R A DODGE

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

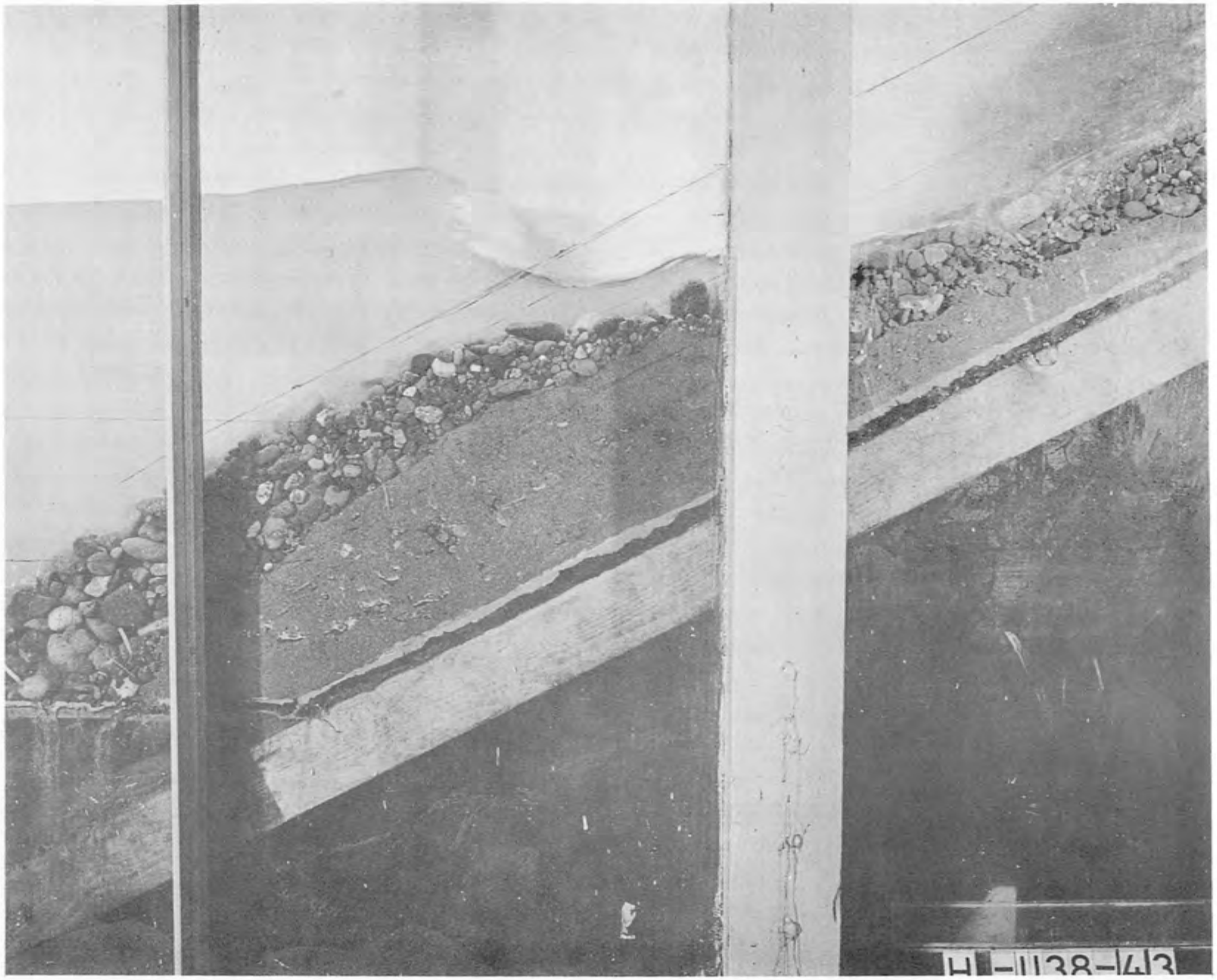
HYDRAULIC MODEL STUDIES TO DETERMINE THE REQUIRED COVER BLANKET TO PREVENT FINE BASE MATERIAL FROM LEACHING DUE TO WAVE ACTION--KENNEWICK MAIN CANAL YAKIMA PROJECT, WASHINGTON

Hydraulic Laboratory Report No. Hyd-381

ENGINEERING LABORATORIES

OFFICE OF THE ASSISTANT COMMISSIONER AND CHIEF ENGINEER
DENVER, COLORADO

June 4, 1954



(FRONTISPIECE)
Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 8 - AFTER 5 HOURS OF OPERATION
Model study

FORWARD

Hydraulic model studies were conducted on earth materials, from the Kennewick Main Canal site, Yakima Project, Washington, in the Hydraulic Laboratory of the Bureau of Reclamation at Denver, Colorado, during August and September of 1953. The studies were conducted primarily to determine the required cover blanket to prevent leaching of the fine bed material through the gravel cover due to wave action.

