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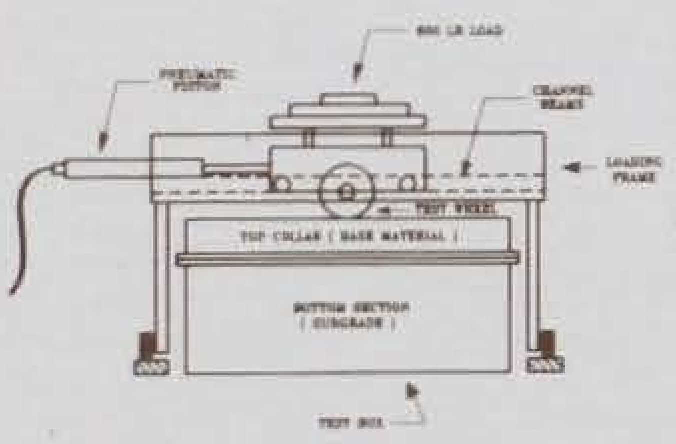


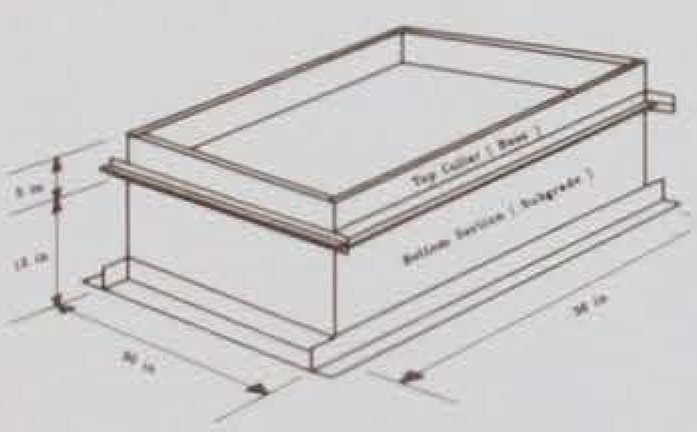


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# STABILITY OF OPEN-GRADED BASES UNDER WHEEL LOADS USING A MODEL TESTING APPROACH

by

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The stability of open-graded bases of various gradations and types of aggregates were examined when subjected to traffic. A small scale test box was designed and constructed to contain the base materials to be tested. Traffic was applied with a tire load directly on top of the bases. Rut depths at the deepest point of the wheel path were taken and used as a measurement of the stability of the material. Six different gradations of two types of materials were tested and compared with the performance of the US Army Corps of Engineers standard crushed stone base coarse gradation. Recommendations are given as to the type of material and gradation that would be most stable under direct traffic.

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## PREFACE

The investigation reported herein was sponsored by the Office, Chief of Engineers (OCE), under the work effort "Life Cycle Cost for Drainage Structures (Pipe)," of the Facilities Investigation and Studies Program. The OCE Technical Monitor was Mr. M. K. Lee.

This study was conducted at the US Army Engineer Waterways Experiment Station (WES) from June 1987 through December 1987 by the Pavement System Division (PSD) of the Geotechnical Laboratory (GL). This report was written by Mr. Garlos R. Gonzalez under the supervision of Dr. George M. Hammitt II, Chief, PSD; and D. M. Ladd, Chief, Criteria Development Unit, PSD. The work was performed under the general supervision of Dr. W. F. Marcuson III, Director, GL.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander and Deputy Director was COL Leonard G. Hassell, EN.

CONTENTS

CONVERSION FACTORS, NON-SI TO SI (METRIC) UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

| Multiply | By | To Obtain |
|---|---|---|
| feet | 0.3048 | metres |
| inches | 2.54 | centimetres |
| pounds (force) | 4.448222 | newtons |
| pounds (force) per square inch | 6.894757 | kilopascals |

STABILITY OF OPEN-GRADED BASES UNDER WHEEL LOADS USING A MODEL TESTING APPROACH

## PART I: INTRODUCTION

1. The rising concern within the Corps of Engineers (CE) in improving the drainage of pavements has brought the idea of using open-graded bases. Open-graded bases are layers of granular aggregates sufficiently permeable to allow rapid drainage of pavement systems and strong enough to sustain the expected traffic loads. The ability of these layers to sustain repetitive wheel loads within a reasonable deflection range is called stability. The stability, which is determined by measuring the rut depths on the wheel path, depends on the material that the layers are made of, the magnitude of the load, and the number of applications (passes) of that load. For aggregate layers to achieve adequate strength, the interaction between particles must be such that maximum shear resistance is developed. This usually happens when the material is densely compacted by adding a certain amount of fines, thereby reducing the void spaces within the layer. Consequently, because the drainage of an aggregate layer depends upon the voids available to drain the water, the addition of fines will reduce its permeability. The drainage condition is satisfied if larger aggregates are used. Therefore, a compromise between strength and permeability is necessary in the selection of the appropriate gradation for an open-graded layer. Because of these requirements, open-graded bases will probably have gradations with slightly less strength than the densely compacted bases. This has raised the question of how stable are these layers under typical construction operations where the traffic is applied directly on the open-graded bases.

### Purpose

2. The purpose of this study was to examine the stability of different gradations and types of aggregates when subjected to traffic.

## Approach

3. To study the stability of open-graded bases, a small-scale test box, with dimensions as shown in Figure 1, was designed and constructed. This box basically consisted of two sections--a bottom section containing a 12-in.* layer of sandy gravel material which acted as a subbase and a 5-in. top section (collar) that contained the open-graded base course material to be trafficked. To determine the open-graded thickness of 5 in., the CE flexible pavement design criteria was used for a tire load of 600 lb inflated to its maximum allowable pressure of 32 psi (Grau 1984**). A synthetic filter fabric was installed between these two layers to avoid the migration of fines from the subgrade to the base. The loaded wheel was driven back and forth by a pneumatic piston to apply repeated traffic directly over the base course. Rut depths at the deepest point on the wheel path were taken and used as a measurement of the stability of the material. Readings were also taken at various pass levels until the deformations ceased to increase.

4. The stability of the different materials under direct traffic loads was measured relative to a reference material. The reference material selected for this investigation was the CE standard crushed base stone coarse gradation. Several different gradations of crushed stone and river-run gravel were tested and their performance compared and evaluated against the reference material by measuring rut depths during traffic. Plots of the rut depths against the number of repetitions are presented for the different gradations and materials tested.

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* A table of factors for converting non-SI to SI (metric) units of measurement is presented on page 3.

** Grau, Richard H. 1984. "Engineering Criteria for Use of Geotextile Fabrics in Pavement and Railroad Construction," Technical Report GL-84-6, US Army Engineer Waterways Experiment Station, Vicksburg, MS.

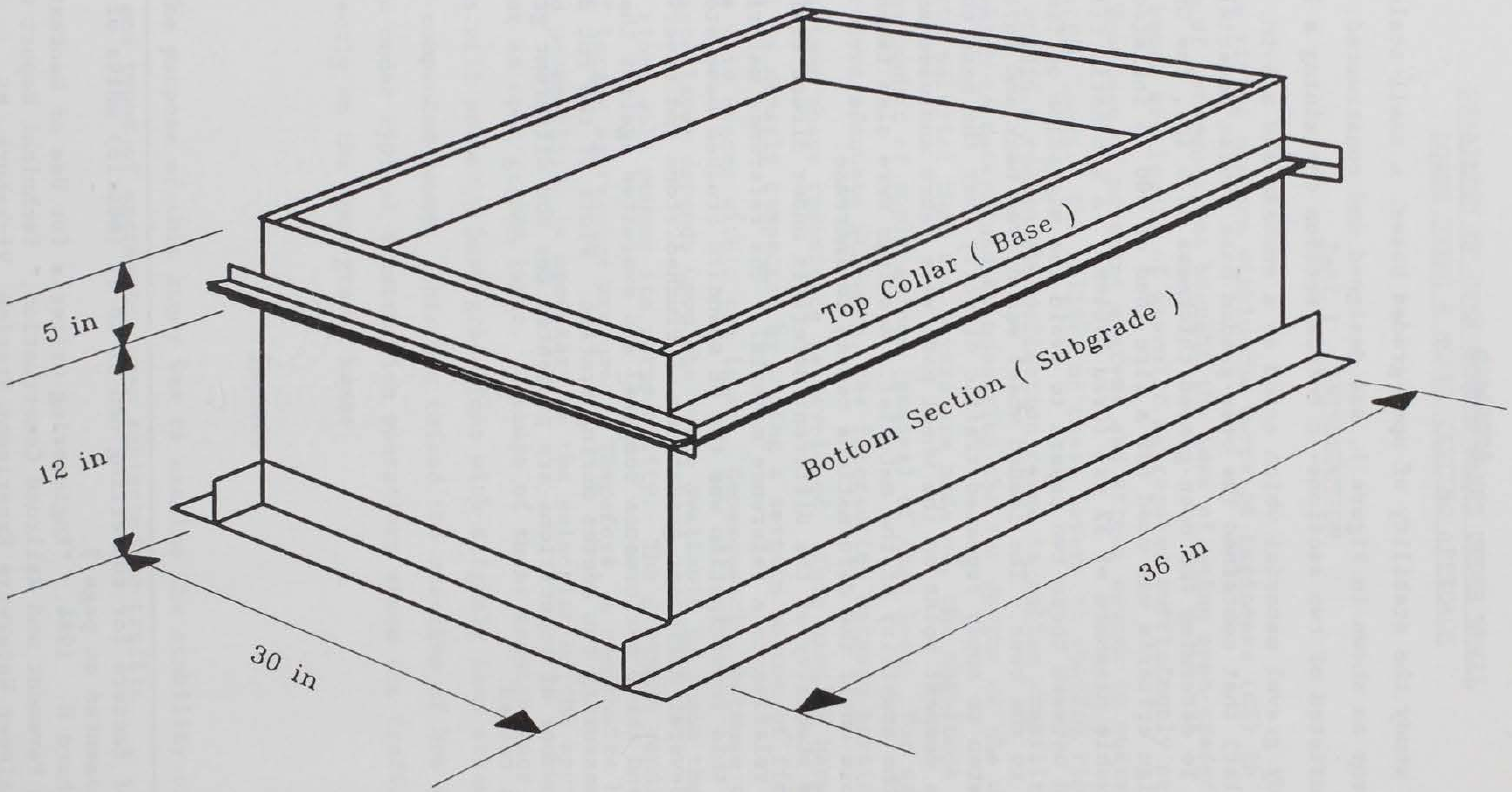


Figure 1. Small-scale test box

## PART II: MATERIALS AND EQUIPMENT

5. Six different gradations and the standard CE base course gradation were tested in the first test series. Table 1 shows the aggregate size distributions and Figure 2 illustrates their corresponding gradation curves. The openness of the materials was controlled by reducing the amount of fines in the mixture and by permitting the use of larger aggregates. Crushed limestone was first utilized as the basic base course material for the first test series whose objective was to determine the gradation most suitable to be used as an open-graded base. A second test series was performed on the standard gradation and on the more stable gradation resulting from the first test series, using river-rounded aggregates to evaluate the effect of rounded materials on the performance of open-graded bases.

6. The preparation of each base course consisted of weighing the different sizes of aggregates according to their specific gradations, blending them together to get a uniform mixture, filling the box with the mixture, and compacting it. Due to the small size of the box, the blending and compaction procedures could be achieved manually. Two hand tampers, weighing 20 lb each were used to densify the subbase and base courses. Figure 3 shows a diagram of the hand tampers used during the tests.

7. Figure 4 illustrates in more detail the small-scale test box and the loading system used. The box consisted of a 12 in. high fixed bottom section designed to contain the subbase material and a 5 in. high top collar where the open-graded material is placed. A moving frame holding the small tire and the loading plate was used to apply the loading. This outer frame has two channel beams where the wheel and the loading plate roll over. The test wheel can move freely up and down if necessary, but the loading plate assembly will always slide over the channel beams. The horizontal pneumatic piston drives the test tire back and forth directly over the base material at a speed of approximate 1 ft/sec.

