOR CRAWLER
BELT SHOE ON 1.5" AND 0.5" THICK
CPS MORTAR SURFACES