The protective cover, evolved from this study, was developed through the cooperation of the staffs of the Canals Branch and the Hydraulic Laboratory.

While the studies were in progress, Messrs. A. W. Kidder, H. E. White, and F. D. Ritchey frequently visited the laboratory to observe the model in operation and to discuss test results. Personnel from the Chief Designing Engineer's office, Earth Dams Branch, Canals Branch, Earth Materials Laboratory and Diversion Works Section frequently visited the Hydraulic Laboratory to view the model in operation and observe movies taken of the study.

The studies were conducted by the writer, P. F. Enger, and were under the supervision of E. J. Carlson.

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Office of the Assistant Commissioner and Chief Engineer
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Laboratory Report No. Hyd-381
Hydraulic Laboratory
Compiled by: P. F. Enger
Checked by: R. A. Dodge
Reviewed by: E. J. Carlson

Subject: Hydraulic model studies to determine the required cover blanket to prevent fine base material from leaching due to wave action--Kennewick Main Canal--Yakima Project, Washington

SUMMARY

Tests were conducted primarily to determine the required cover blanket to prevent leaching of the fine base material through the gravel cover due to wave action. Materials were shipped to the laboratory from the site of the Kennewick Main Canal. The materials were tested in a flume in which a wave machine for producing variable waves had been constructed.

A cover was found which prevented leaching of the fine material and which resulted in a stable surface. In developing the protection cover, 14 tests were conducted. Angular talus material (Figure 5), which is available at the site, resulted in a more stable cover than a rounded gravel material. To form the protective blanket it was found advisable to screen the talus material (analysis curves shown in Figure 17) on a 3/4-inch screen. The blanket was constructed by placing a layer of talus material smaller than 3/4 inch over the fine base material and, as a surface protection, placing a layer of talus material larger than 3/4 inch.

In the course of developing the cover blanket, it was discovered there was a lack of information regarding the heights and frequencies of waves occurring on canals. Opinions voiced on height of waves which would occur in canals varied widely.

In the model operation, the recommended cover resulted in a stable protective blanket. The fine material was prevented from leaching through or into the cover blanket. The surface of the cover blanket was relatively stable with beaching resulting from only large waves. A photograph of the recommended cover blanket after 128 hours of operation at various wave heights and frequencies may be seen in Figure 26.

Movies were taken of all tests and are available from the Hydraulic Laboratory.

INTRODUCTION

The Kennewick Main Canal is located in Benton County, Washington, near the Yakima River, between Prosser and Kennewick, Figure 1. Construction of the Main Canal will provide irrigation for approximately 14,500 irrigable acres of new land and additional irrigation for approximately 4,600 acres of land in the area that is presently irrigated. Water from the Chandler Pumping and Powerplant will be pumped and lifted over 100 feet to the Main Canal. The 42.3-mile-long Main Canal and approximately 100 miles of laterals will distribute water to the new lands and deliver water into the existing distribution system of the presently irrigated lands. Sufficient Main Canal capacity will be provided to permit the eventual irrigation of approximately 6,100 acres of additional land.

The canal, as shown in Figure 2, has a bottom width of 14 feet, a depth of 7.61 feet, and 2:1 side slopes. The resulting surface width is 44.44 feet. With the comparatively wide surface width and various straight alignments (approaching 1/2 mile), it was assumed that some detrimental wave action would occur in the canal.

The Main Canal passes through an area of fine material (analysis curve shown in Figure 3). As the material consisted mostly of silt--over 70 percent passing the No. 200 United States Standard screen, and there was very little cohesion in the material--a protective cover was essential. A gravel material and two talus materials (Figures 4 and 5) were available for use as a protective cover. The gravel and talus material were, to the extent of the laboratories' information, both equally available and in adequate supply. As the materials available for a protective blanket fell largely outside the Bureau of Reclamation filter criteria for the base material, as shown in Figures 4 and 5, the effectiveness of the cover materials in preventing leaching of the fine base material due to wave action was investigated. The request for the studies was made by memorandum to Chief, Engineering Laboratories from Chief, Canals Branch, July 23, 1953.