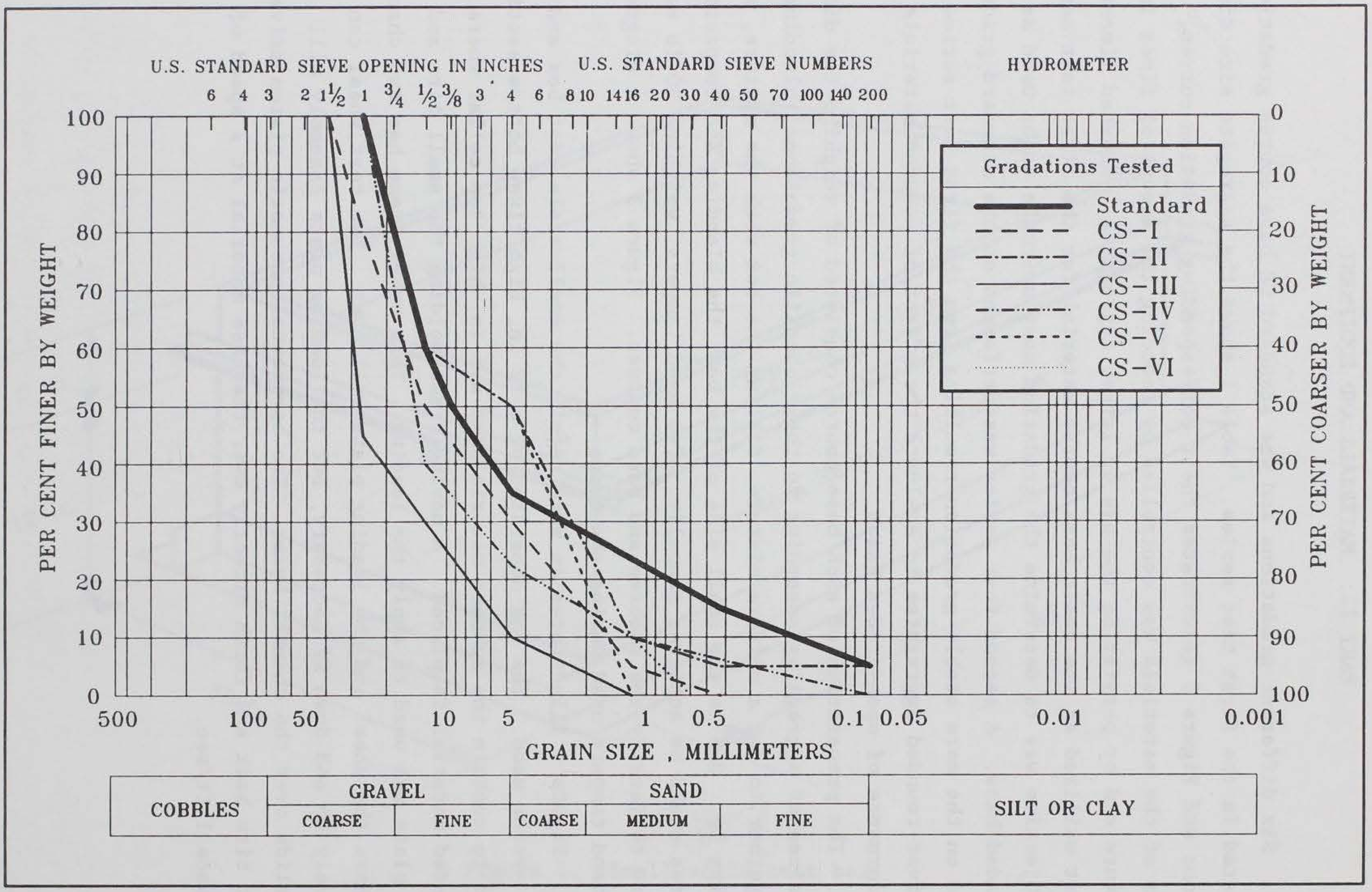


Figure 2. Gradation curves

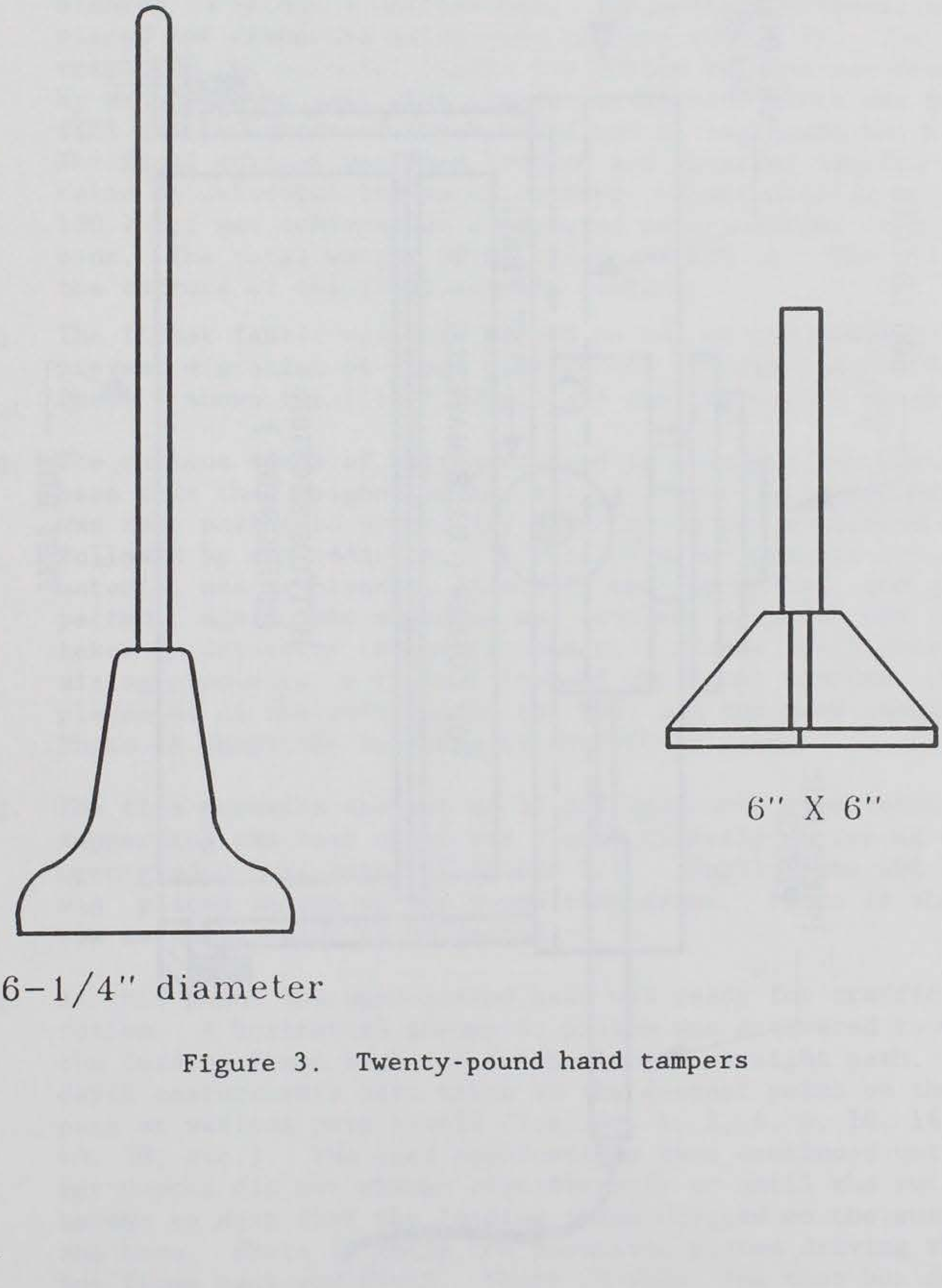


Figure 3. Twenty-pound hand tampers

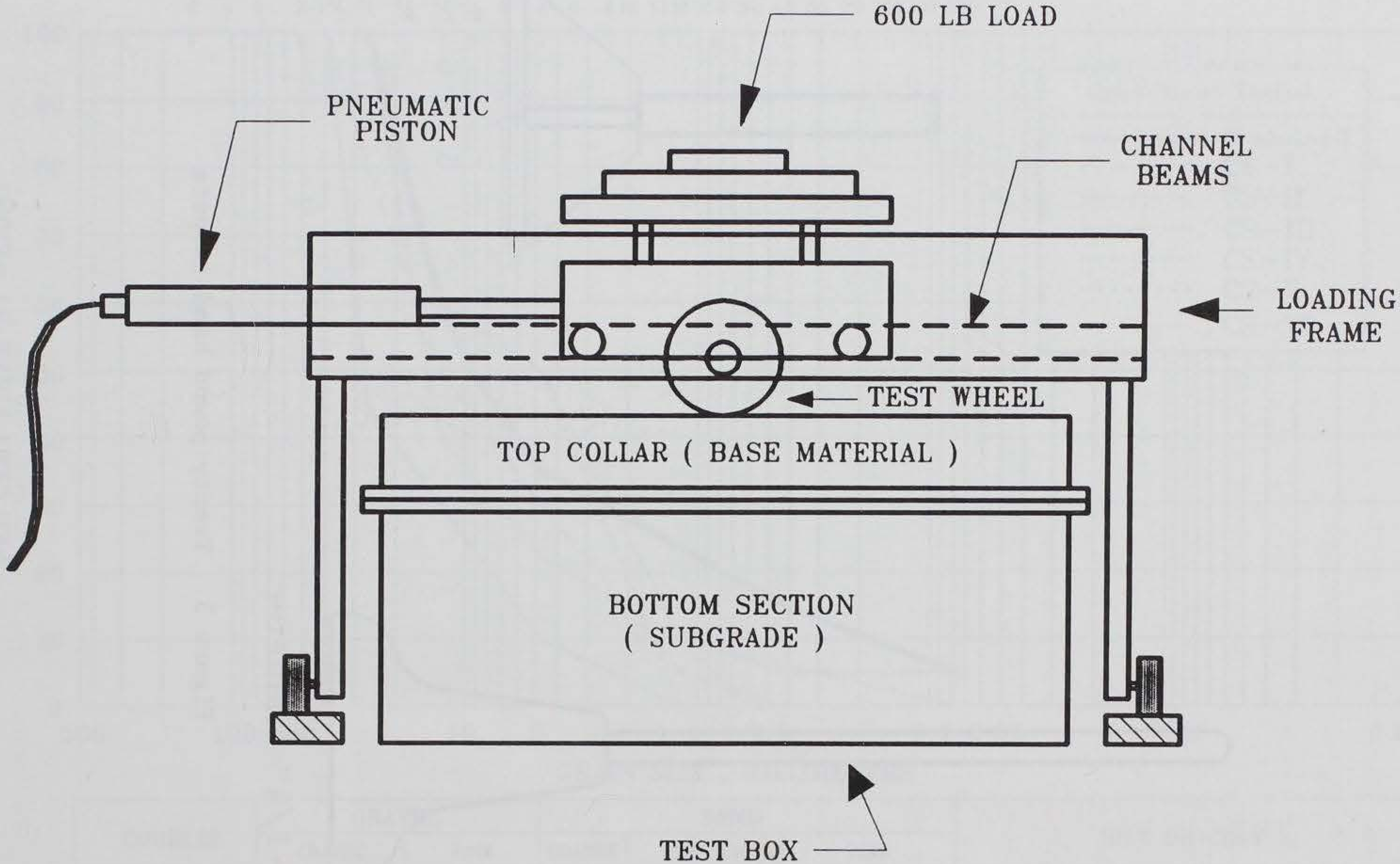


Figure 4. Loading system used

## PART III: TESTING PROCEDURE

8. This section outlines the testing procedure followed throughout the tests.

<u>a</u>. The first step was to place and to compact the subbase material in the bottom section of the test box. Approximately, 1,080 lb of sandy gravel was mixed with 5 percent of water and then hand blended to obtain a uniform mix. The subbase material was placed and compacted using hand tampers (Photo 1). The total weight of the material inside the bottom section was determined by weighing the soil when placed in the box. Care was taken to fill all the areas of the box and not to segregate the material. The final surface was then leveled and material samples were taken to determine its water content. A wet density of 130.7 pcf was achieved at a measured water content of 4.4 percent. The total weight of material was 980 lb. Photo 2 shows the texture of the final subbase surface.

<u>b</u>. The filter fabric was then placed on top of the subgrade to prevent migration of fines between the subbase and the base. Photo 3 shows the filter fabric and the top collar in place.

<u>c</u>. The various sizes of aggregate used in blending the open-graded base were then weighed before mixing (Photo 4). Hand blending was then performed on the dry material to get a uniform mixture, followed by the addition of 5 percent water (Photos 5-9). The material was re-blended, placed in the top collar, and compacted. Again, the material was leveled, weighed, and samples taken to determine its water content. Photos 10-15 show the mixing procedure, a typical look of the final mixture, the placement of the material in the box, and the hand compaction. Photo 16 shows the weighing of the 600-lb load.

<u>d</u>. The tire pressure was set to 32-psi pressure. The loading frame supporting the test wheel was placed directly on top of the open-graded base material (Photo 17). Finally, the 600-lb load was placed on top of the supporting frame. Photo 18 shows the box assembly ready to be tested.

<u>e</u>. At this point the open-graded base was ready for traffic application. A horizontal pneumatic piston was activated to drive the loading frame back and forth along a straight path. Rut depth measurements were taken at the deepest point on the wheel path at various pass levels (i.e. No. 1, 2, 4, 6, 10, 16, 20, 40, 50, etc.). The load applications were continued until the rut depths did not change significantly or until the rut depths became so deep that the loading frame dragged on the surface of the base. Photo 19 shows the pneumatic piston driving the loading frame back and forth. Photo 20 shows the test box during testing.

f. Finally, to obtain the relative permeability of the different gradations, a simple test was performed directly on top of the base. The test consisted of measuring the time it required for a 2-1/8-in.-diam column of water to fall 5 in. while draining into the base course. Photos 21 and 22 show the PVC pipe utilized for this purpose. It consisted of a pipe with a plastic base and a hole in its side connected to a water hose. Clay was used to seal the contact between the plastic base and the surface of the base course so that the water was forced to move downward through the base. A weight was placed on top of the pipe to keep it from moving during the test. After the pipe was filled close to its top, the time required for the water to fall freely 5 in. was recorded using a stop watch. The test was performed three times and the average used as the measurement of the permeability. Photos 23-37 show the texture of each of the gradations tested before and during traffic.

## PART IV: ANALYSIS OF TRAFFIC RESULTS

9. Table 2 contains the rut depth measurements resulting from the applied traffic on the different gradations of crushed stone tested. Figure 5 illustrates graphically their relative performance as the number of passes increased. Two patterns of performance can be easily noted from the shape of the curves. The first pattern, developed from tests on materials CS-I, CS-III, and CS-IIIA, showed the rut depth increasing rapidly as traffic increased and then stabilized at about 20 passes. The second pattern, developed by tests on the remaining gradations, showed some kind of material densification and aggregate rearrangement before following a stable behavior. Again, this occurred at about 20 passes. It is important to notice that rutting was larger for the first pattern of performance than for the second pattern.

10. In these tests the CS-III gradation represented the most open-graded base and the standard CE gradation represented the least open. This is illustrated in Figure 2, where CS-III is the gradation with the least percent of fines and the larger aggregates, and the standard CE gradation has a more uniform aggregate size distribution and a the higher percent of fines. As expected, these two gradations also became the lower and upper boundaries in terms of rutting stability. The CS-III gradation exhibited rapid rutting after a small number of passes. After 4 passes the rut depth already exceeded 1 in., increasing from that point to 2.25 in. The CS-III gradation had the same aggregate gradation as the CS-IIIA, but the behavior of the former was greatly affected by material segregation that occurred during the filling of the box. The CS-III showed significantly more rutting than the CS-IIIA, which was carefully placed and compacted. For example, at 100 passes the CS-IIIA had a 1.31-in. rut depth while the CS-III had 2.25-in. rut. This represents approximately 70 percent increase in rutting and, consequently, a 70 percent reduction in stability due to construction errors. This points out the importance of proper material quality control during the placement of any open-graded base.