To study the proposed structure a wave machine and a model of the canal side slope were constructed in the Hydraulic Laboratory. Waves were created and their action on material shipped from the canal site was studied.

As the height and frequency of the waves which the canal would be subjected to were not known, various heights and frequencies were used in developing the protective blanket. Tests were conducted with the understanding that wave forms and frequencies would not duplicate waves which would occur in the field, but that wave heights would be approximately the same. Having approximately the same surface fluctuation in the model as in the field, resulted in similar forces.

In the model tests, waves were made to move at right angles to the canal slope. The resulting beaching action was probably more severe than in the field where maximum waves would move longitudinally along the canal.

CONSTRUCTION AND OPERATION OF THE MODEL

A model of a portion of the side slope of the Kennewick Main Canal was constructed in an existing flume. As shown in Figure 6, a 2:1 slope of plywood was built in the flume which was 2 feet wide, 6 feet deep, and approximately 24 feet in length. A plywood divider was placed on the slope dividing it into two sections. The 1-foot-wide area on one side of the plywood divider was used for placing the test section. On the other side a coarse gravel was placed to the same thickness as the section being tested. A large glass window allowed the test section to be viewed at all times. The open end of the flume was sealed with sheathing and sheet metal.

A wave machine was constructed by utilizing an existing tailgate in the flume and equipment on hand in the Hydraulic Laboratory. As shown in Figure 7, a 3/4-horsepower motor, which had been geared down to 190 rpm, was connected in series with a set of variable speed pulleys and a 12-inch pulley wheel. The large pulley had holes at various radii drilled in it and was designed for use with an extension arm. The pulley wheel was connected to an extension on the tailgate. When the pulley wheel turned, the gate, which was hinged at the bottom, was forced to move back and forth thus creating a wave. By manipulation of the variable speed pulleys, it was possible to change the frequency of the wave from 6 to 315 waves per minute. The displacement of the gate could be changed, thereby changing the height of the wave, by utilizing the various radii of the pulley wheel. The radii could be varied from 2-1/8 to 11 inches.

Prior to operation, the model was filled slowly to the desired depth. The depth was maintained constant by allowing a small discharge to run in the model and manipulating an overflow pipe to the proper elevation.

Water surface elevations were determined by use of a hook gage in a well outside the wave area of the model. For each test both still and moving photographs were taken as an aid in recording data.

THE INVESTIGATIONS

Test 1 (Gravel Moistened and Well Mixed)

The first test was conducted on the gravel material (Figure 4). Six inches of the material, moistened and well mixed, was placed on the

2:1 slope. No effort to compact the material was made. The moist sand particles adhered to the gravel and were well distributed throughout the 6-inch layer. As shown in Figure 8a, the water was raised to a depth of 2.7 feet. The wave machine was operated at 32 waves per minute which created a wave with a height from trough to crest of approximately 0.32 foot.

Immediately after the wave machine was turned on, the Kennewick gravel material began to slip and roll down the slope. As sand had adhered to the gravel particles, it is believed the sand, washing from between the gravel particles, reduced friction throughout the layer, and the force of the water flowing out of the blanket was enough to start the particles to slide and roll down the slope. Approximately 20 minutes after the beginning of the test the board slope was exposed. The photograph of Figure 8b shows Test 1, after the test had been in operation for 45 minutes. Complete failure near the water surface had occurred. The model was turned off after 1 hour.

Test 2 (Gravel Separated on 3/4-inch Screen)

The gravel material, used in Test 1, was dried and separated on a 3/4-inch screen. The resulting analysis curves and Bureau of Reclamation filter criteria are shown in Figure 9. The analysis curve for the fine base material, the minus 3/4-inch material, and the plus 3/4-inch material are shown. Filter criteria limits for the base material and the minus 3/4-inch material are shown on the same graph. The graph shows that the minus 3/4-inch material falls roughly within the limits of the graded filter criteria for the base material, except there is very little material between the No. 4 and No. 30 sieve sizes. The plus 3/4-inch material falls within the limits of the uniform filter criteria for the minus 3/4-inch material.

A 4-inch layer of the material smaller than 3/4 inch in size was placed on the 2:1 slope and protected by a 4-inch layer of material larger than 3/4 inch in size. The water was raised to a depth of 2.7 feet, and the wave frequency was set at 32 waves per minute. The resulting wave height was 0.32 foot. The model, ready for operation, may be seen in Figure 10a. The model was run for 1 hour at the preceding conditions.

As 32 waves per minute caused no damage, the frequency of the waves was increased to 42 per minute. The increase in frequency caused the wave height to increase from 0.32 to 0.43 foot.

At 42 waves per minute there was a small amount of beaching of the surface material. The resulting damage, shown in Figure 10b, after a 24-hour operational period was considered not sufficient to cause failure in a canal installation.

There was movement of sand in the gravel material below 3/4 inch in size. The sand appeared to move down the slope through the gravel in the area where the two layers were in contact. As may be seen by studying the photographs in Figure 10, the sand moved in the top 1-1/2 inches of the 4-inch layer of minus 3/4-inch material. Some of the sand in the material smaller than 3/4 inch in size concentrated at the bottom of the layer thus, probably, improving the action of the material in preventing leaching.

Test 3 (Gravel Placed Dry and Raked)

An attempt was made to find a less expensive method of placing the cover material by stabilizing it with a raking or harrowing process. It was thought that with raking the finer material in the gravel would tend to settle to the lower portion of the cover, thus leaving the coarse material to form a more stable surface, while the finer material near the base would tend to prevent leaching. To check the stability that could be obtained from raking, an 8-inch layer of gravel (containing 1.7 percent moisture by dry weight) was dumped on the 2:1 slope. The gravel material was then raked vigorously for 3 to 4 minutes. The rake used for this purpose is shown in Figure 11a. The rake was constructed by driving spikes through a 2 by 4. The spikes were placed 4 inches apart and protruded 4-3/8 inches.

The wave machine was started to operate at 32 waves per minute and soon after starting was stepped up to 42 waves per minute. The resulting wave heights were 0.32 and 0.43 foot, respectively. The depth was held constant at 2.7 feet.

The raked material withstood the wave action much better than the unraked and moist material used in Test 1. Some beaching started at the water surface when the machine was first turned on. The beaching continued until the wave machine was turned off 24 hours later. A photograph taken after the model had been in operation for 19 hours may be seen in Figure 11b. The final beaching slope reached after 24 hours' operation was approximately 5.14:1.

Test 4 (Gravel Separated on 1-inch Screen)

As the gravel separated on the 3/4-inch screen indicated promising results, additional tests to find the optimum point of screening were made. In Test 4 the gravel was separated on the 1-inch screen and 4 inches of material smaller than 1 inch in size was placed on the 2:1 slope and protected with 4 inches of plus 1-inch material. The resulting analysis curves plotted with the base material and filter criteria are shown in Figure 12.

The model was filled to a depth of 2.7 feet, turned on and operated at 42 waves per minute for approximately 45 minutes. Although the surface material withstood the 0.43-foot-high waves very well, the sand moved from the lower layer quite freely. Figure 13a shows a photograph of the model after 45 minutes of operation. The area from which the sand has moved may be seen in the photograph.

After 45 minutes of operation at 2.7-foot depth, the model was turned off and the water surface was raised to a depth of 3.2 feet. The wave machine was left at 42 waves per minute. The resulting increase in depth increased the displacement of the wave machine at the water surface and resulted in a wave 0.5 foot high from trough to crest. The model was operated at the new depth for 30 minutes.

With the larger wave height there was some movement of surface material, however, this movement was considered not serious. Increased movement of the sand from the material smaller than 1 inch in size was noted. A study of the photograph in Figure 13b, reveals the sand has moved in the lower layer to the full depth of 4 inches. The comparatively larger voids in the plus 1-inch material allowed a flow of water through the gravel great enough to cause the fine sand to leach out. The fine base material placed under a protective blanket similar to that in Test 4 would apparently leach out.

Tests 5 and 6 (Gravel Separated on 1/2-inch Screen)

In a continuation of tests to find the optimum screening size, the gravel was separated on a 1/2-inch screen for Test 5. The resulting analysis curves with filter criteria and the bed material curve are shown in Figure 14. Four inches of material smaller than one-half inch in size was placed on the 2:1 slope and protected with four inches of material larger than one-half inch in size. A photograph of Test 5 ready for operation may be seen in Figure 15a. The material was screened while damp, and it was noticed that the sand adhered to the coarse gravel particles even after considerable vigorous shaking in the screening machine.