11. The CS-II material was similar to the standard CE material but contained fewer fines (see Figure 2). As expected, it exhibited a very good performance under traffic having almost the same behavior as the standard

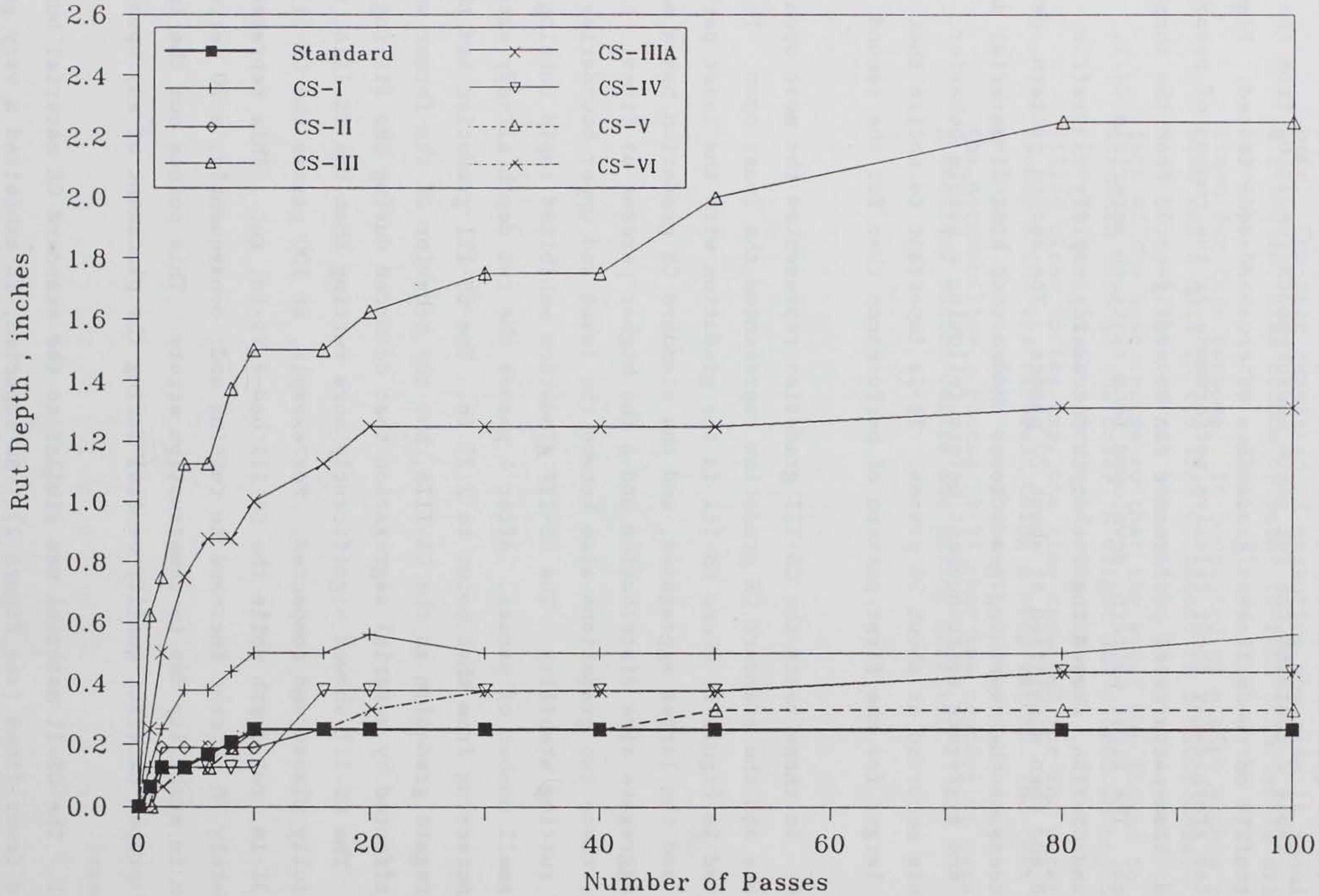


Figure 5. Relative performance

gradation. This reduction in fines permitted the CS-II gradation to drain the water faster. It also demonstrated that decreasing the amount of fines in the mixture will not necessary decrease the stability of the base. Based on these results, the fines for the CS-II were again decreased to make it more open and to evaluate its behavior. The percent of material passing sieve No. 30 and sieve No. 16 were set to zero to obtain the CS-V and CS-VI gradations, respectively. The results clearly demonstrated that the reduction of fines in the mixture only slightly reduced the capacity of the material to sustain traffic (Figure 5). Surprisingly, both resulted in rut depths only slightly higher than the standard base, not exceeding five-sixteenths inch for the CS-V and seven-sixteenths inch for the CS-VI.

12. The gradation of CS-I was similar to the CS-III gradation curve but it is considerably less open. This gradation resulted in a fairly good stability, with a performance between the CS-III and the CS-VI, having rut depths slightly more than one-half inch, but not exceeding five-eighths inch. On the other hand, the gradation represented by CS-IV, which followed the shape of the standard gradation curve, showed a stability as good as the CS-V and CS-VI, but again, this gradation contains a much greater amount of fines than the CS-V or CS-VI. The amount of fines in the CS-IV gradation makes it less permeable and, therefore, less suitable as an open-graded base. CS-V was judged to be the most stable of the nonstandard gradation bases.

13. The results of two tests performed on the CE standard and the CS-V gradations, utilizing in this case rounded aggregates instead of crushed stone, are presented in Table 2 and Figure 6. The rut depths of the standard gradations indicate that its stability was greatly reduced when compared with the standard crushed stone gradation. In this case the rut depth increased up to eleven-sixteenths inch compared with only one-fourth inch for the crushed stone. In fact, the resulting rut depths were greater than all of the more open crushed graded bases tested, except the CS-III. This is an indication of the poor stability that can occur in the field during the placement of bases with rounded aggregates. This fact was confirmed with the results from the CS-V gradation. In this case, the deformations became so large that the test had to be stopped after only a few passes because the equipment was dragging on top of the base. After only 8 passes the rut depth increased to 2-11/16 in. As these tests demonstrated, rounded materials do not provide

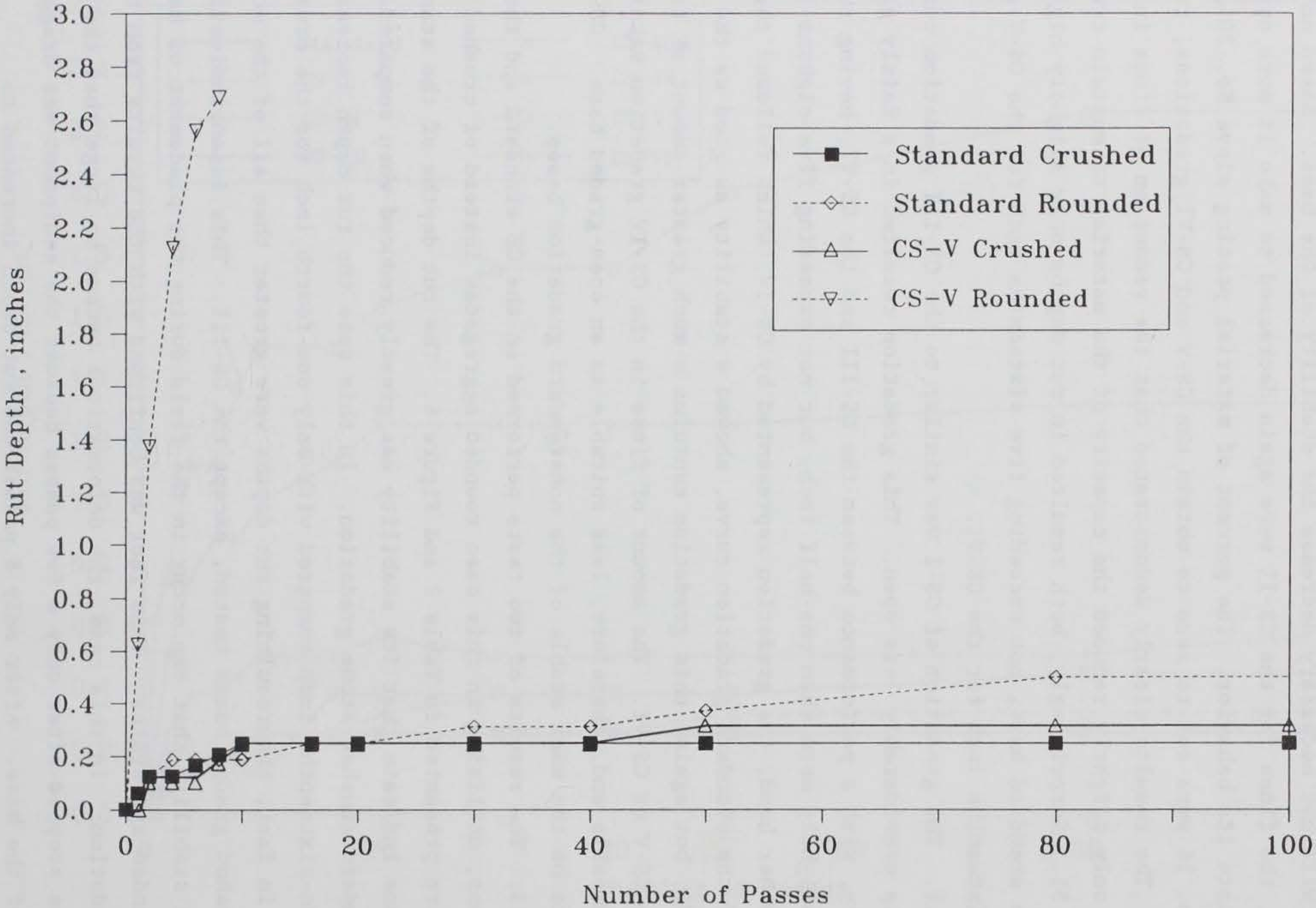


**Figure 6. Test results, crushed and rounded aggregate**

good particle interlock, resulting in slip between aggregates and reduction of stability under traffic.

14. Table 3 contains the results of the permeability tests. These results show that water percolates as much as 12 times faster in the open gradations CS-V and CS-VI than for the standard base. The standard material drained the water in about 23.5 sec while the CS-V and CS-VI drained it in about 2.0 sec. An interesting point was that the CS-II took more than twice the drainage time of the CS-V or CS-VI, indicating that the reduction of fines in the CS-II to produce the CS-V or CS-VI had the expected effect on permeability.

## PART V: CONCLUSIONS AND RECOMMENDATIONS

### Conclusions

15. Based on the results of the tests conducted, the following conclusions are presented:

- a. Gradations similar to the CS-V or CS-VI were found to be suitable for use as open-graded bases. These gradations provided an acceptable permeability without sacrificing strength or stability under direct traffic loads.
- b. The performance of the open-graded base made up of rounded aggregates (CS-V) resulted in a dramatic reduction in stability. Even the standard gradation base constructed from rounded aggregates did not show an acceptable stability under traffic. Therefore, rounded aggregates should not be used for open-graded bases.
- c. Segregation of the open-graded bases during placement could be a cause for considerable loss in stability. Care should be taken to control the quality of open-graded base.
- d. The permeability, as determined in these tests, can be at least 12 times greater for open-graded bases than for well graded bases.

### Recommendations

15. Based on this study, the following recommendations are suggested:

- a. Determine the stability and permeability of asphalt or cement stabilized open-graded bases through further research.
- b. Compliment the data and establish the best gradation to be used as an open-graded base through field testing of open-graded bases constructed with gradations similar to those investigated in this study.
- c. Conduct a research effort to develop a method for measuring the field permeability of pavement bases.

Table 1

Base Course Gradation Tested

| | Percent Finer by Weight | | | | | | |
|---|---|---|---|---|---|---|---|
| Sieve Size | Standard | CS-I | CS-II | CS-III | CS-IV | CS-V | CS-VI |
| 1-1/2 in. | | 100 | | 100 | | | |
| 1 in. | 100 | 80 | 100 | 45 | 100 | 100 | 100 |
| 1/2 in. | 60 | 50 | 60 | 30 | 40 | 60 | 60 |
| 3/8 in. | 50 | | | | | | |
| No.4 | 35 | 30 | 50 | 10 | 22 | 50 | 50 |
| No. 16 | | 5 | 10 | 0 | 10 | 10 | 0 |
| No. 30 | | | | | | 0 | |
| No. 40 | 15 | 0 | 5 | | 6 | | |
| No. 100 | | | | | | | |
| No. 200 | 5 | | 5 | | 0 | | |

Table 2

Test Results

| Number of Passes | Rut Depth Measurements, in. Crushed Aggregates | | | | | | | | Rounded Aggregates | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Standard | CS-I | CS-II | CS-III | CS-IIIA | CS-IV | CS-V | CS-VI | Standard | CS-V |
| 1 | 0.063 | 0.125 | 0.000 | 0.625 | 0.250 | 0.063 | 0.000 | 0.063 | 0.063 | 0.625 |
| 2 | 0.125 | 0.250 | 0.188 | 0.750 | 0.500 | 0.125 | 0.125 | 0.063 | 0.125 | 1.375 |
| 4 | 0.125 | 0.375 | 0.188 | 1.125 | 0.750 | 0.125 | 0.125 | 0.125 | 0.188 | 2.125 |
| 6 | | 0.375 | 0.188 | 1.125 | 0.875 | 0.125 | 0.125 | 0.188 | 0.188 | 2.563 |
| 8 | | 0.438 | 0.188 | 1.375 | 0.875 | 0.125 | 0.188 | 0.188 | 0.188 | 2.688 |
| 10 | 0.250 | 0.500 | 0.188 | 1.500 | 1.000 | 0.125 | 0.250 | 0.250 | 0.188 | |
| 16 | | 0.500 | 0.250 | 1.500 | 1.125 | 0.375 | 0.250 | 0.250 | 0.250 | |
| 20 | | 0.562 | 0.250 | 1.625 | 1.250 | 0.375 | 0.250 | 0.313 | 0.250 | |
| 30 | 0.250 | 0.500 | 0.250 | 1.750 | 1.250 | 0.375 | 0.250 | 0.375 | 0.313 | |
| 40 | | 0.500 | 0.250 | 1.750 | 1.250 | 0.375 | 0.250 | 0.375 | 0.313 | |
| 50 | 0.250 | 0.500 | 0.250 | 2.000 | 1.250 | 0.375 | 0.313 | 0.375 | 0.375 | |
| 80 | | 0.500 | 0.250 | 2.250 | 1.312 | 0.438 | 0.313 | 0.438 | 0.500 | |
| 100 | 0.250 | 0.562 | 0.250 | 2.250 | 1.312 | 0.438 | 0.313 | 0.438 | 0.500 | |
| 200 | 0.250 | 0.625 | | | | 0.500 | | 0.438 | 0.688 | |
| 300 | | | | | | | | | 0.688 | |
| 400 | 0.250 | | | | | | | | | |
| 500 | 0.250 | | | | | | | | | |
| 600 | 0.250 | | | | | | | | | |
| 700 | 0.250 | | | | | | | | | |
| 800 | 0.250 | | | | | | | | | |
| 900 | 0.250 | | | | | | | | | |
| 1000 | 0.250 | | | | | | | | | |

Table 3

Permeability Results for the Gradations Tested

| Gradation | Time sec* |
|---|---|
| Standard | 23.5 |
| CS-I | 1.0 |
| CS-II | 5.0 |
| CS-III | 0.0** |
| CS-IIIA | 0.0** |
| CS-IV | 9.0 |
| CS-V | 2.9 |
| CS-VI | 1.9 |

* Average of the time for water to fall freely 5 in. in a 2-1/8 in. diam tube.
** Too fast to measure.

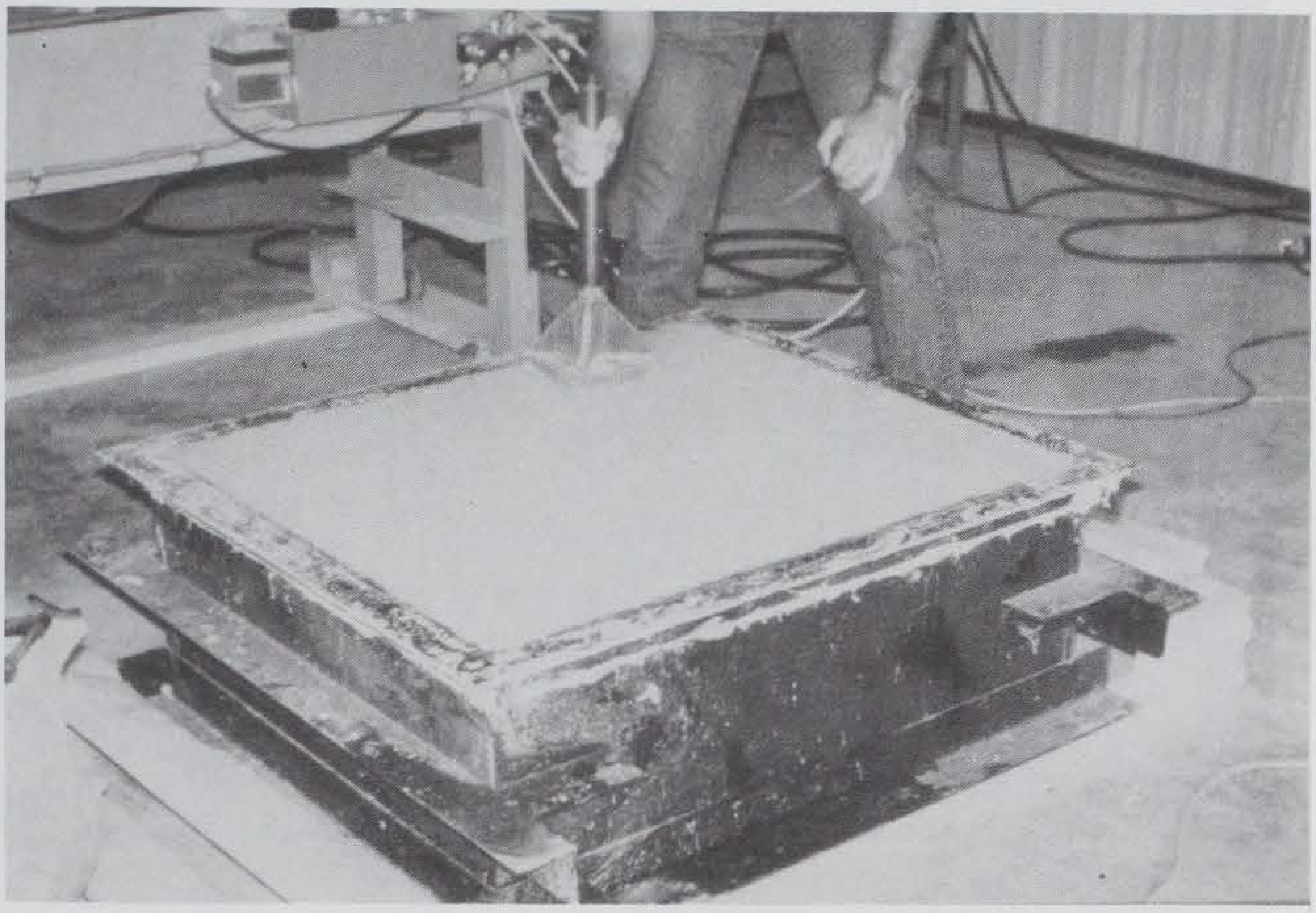

Photo 1. Compaction of subgrade material

Photo 2. Finished subgrade surface

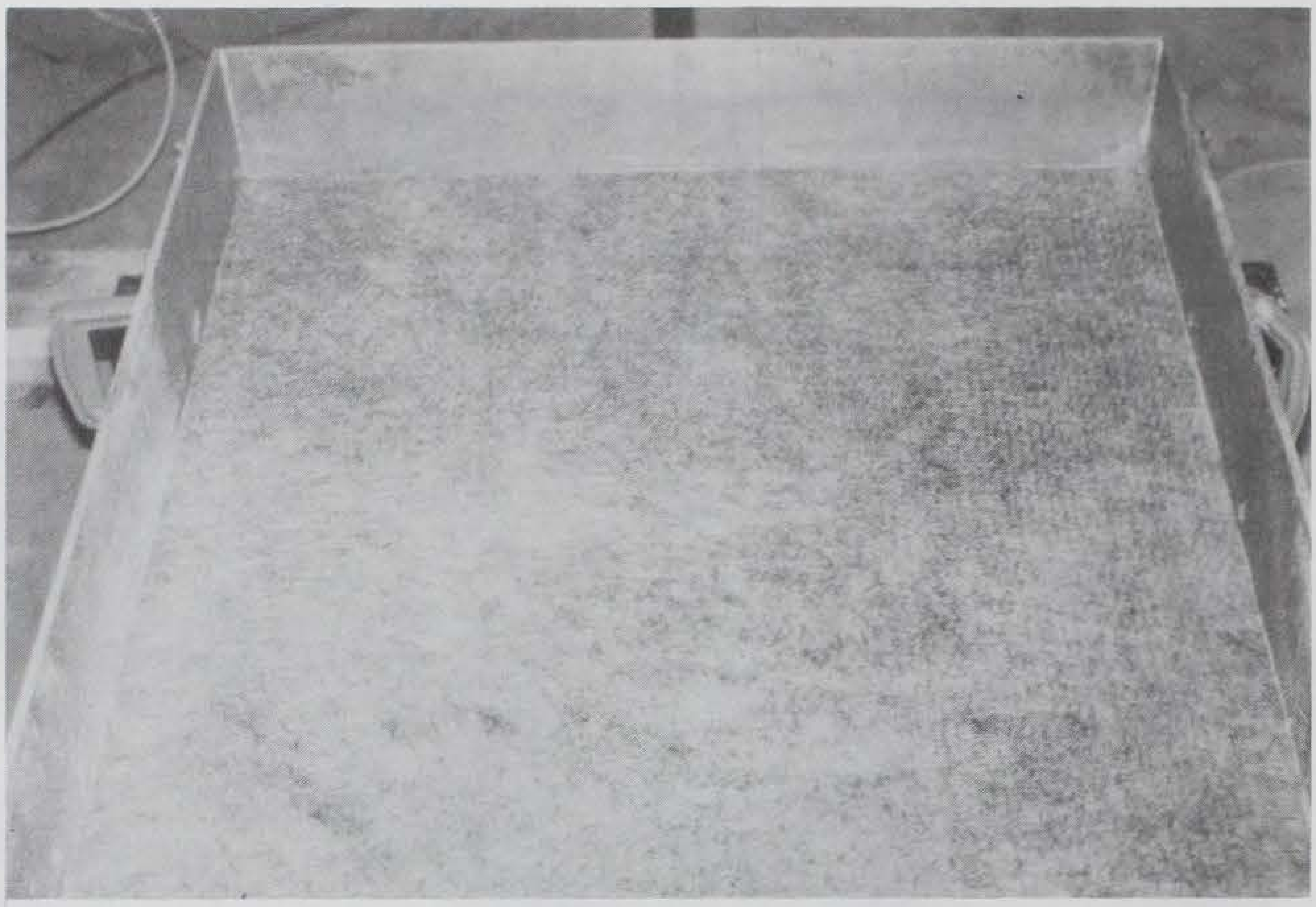

Photo 3. Filter fabric in place

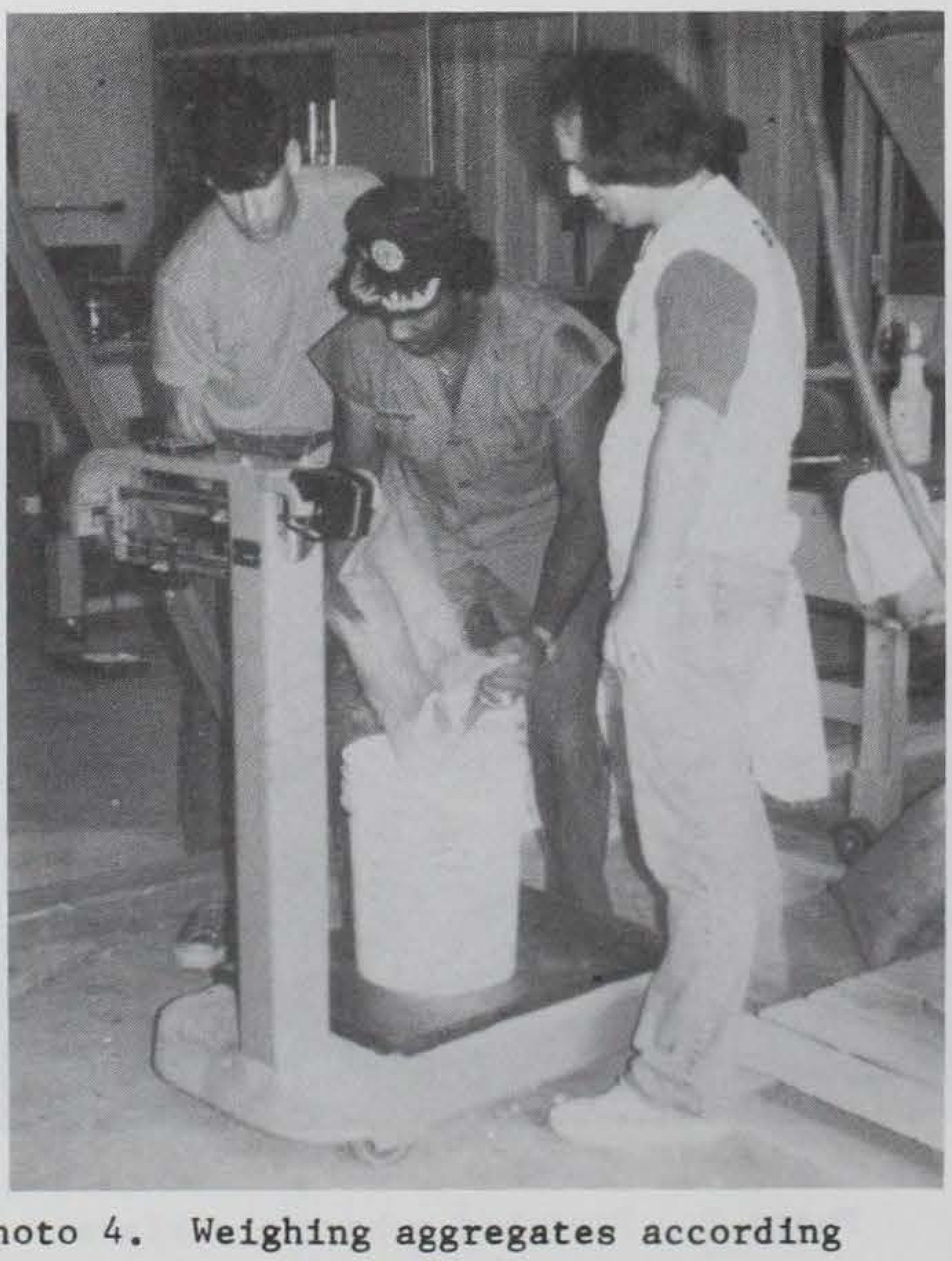

Photo 4. Weighing aggregates according to gradations

Photo 5. Hand mixing of the coarser aggregates

Photo 6. Addition of finer aggregates

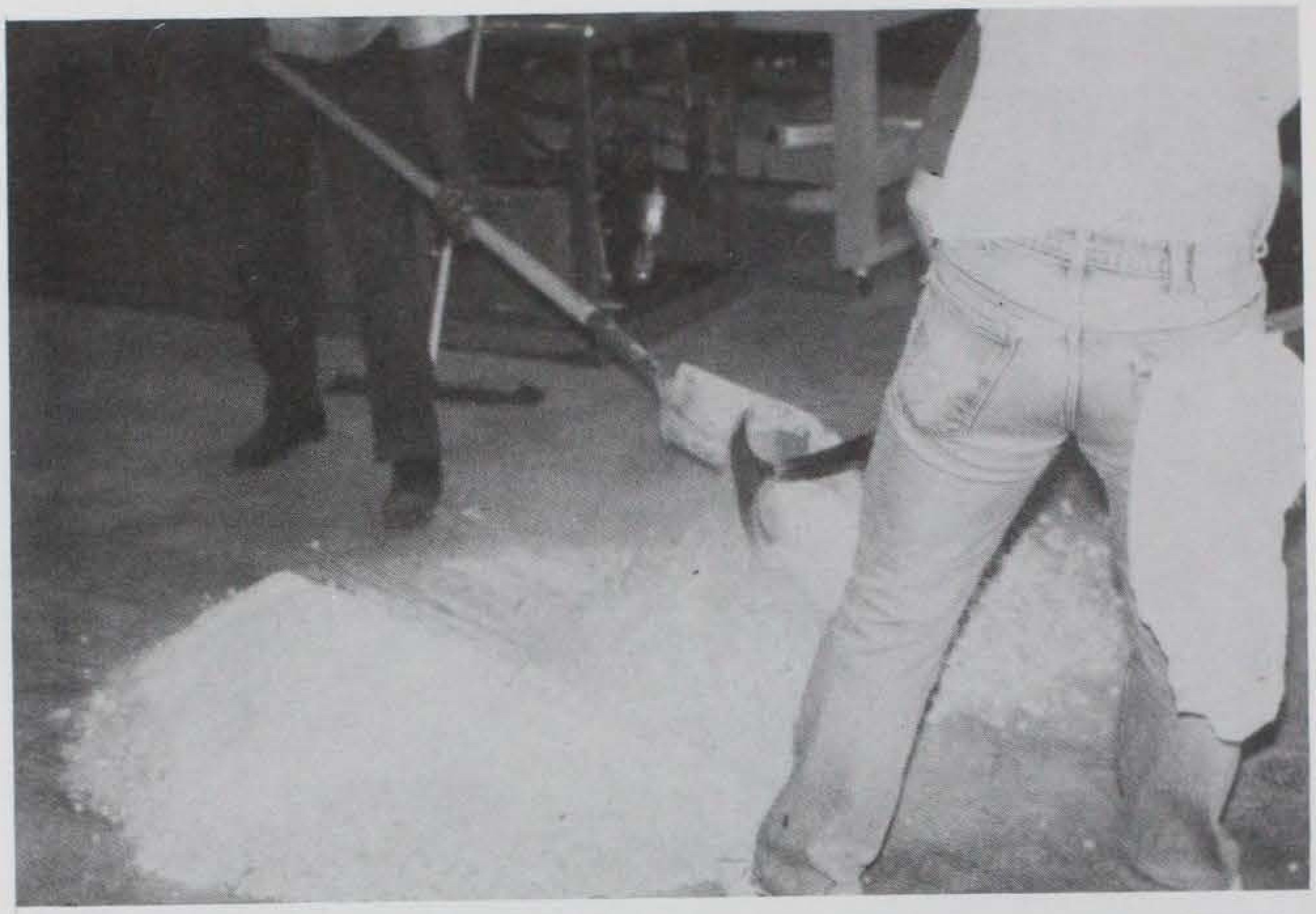

Photo 7. Re-blending of the mix


Photo 8. Weighing water to be added