The water was raised to a depth of 2.7 feet, and the wave machine was started at 42 waves per minute, creating waves with a height of 0.43 foot. After a few waves had washed up the slope, a slide occurred. The slide appeared to start in the area where the water from the wave flowed out of the gravel material and continued to the toe of the slope. A photograph showing the condition of the slope after the slide may be seen in Figure 15b. Movies taken of Test 5 including the slide are available in the Hydraulic Laboratory. From viewing the movies it appeared that the sliding surface started at the surface of the plus 1/2-inch material, progressed through the plus 1/2-inch material, then through the minus 1/2-inch material, and ended at the board surface at the toe of the slope. As the material had been placed in the same manner as for other tests, except it was damp, and the sand remained coated to the rocks, it is believed the sand reduced the friction between rocks in the top layer and the force of the water flowing out of the blanket was enough to start the slide.

Because of the slippage which occurred during Test 5, the material was removed, rescreened, and replaced in the same two layers as for Test 5, except the material was dry. This was called Test 6. The model was then backfilled to a depth of 2.7 feet, the wave machine was set as before and operated for 24 hours. No slippage occurred and the fine material appeared stable with very little movement of sand. Some of the surface material (larger than 1/2 inch) moved forming a beaching slope. The 1/2-inch and larger material had a tendency to move more readily than the 3/4 inch and larger or the 1 inch and larger, which had been tested previously. A photograph showing the condition of the model after 23 hours of operation is shown in Figure 16a.

Tests 7 and 8 (Tests to Determine Effect of Sand on Slippage Failure)

Tests 7 and 8 were conducted in an attempt to determine the effect of the sand (when it remained coated to the rocks) in causing failure. For Test 7, the gravel was screened while damp on the 3/4-inch screen and placed as in Test 2. A 4-inch layer of material smaller than 3/4 inch in size was protected by a 4-inch layer of material larger than 3/4 inch in size. The only difference between Tests 2 and 7 was that the material in Test 7 was screened damp, thereby leaving a coating of sand particles on the larger rocks.

The flume was filled to a depth of 2.7 feet, and the wave machine was started to operate at 42 waves per minute with the resulting wave heights of 0.43 foot. Immediately on starting the wave action, considerable slippage occurred. The slippage was less pronounced than when the material was separated at 1/2 inch. The coarse material slipped near the surface until it had decreased in thickness by approximately 1 inch. After approximately 1 minute of operation, the material became stable. Further operation produced little change. This test appeared to confirm the fact that the sand coated to the larger material contributed largely to the slippage failure in Test 5.

For Test 8, the gravel was placed as in Test 1, well mixed, but instead of being in a damp condition, it was dry. An 8-inch layer was placed on the 2:1 slope. The model was filled to a depth of 2.7 feet, and the wave machine was started at 42 waves per minute.

Approximately 3 inches of beaching occurred in the first 2 minutes. After about 3-1/2 inches of beaching had occurred, the gravel appeared to be quite stable. A photograph showing the condition of the cover, after 5 hours of operation, is shown in the Frontispiece. The dry gravel resulted in a more stable condition than the damp gravel of Test 1.

Test 9 (Recommended Cover--Talus Separated on 3/4-inch Screen)

As the mechanical analyses and the specific gravity of the two talus samples were quite similar (see Figure 5), the two samples were mixed before being tested. The mixed talus material was screened on the 3/4-inch screen, resulting in the analyses curves shown in Figure 17 together with the base material analysis curve and Bureau of Reclamation filter criteria. Before placing the material, 3.6 percent moisture (by dry weight) was added to the material smaller than 3/4 inch in size to simulate field conditions. Four inches of material smaller than 3/4 inch in size was placed on the 2:1 slope and protected by 4 inches of material larger than 3/4 inch in size (Figure 16b). The model was filled to a depth of 2.7 feet and the wave machine started.

Thirty-two waves per minute were first created. The model was operated with the 0.32-foot waves for 15 minutes. As the material appeared very stable, the frequency of the wave machine was increased to 42 waves per minute. The model was operated at this frequency and wave height (0.43 foot) for 30 minutes. There was a small amount of movement of the fine material. The wave frequency was increased to 68 waves per minute, with a resulting wave height of 0.5 foot. A 0.5-foot wave approaching the slope may be seen in the photograph of Figure 18a. At 68 waves per minute, the surface material was still relatively stable. There was a little movement of the fine material on the lower layer. The movement of the lower layer appeared to stop after 2 hours of operation. The model was operated at 68 waves per minute for 5 hours. A photograph showing the condition of the material after 5 hours of operation is shown in Figure 18b. A comparison of Figures 16b and 18b shows very little change in the appearance of the material.