Photo 9. Addition of water to the mix

Photo 10. Re-blending the final mix

Photo 11. Finished mix

Photo 12. Placement of material in the box

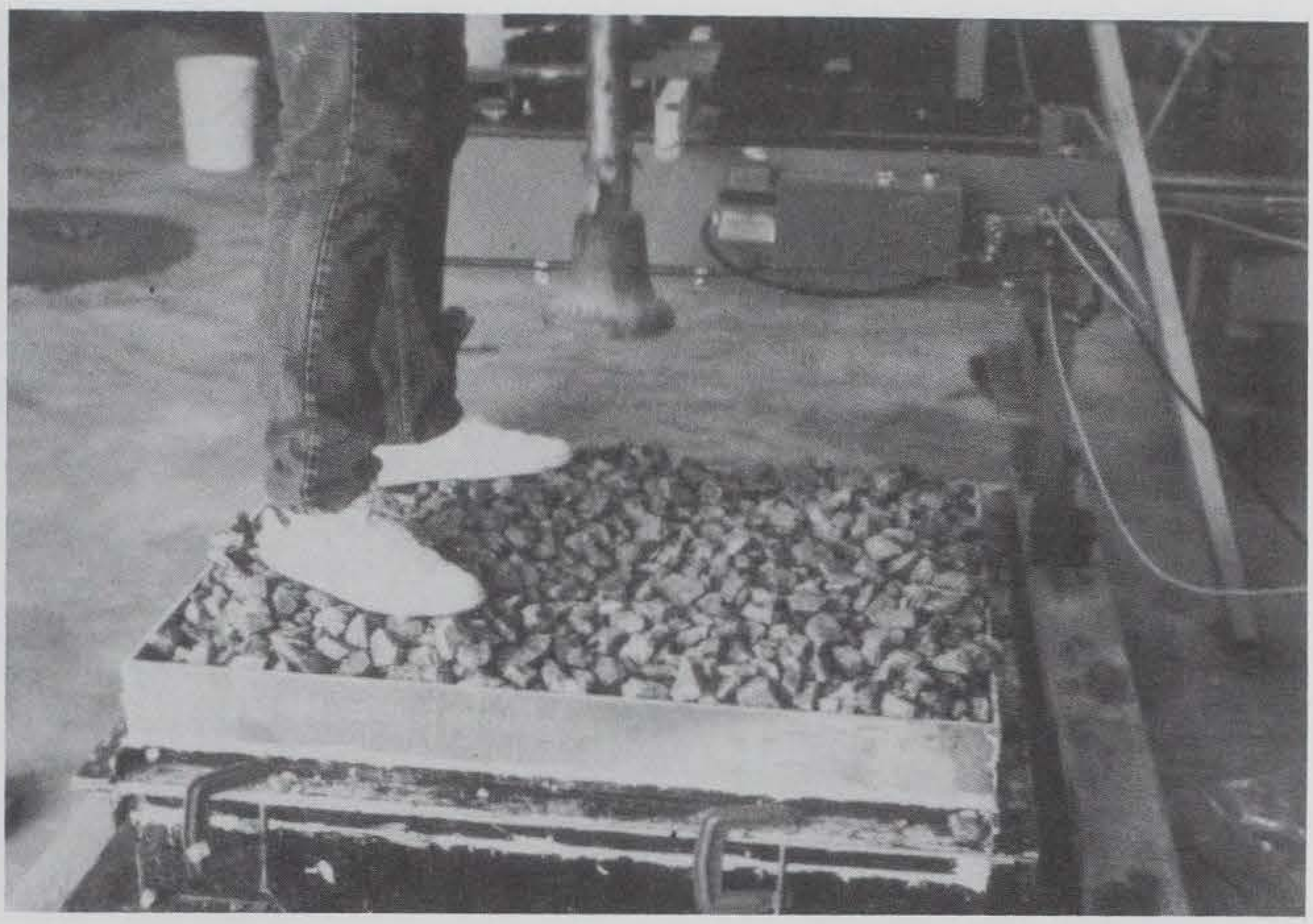

Photo 13. Compaction of the base material

Photo 14. Compaction and edging the base material

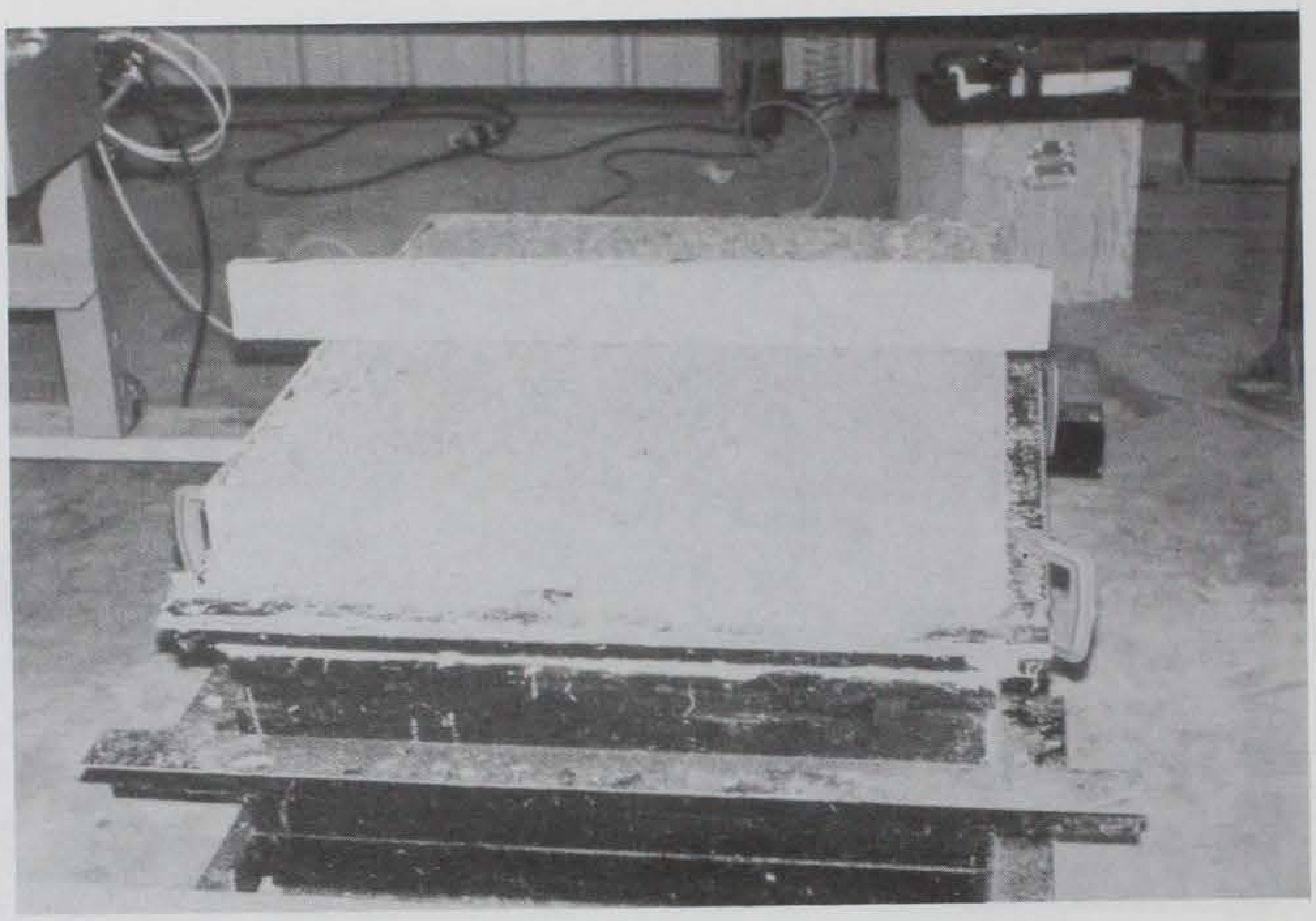

Photo 15. Flattening of the base surface

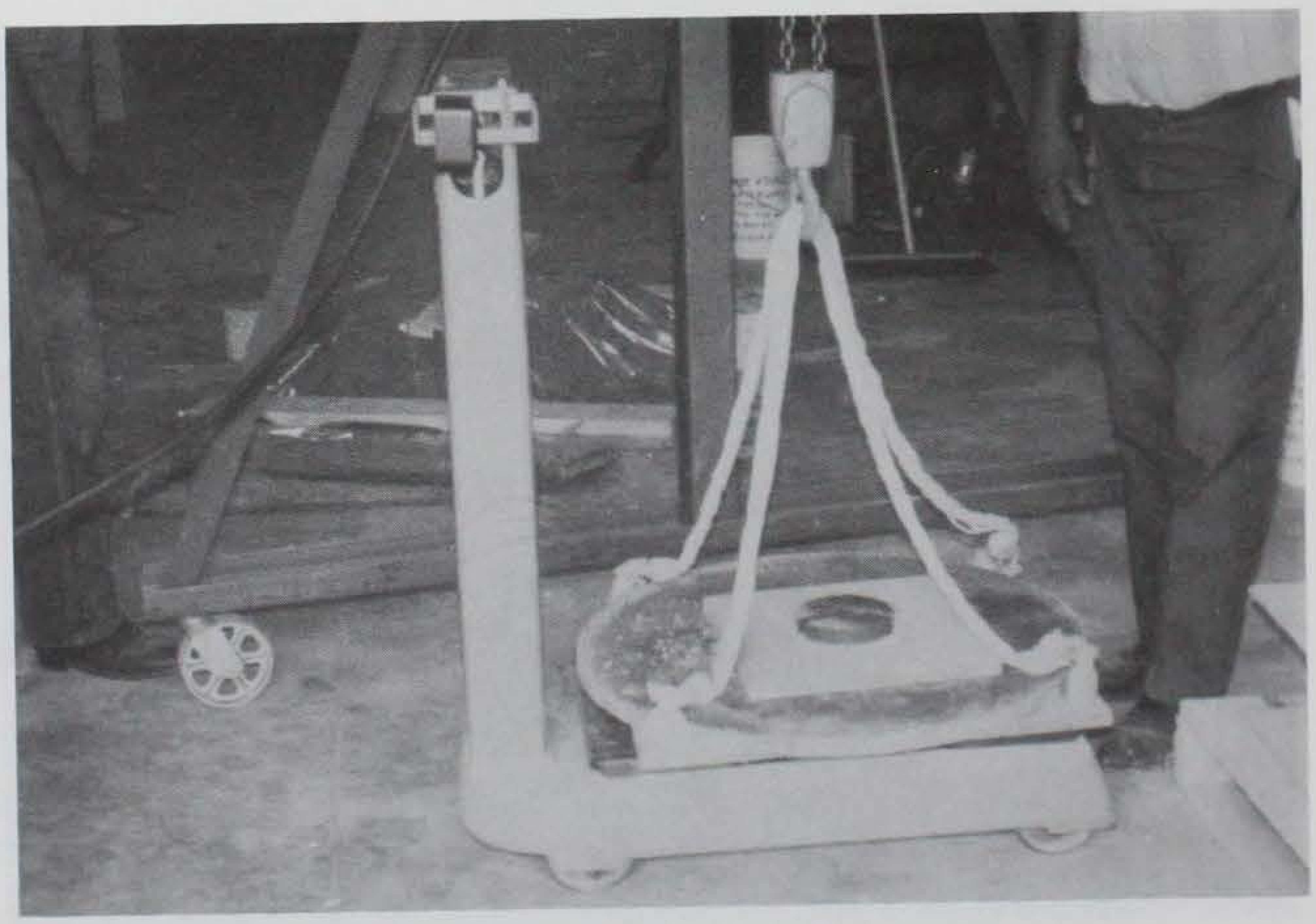

Photo 16. Weighing the 600-lb load

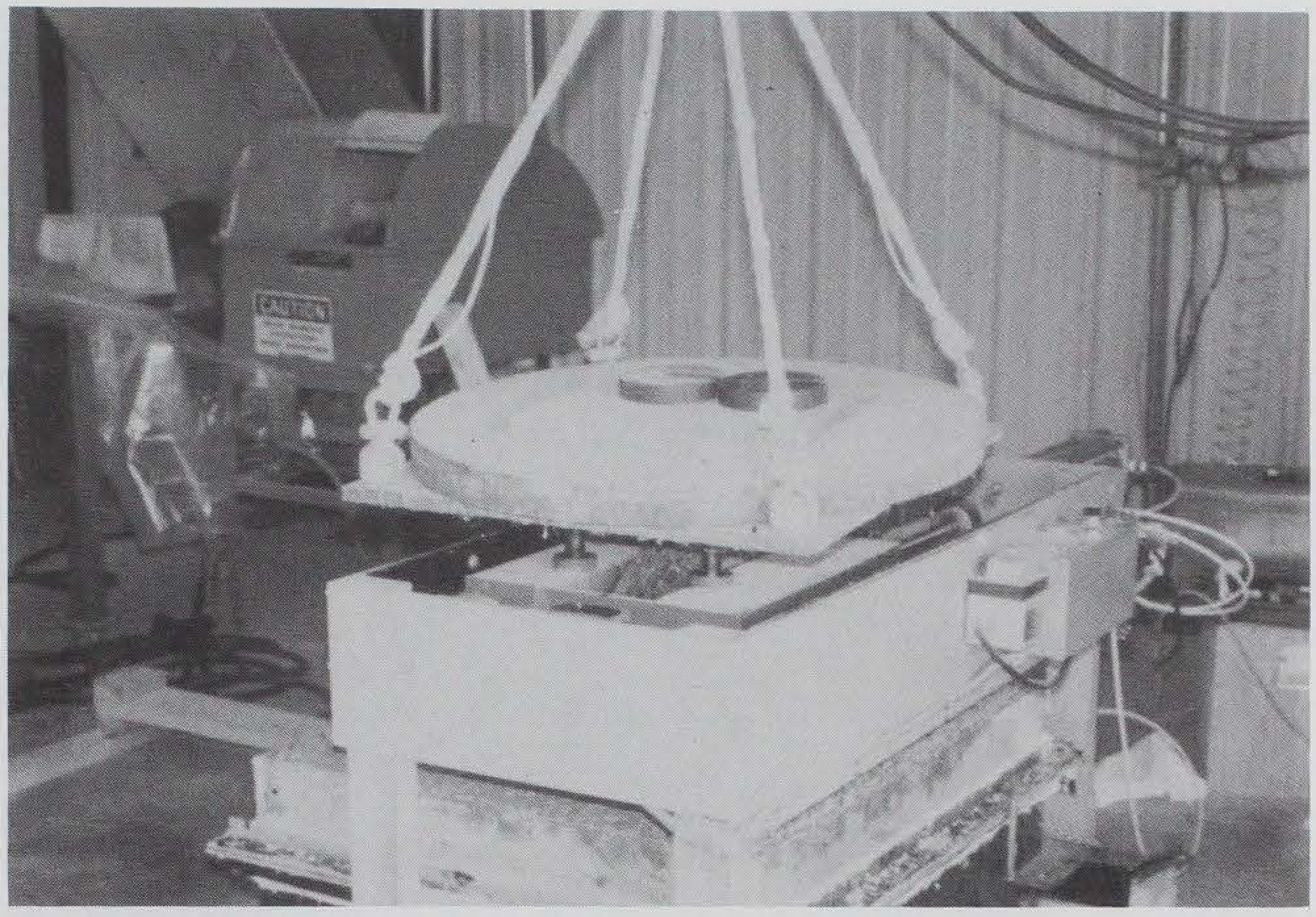