Test 10 (Talus Moistened and Well Mixed)

A 6-inch layer of talus material, moistened and well mixed, was placed on the 2:1 slope in the testing flume. The method of placing was similar to Test 1, in which the gravel material was used. The flume was filled to a depth of 2.7 feet, and the wave machine started at 32 waves per minute. There was movement of the finer talus material, but not as much as that observed in the gravel material of Test 1. After 20 minutes of operation, the frequency of the waves was increased to 42 per minute; and after an additional 20 minutes to 62 per minute, the resulting wave heights were respectively 0.32, 0.43, and 0.5 foot. At the higher frequency and wave heights there was considerable erosion of the talus material, which was washed down to form a beaching slope of 3.66:1. The model was operated for 2-1/3 hours at 62 waves per minute. A photograph showing the condition of the talus material, after the 3-hour total operation described above, may be seen in Figure 19a.

After the beaching slope had been recorded, the model was left running at 62 waves per minute and the water was raised slowly to a depth of 3.2 feet, then lowered to a depth of 2.2 feet. Raising and lowering the water surface caused various wave heights for 62 waves per minute. The scour observed showed considerable material moved down the slope, but at no point was the 2:1 slope exposed. A photograph showing the condition of the model after the raising and lowering of the water surface is shown in Figure 19b. The model was operated for a total of 5 hours.

Test 10 indicated that the angular talus material was considerably more stable than the rounded gravel material placed in the same manner.

Test 11 (Talus Separated on 1/2-inch Screen)

The talus material was dried and screened on the 1/2-inch screen resulting in the analysis curves shown in Figure 20. Four inches of material smaller than 1/2 inch in size was placed on the 2:1 slope and covered by four inches of material larger than 1/2 inch in size. The model was filled to a depth of 2.7 feet, and the wave machine was started at 32 waves per minute, giving a wave height of 0.32 foot. At 32 waves per minute there was very little movement of the surface material. The material in the bottom layer, smaller than 1/2 inch in size, appeared very stable. As no damage occurred at 32 waves per minute, the frequency of the waves was increased to 42 and then to 62 waves per minute, and the model was operated for a 2-hour period. The resulting wave heights were 0.43 and 0.5 foot, respectively. At the higher wave frequencies the surface material moved more freely and approximately 1 inch was eroded in forming the beaching slope, however the material in the bottom layer, below 1/2 inch in size, still appeared very stable and very little movement occurred.

Test 12 (Fine Base Material)

A 6-inch layer of the fine base material (analysis curve shown in Figure 3) was subjected to wave action. In preparing the material enough water was added to bring the moisture content to 18 percent of the dry weight of the material. The 18 percent moisture is the optimum moisture content for maximum compaction. The material was placed on the 2:1 slope in layers of approximately 2 inches, and each layer was tamped to near maximum compaction with a wooden tamper. Before compacting the base material, the 2:1 board slope was roughened with a layer of metal lath. The slope was roughened as an aid in preventing the base material from sliding on the board slope. The model ready for operation may be seen in Figure 21a.

The water was raised slowly in the flume to a depth of 2.7 feet. There was some settlement of the material on the slope and near the water surface cracks could be observed. The wave machine was started and operated at 32 waves per minute for 1 hour. The wave heights varied from 0.25 to 0.40 foot as the material washed down the slope.

During the operation complete failure of the slope occurred. Immediately on starting the wave machine, the earth material began to fail. A photograph taken 2 minutes after operation started may be seen in Figure 21b. A density current of fine material flowed down the slope and to the bottom of the flume. After 12 minutes of operation, the 2:1 slope was completely exposed. The model was operated for 1 hour after which it was turned off and slowly drained. The fine material assumed an approximate level position as shown in Figure 22a.

Test 13 (Base Material and Plus 1/2-inch Talus Material)

A 4-inch layer of the base material was compacted on the 2:1 slope, and protected with 4 inches of talus material larger than 1/2 inch in size (Figure 20). The fine base material was placed at optimum moisture content (18 percent by dry weight) and compacted in thin layers with a wooden tamper. The talus material was dumped on the compacted base material. The model, ready for operation, is shown in Figure 22b. The model was slowly filled to a depth of 2.7 feet, and the wave machine was started at 32 waves per minute (wave height 0.32 foot).