Photo 17. Placement of the load on the loading frame

Photo 18. Load placed and ready to be tested

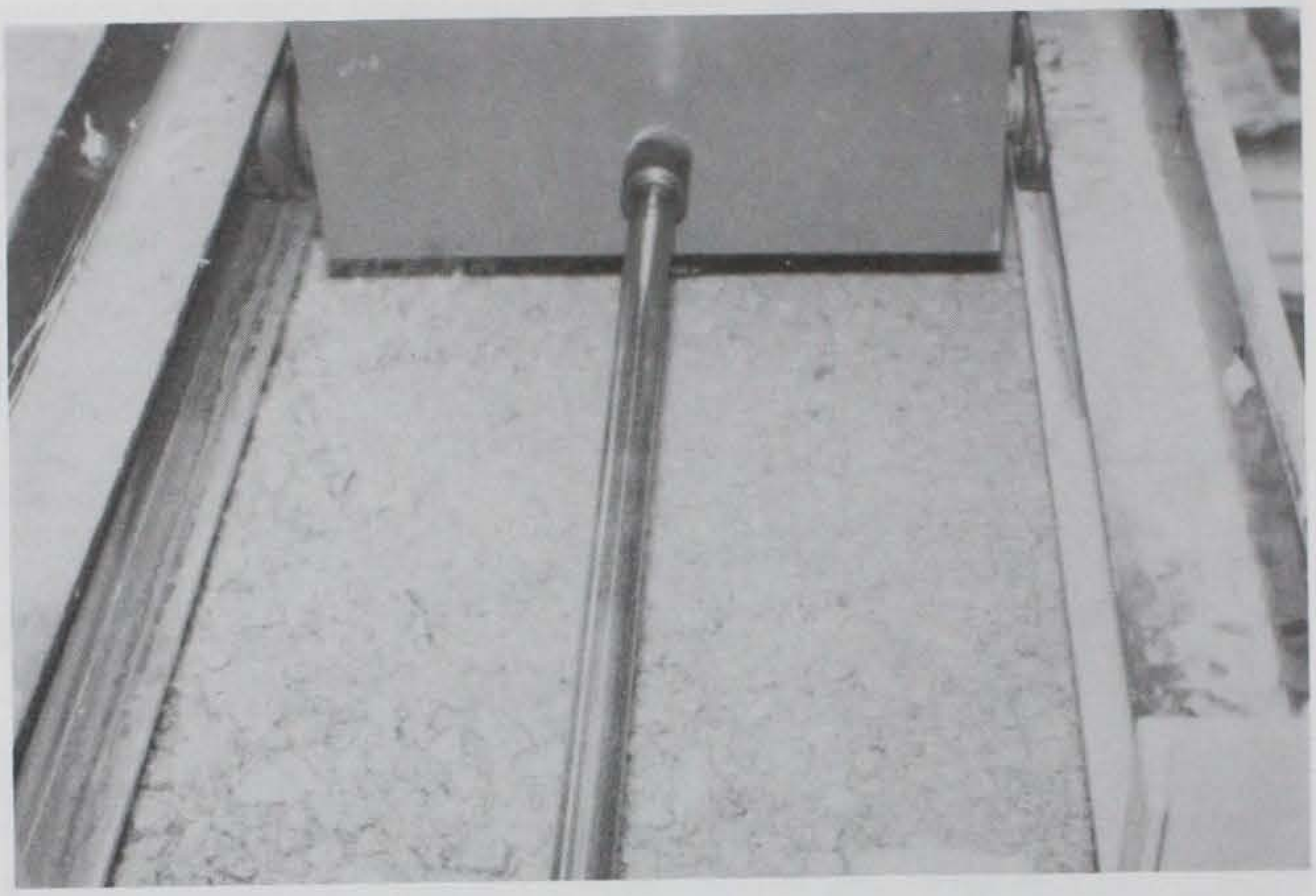

Photo 19. Inside look at the loading frame

Photo 20. Small-scale box assembly during testing

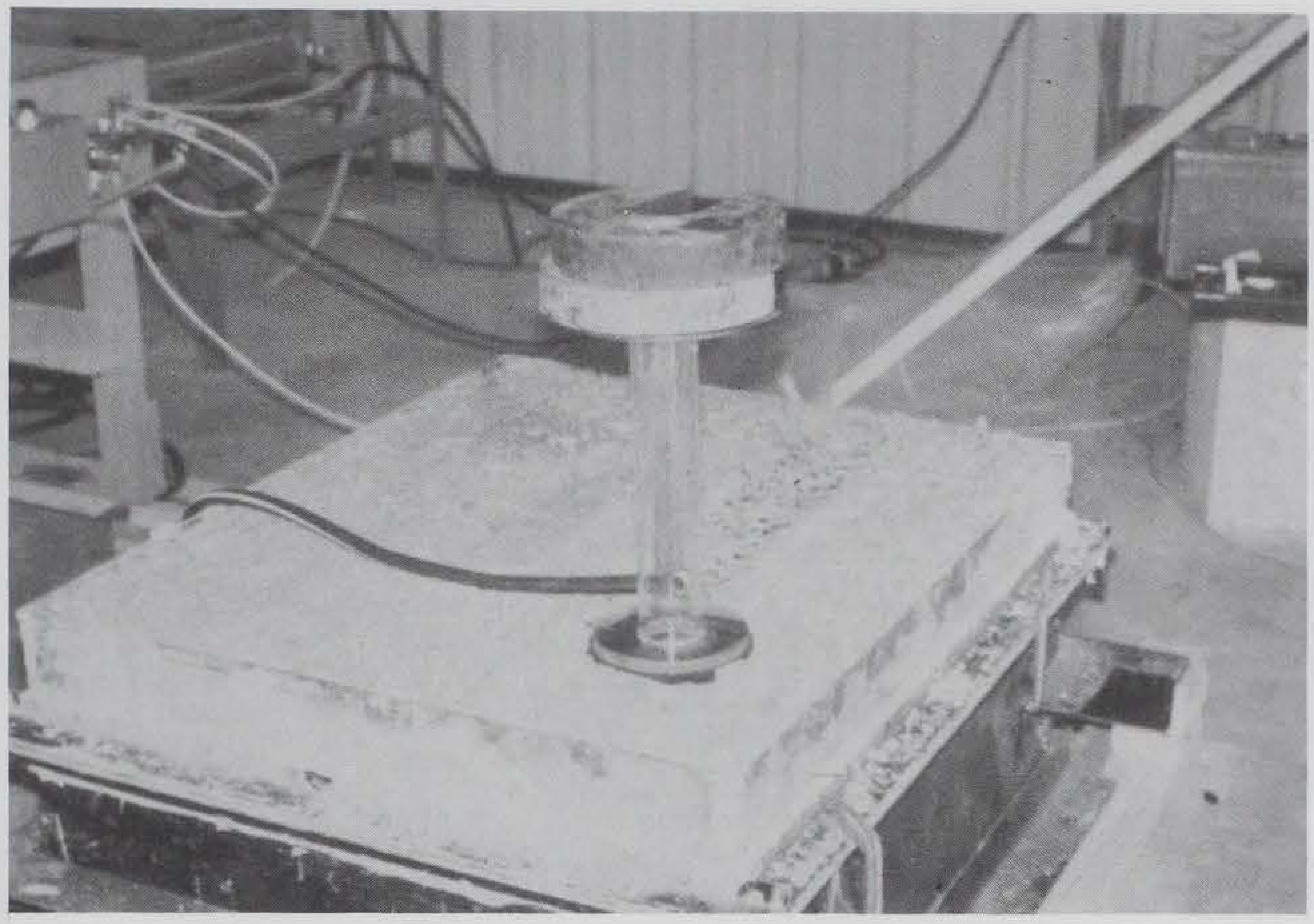

Photo 21. Permeability test

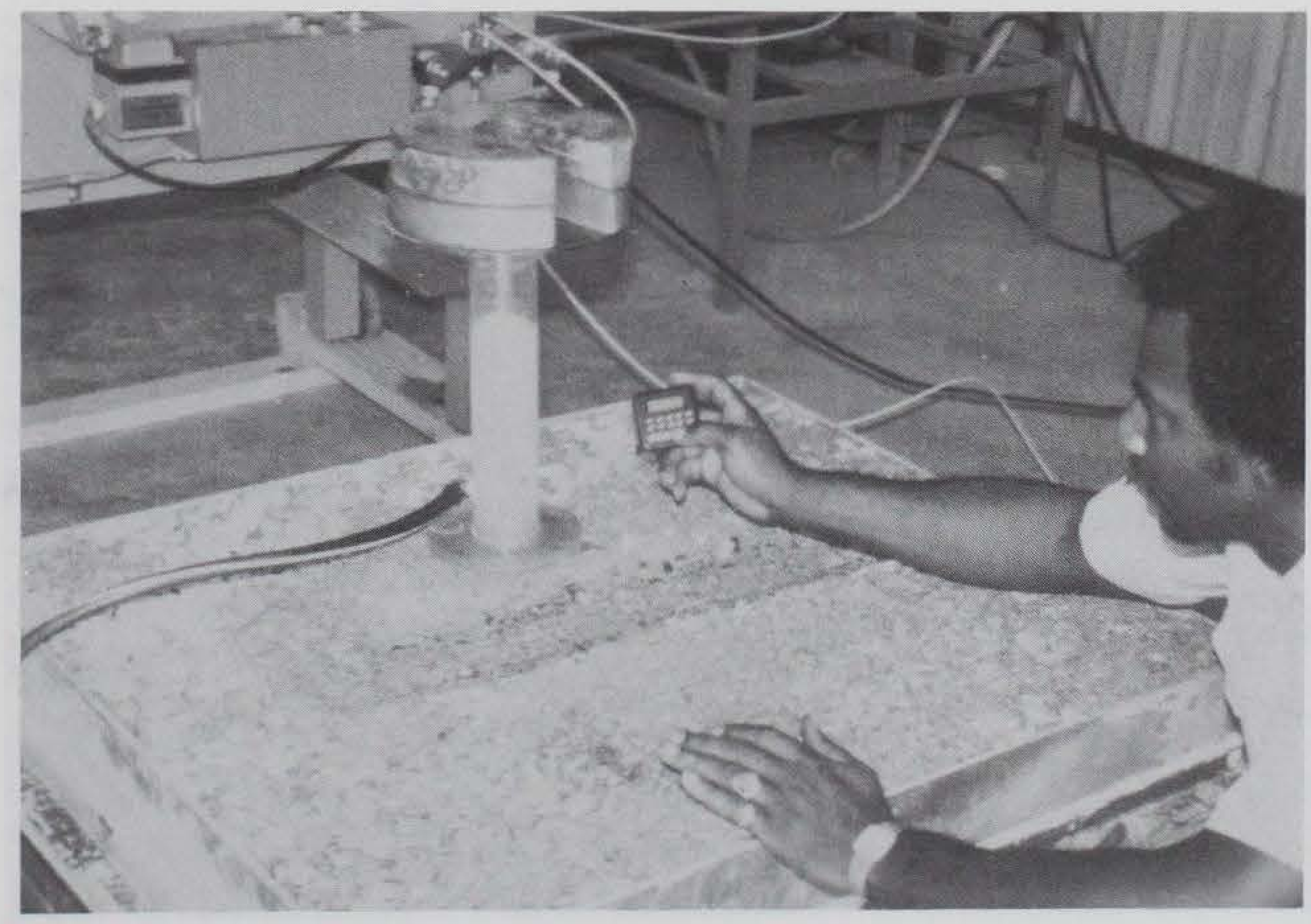

Photo 22. Timing the water fall

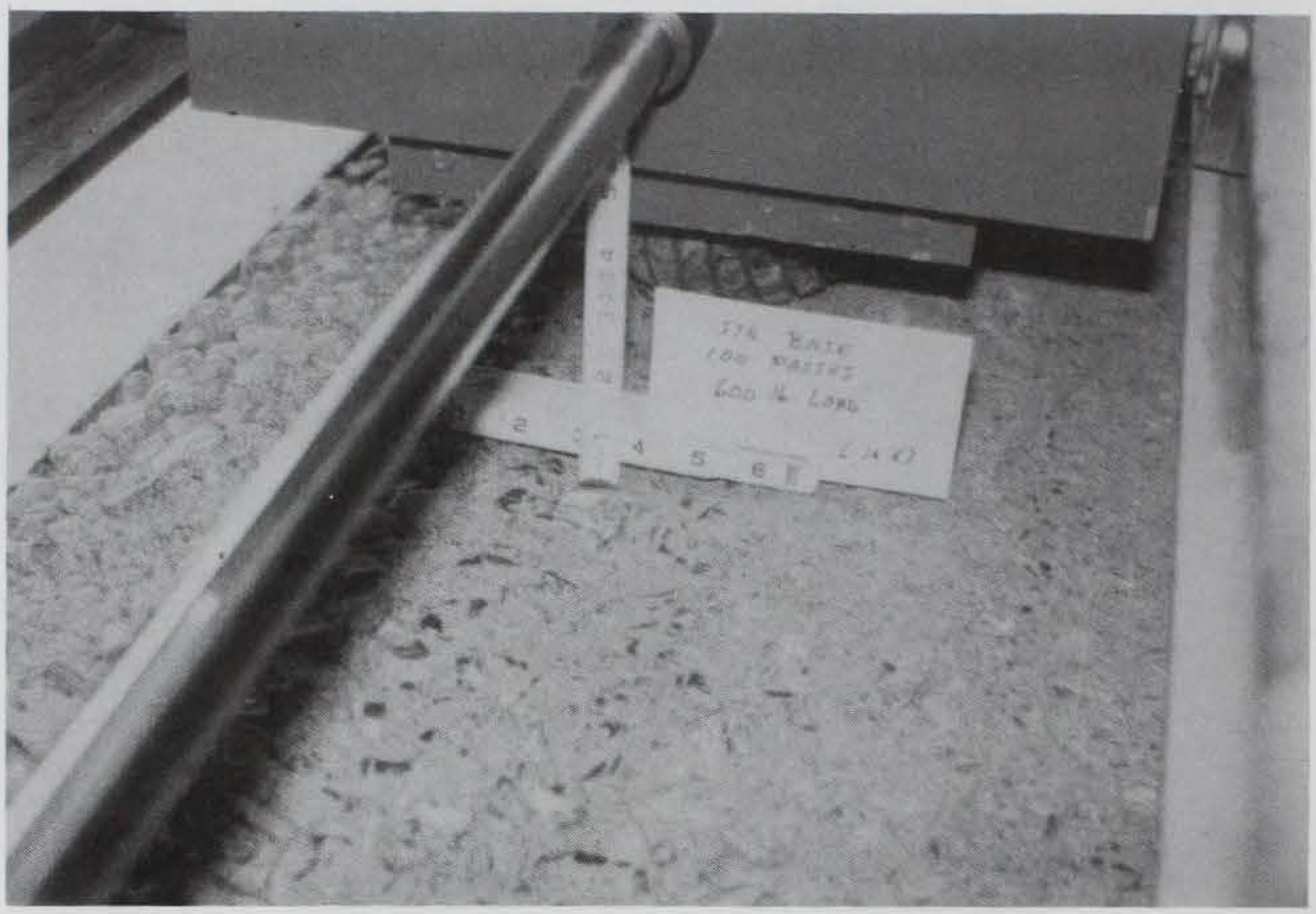

Photo 23. Standard crushed gradation during testing

Photo 24. Standard crushed gradation during testing