Immediately after the model was started, the fine base material began leaching through the talus cover. The material being leached out formed a density current which moved down the slope in the water immediately above the talus cover and continued on into the flume. The density current may be seen in the photograph of Figure 23a, which was taken 7 minutes after the model was turned on. After 30 minutes of operation at 32 waves per minute, the wave machine frequency was increased to 42 waves per minute. The increase in frequency increased the wave heights to 0.43 foot. At the increased frequency the leaching of the base material increased. A photograph, taken 90 minutes after operation started, is shown in Figure 23b. The photograph shows that the base material had washed within approximately 1/2 inch of the board slope.

The model was operated an additional 17.5 hours at 42 waves per minute. During this time the upper part of the slope failed completely. The fine material was completely washed from beneath the talus cover. A photograph showing the failure may be seen in Figure 24a.

Test 14 (Recommended Cover and Base Material)

A final test was run using the talus material as a protective cover for the fine base material. The moisture in the base material was increased to optimum moisture content, and a layer 4 inches thick was placed by the tamping operation explained previously. The talus material was screened on the 3/4-inch screen. Four inches of talus material smaller than 3/4 inch in size was placed (by dumping) over the fine base material. Over the minus 3/4-inch talus material a 4-inch-thick protective blanket of talus material larger than 3/4 inch in size was placed. The analysis curves are shown in Figure 17. The total thickness of the test section was 12 inches. A photograph of the model ready for operation is shown in Figure 24b.

The model was filled to a depth of 2.7 feet and operated for 28 hours at a frequency of 42 waves per minute and a wave height of 0.43 foot. As shown by Figure 25, the test section withstood the waves very well and very little movement occurred in the talus materials. No movement occurred in the fine base material.

To check the stability of the section the model was operated for a total of 128 hours. After the first 28-hour period, the operation was as follows: 24 hours at 3.2-foot depth, 42 waves per minute, 0.43-foot wave height; 24 hours at 2.2-foot depth, 42 waves per minute, 0.42-foot wave height; 4 hours at 2.7-foot depth, 22 waves per minute, 0.6-foot wave height; 24 hours at 2.7-foot depth, 51 waves per minute, 0.62-foot wave height; and 24 hours at 3.03-foot depth, 22 waves per minute, 0.6-foot wave height. As may be seen from a study of Figure 26a, the material withstood the operation very well. At the frequency of 51 waves per minute there was some movement of the surface material. During the complete test the talus material below 3/4 inch in size was very stable, and no leaching of the fine base material was observed. The waves of 22 per minute frequency ran up and down the slope, from maximum to minimum, a distance of 2.2 feet. The 0.6-foot high waves, at 22 waves per minute, resulted in the most damaging condition where leaching action was concerned. However, no leaching of the base material occurred.

The section was operated to failure after the above test. The water surface was raised to a depth of 3.03 feet, and the wave machine set for 45 waves per minute and a resulting wave height of 0.75 foot. For this condition the material failed. Failure started on the surface and progressed to the bed material. Total failure occurred in 12 minutes as may be seen from the photograph of Figure 26b.

RESULTS AND CONCLUSIONS

The gravel used in the first tests was well rounded and sand adhered to the larger particles when the material was moistened and mixed. When sand adhered to the large particles, failure of the 2:1 slope by a slip occurred. The rounded particles of the gravel moved more readily when exposed to wave action than did the same mean-size angular particles of talus material used in Tests 9, 10, 11, 13, and 14.

The tests indicated that, if a stable cover blanket is to be maintained against wave action, it is desirable to screen the cover material and place it in two layers with the larger material protecting the finer material. The larger the average size of material on the surface layer the more stable was the surface to wave action, and the more susceptible were the fines to leaching. The smaller the average size of the surface material the more susceptible the surface was to movement by wave action.

The material that fell within the Bureau of Reclamation filter criteria limits appeared to provide an effective filter against leaching of fine materials by wave action.

The study indicated that a protective material must be fine enough to prevent leaching of the base material through it, and that particles on the exposed surface of the protective material must be of sufficient size and weight to resist rolling down the slope from wave action. The study further indicated that the angular talus particles form a more stable protection blanket than the rounded gravel particles.