Photo 25. CS-I crushed gradation before traffic

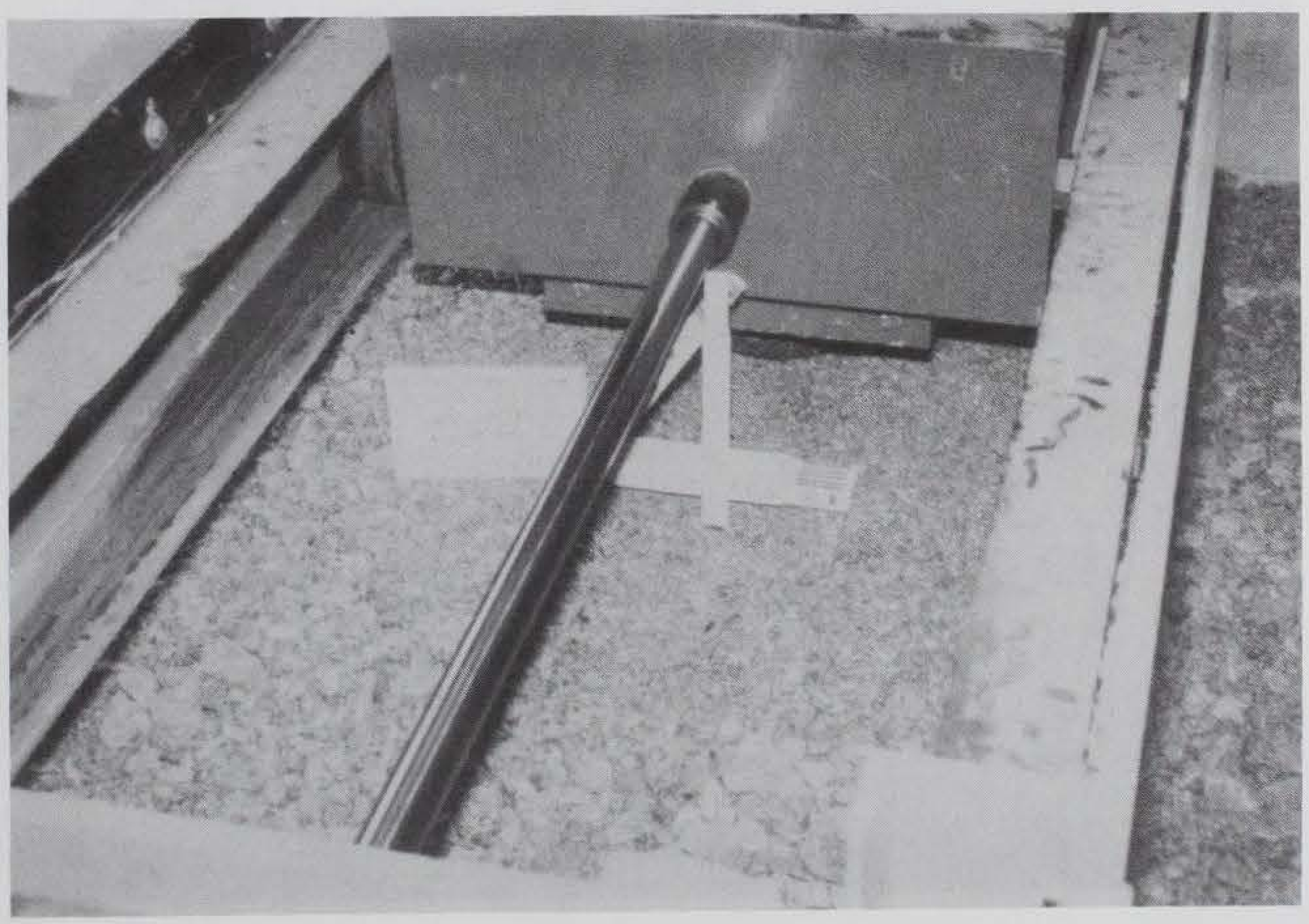

Photo 26. CS-I crushed gradation during testing

Photo 27. CS-II crushed gradation before traffic


Photo 28. CS-II crushed gradation during testing

Photo 29. CS-III crushed gradation before traffic

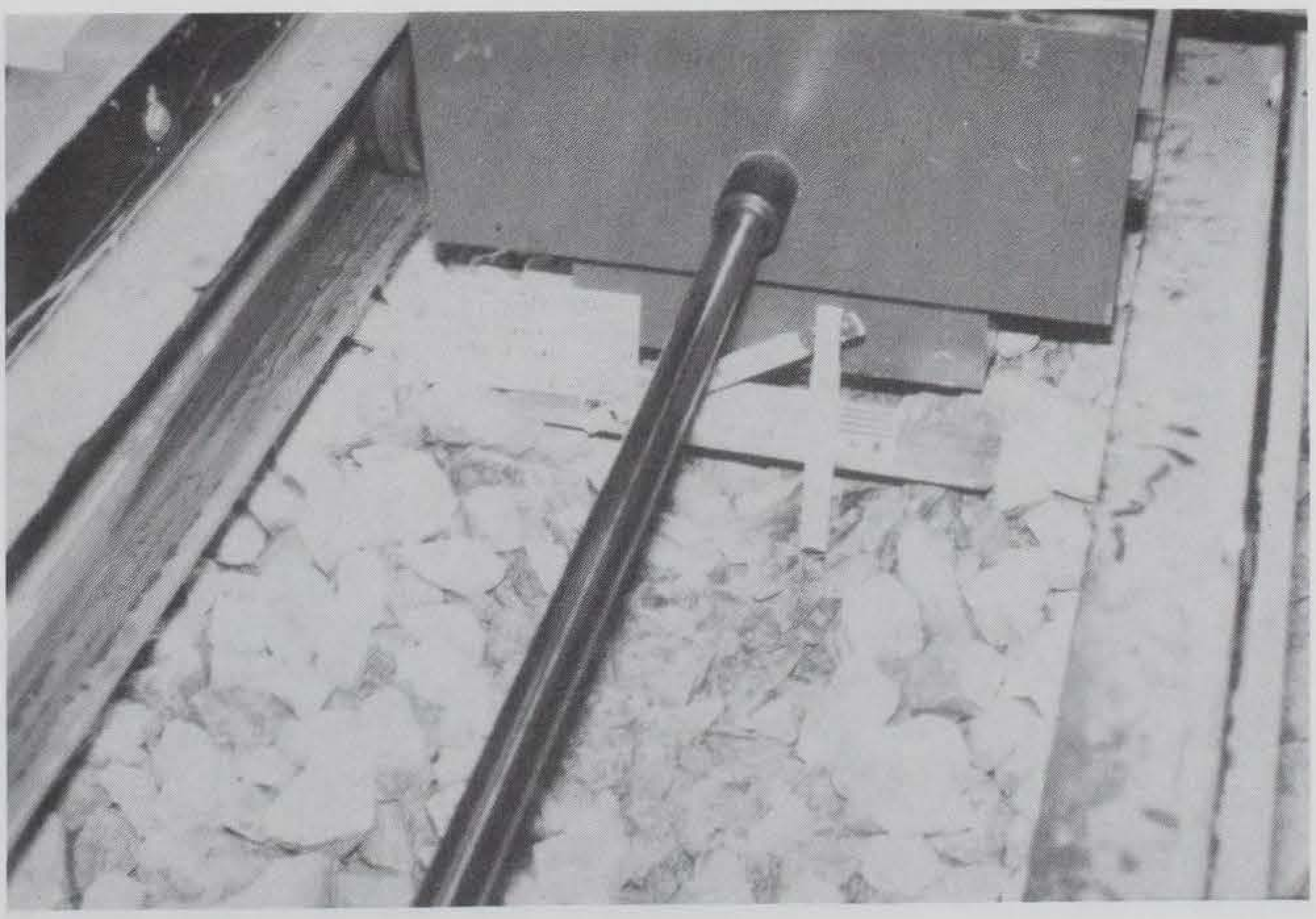

Photo 30. CS-III crushed gradation during testing

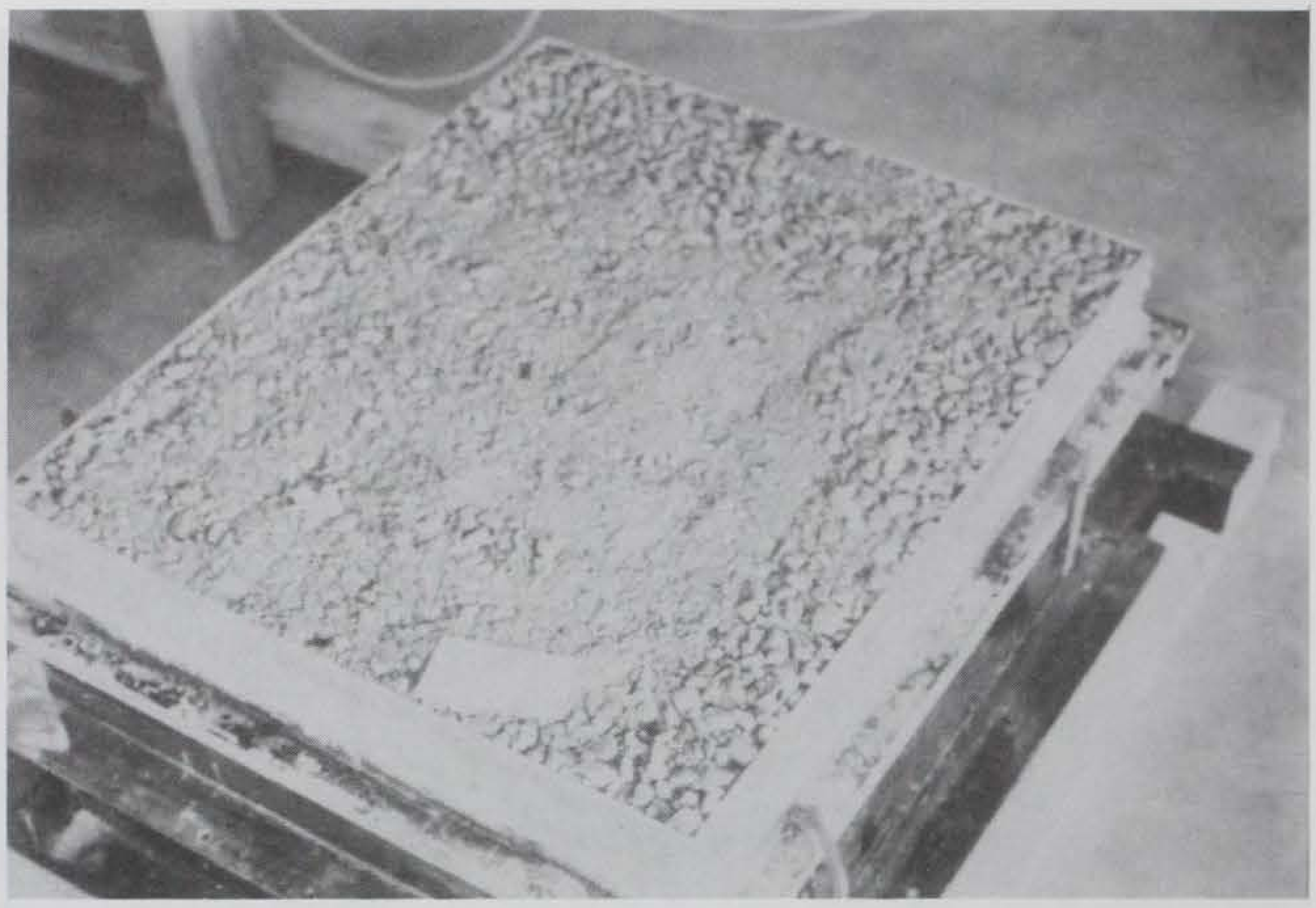

Photo 31. CS-IV crushed gradation before traffic

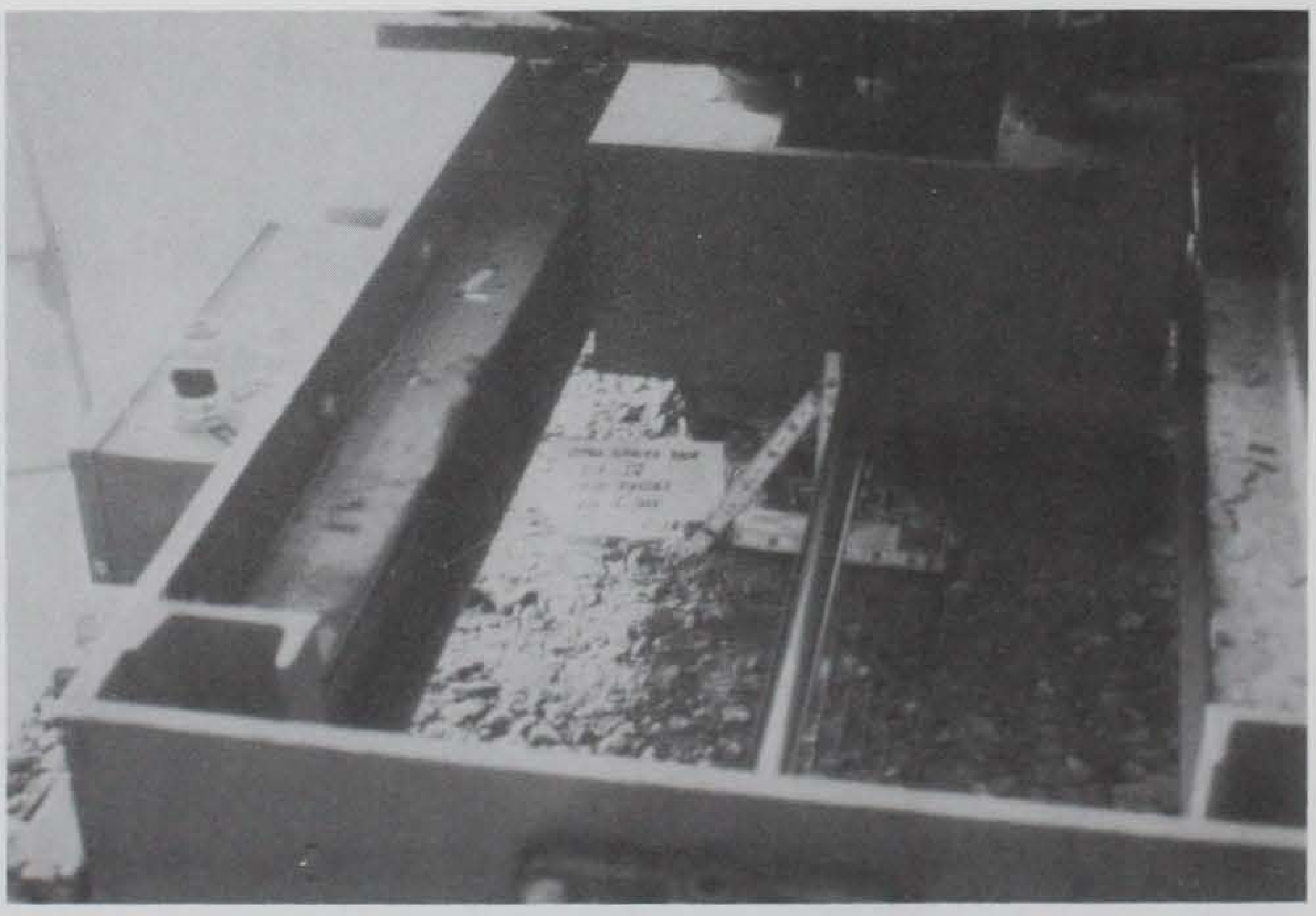

Photo 32. CS-IV crushed gradation during testing

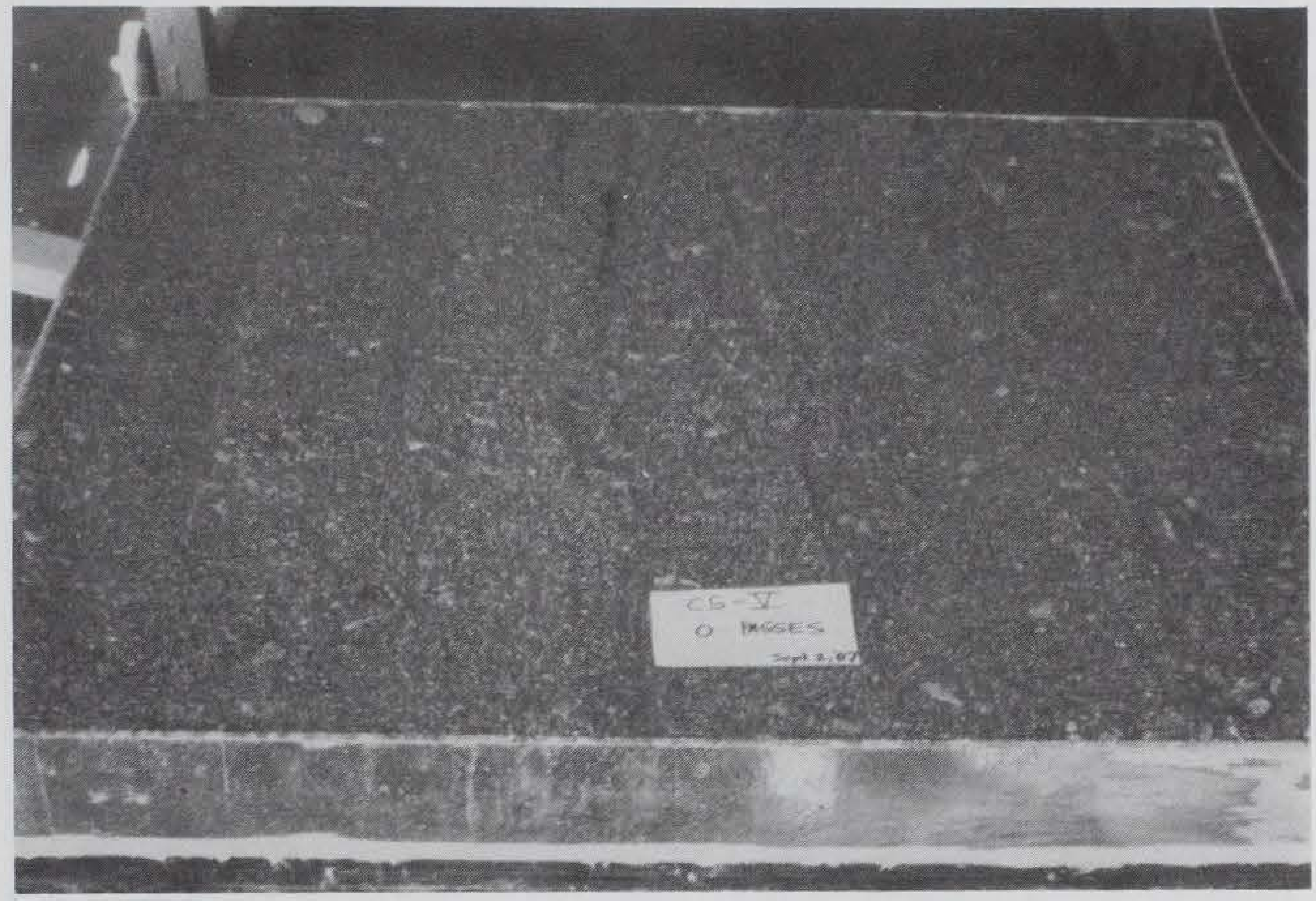


Photo 33. CS-V crushed gradation before traffic

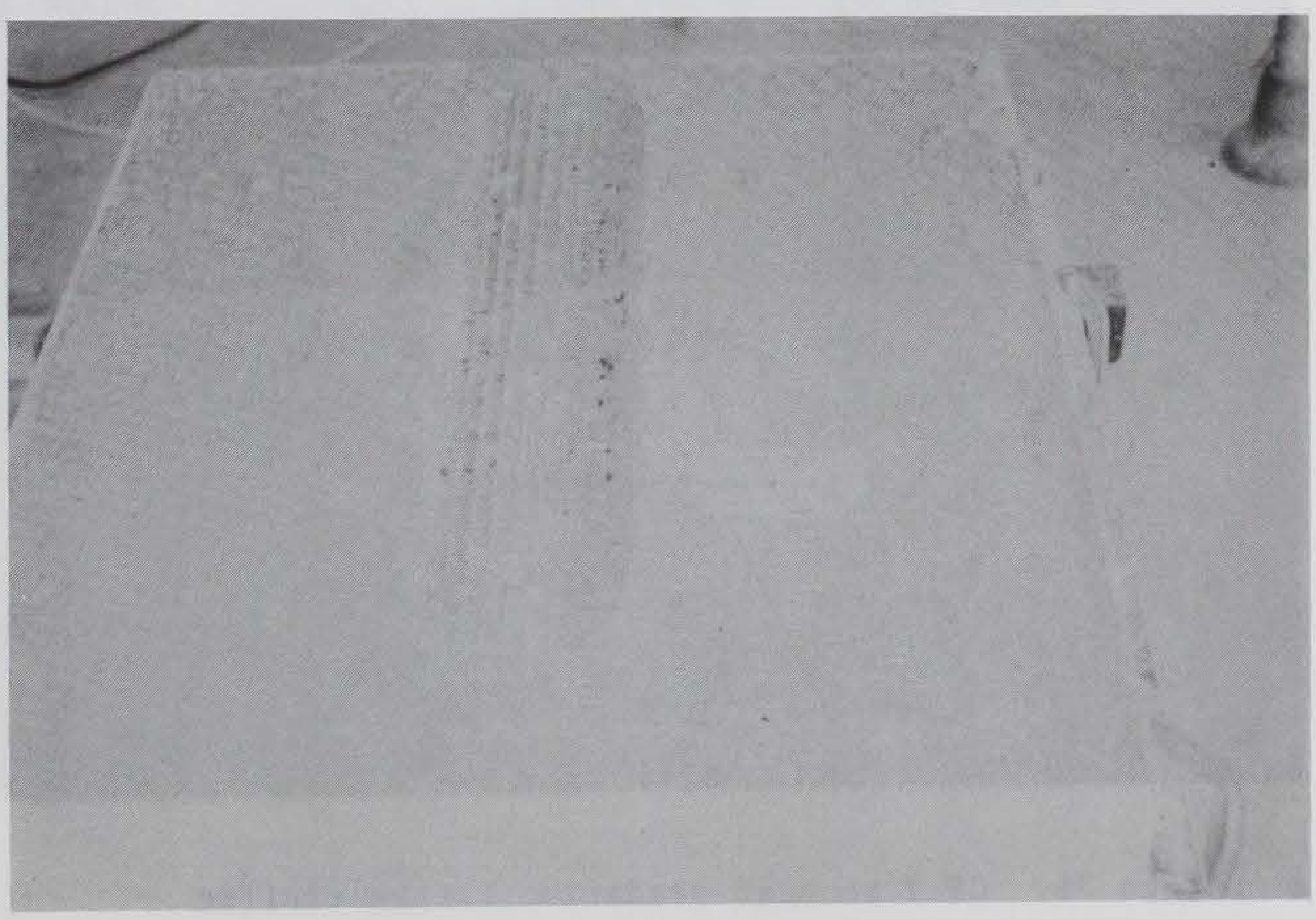

Photo 34. CS-V crushed gradation during testing

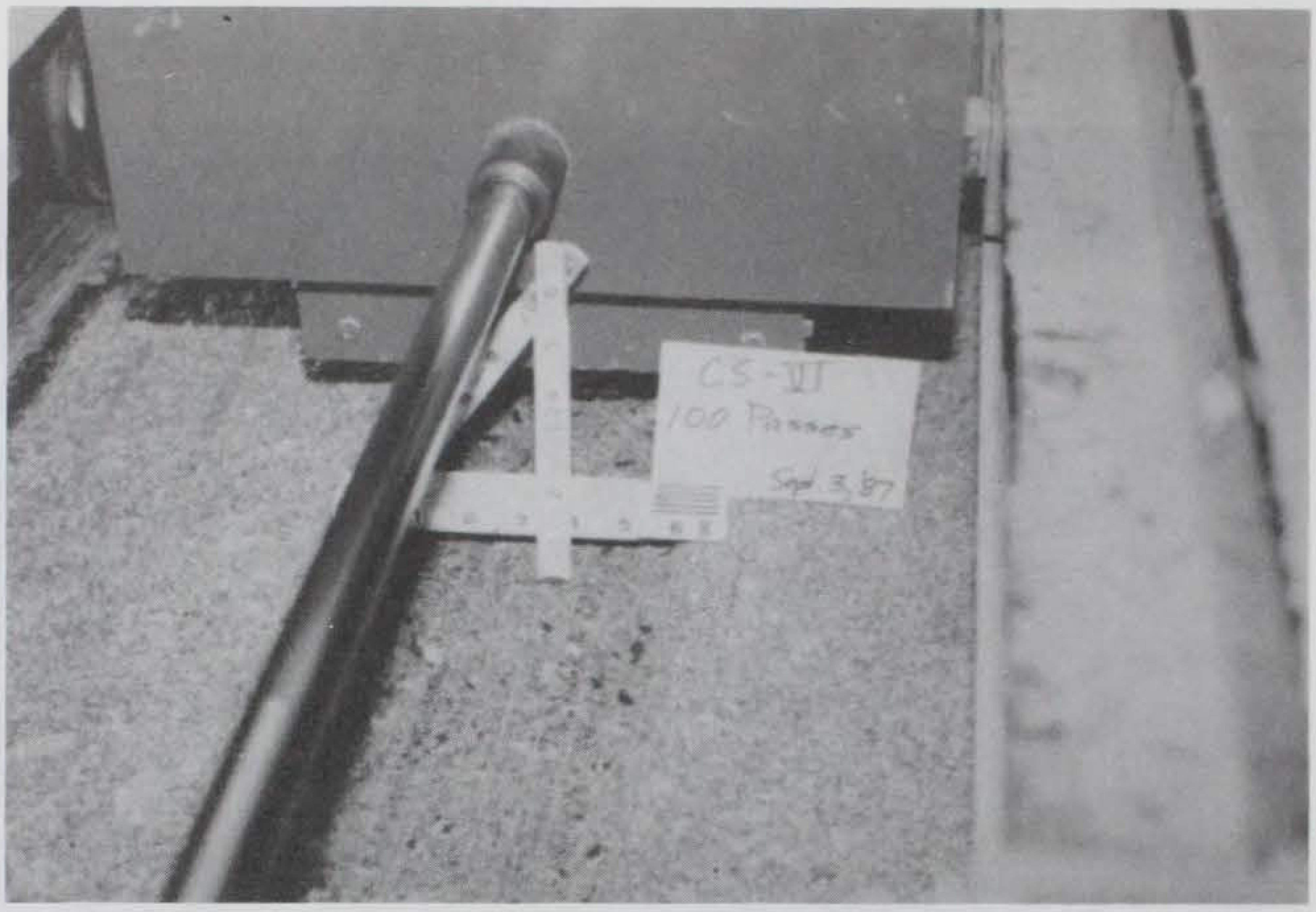


Photo 35. CS-VI crushed gradation before traffic

Photo 36. CS-V rounded gradation before traffic

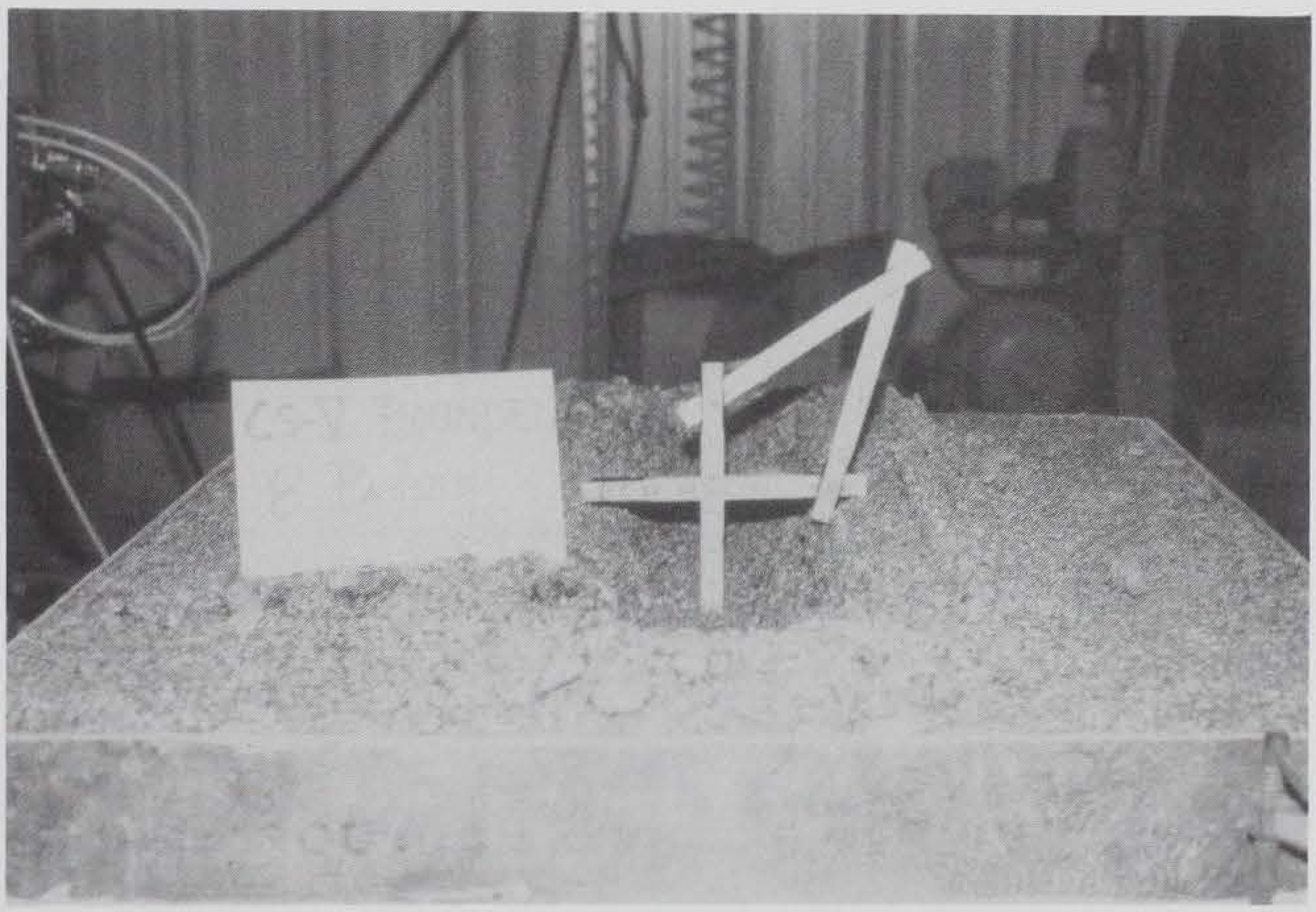

Photo 37. CS-V rounded gradation after 8 passes