The results of Tests 9 and 14 showed the best protective cover was the talus material separated on a 3/4-inch screen and placed in two layers: (1) a layer of talus material smaller than 3/4 inch placed over the fine base material and (2) a layer of talus material larger than 3/4 inch placed on the surface. The resulting analysis curves and the Bureau of Reclamation filter criteria are shown in Figure 17. The tests showed that the layers of cover material should not be less than 4 inches in thickness for adequate resistance to erosion by small waves.

FIGURE 1
REPORT HYD 381

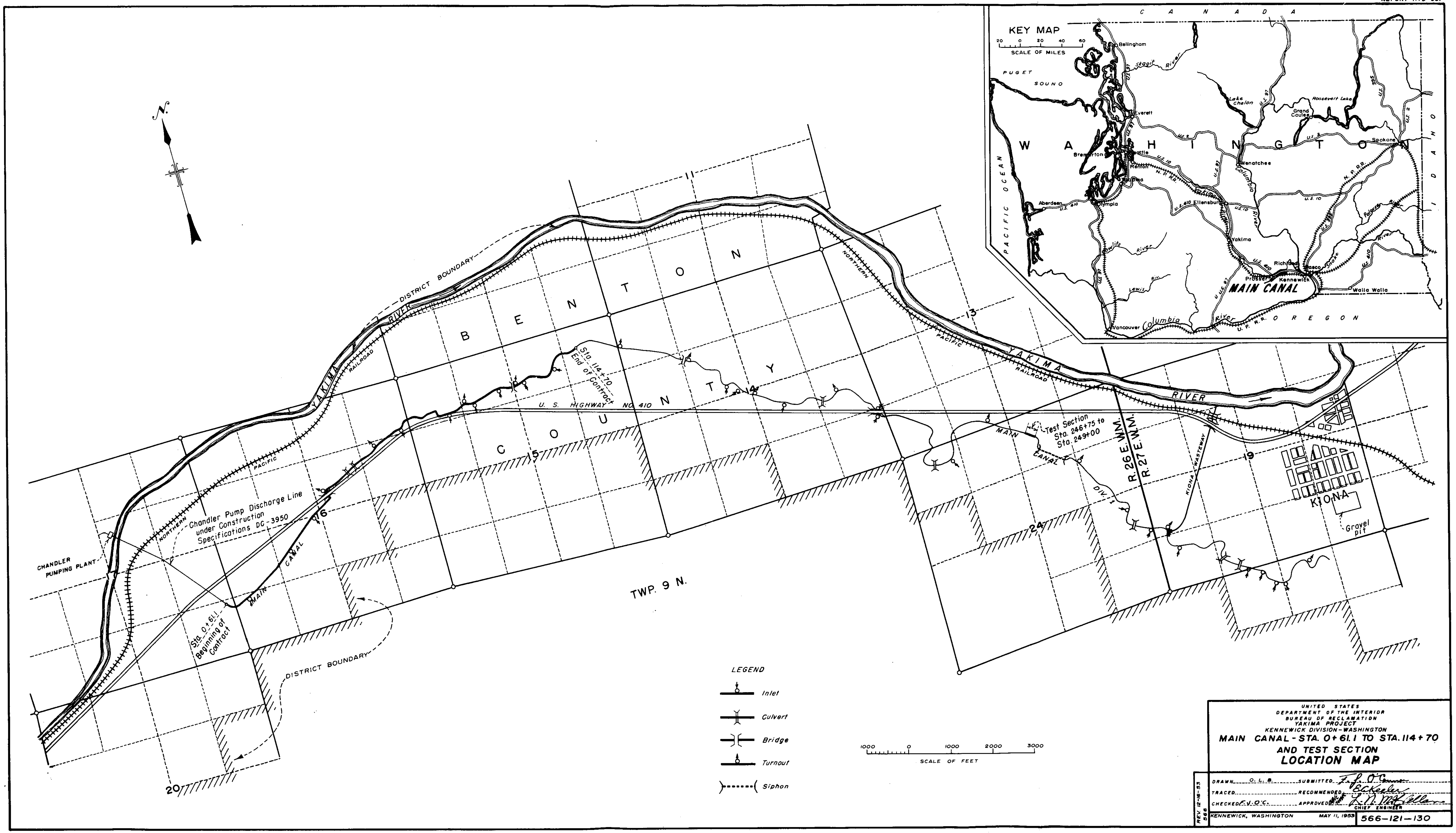
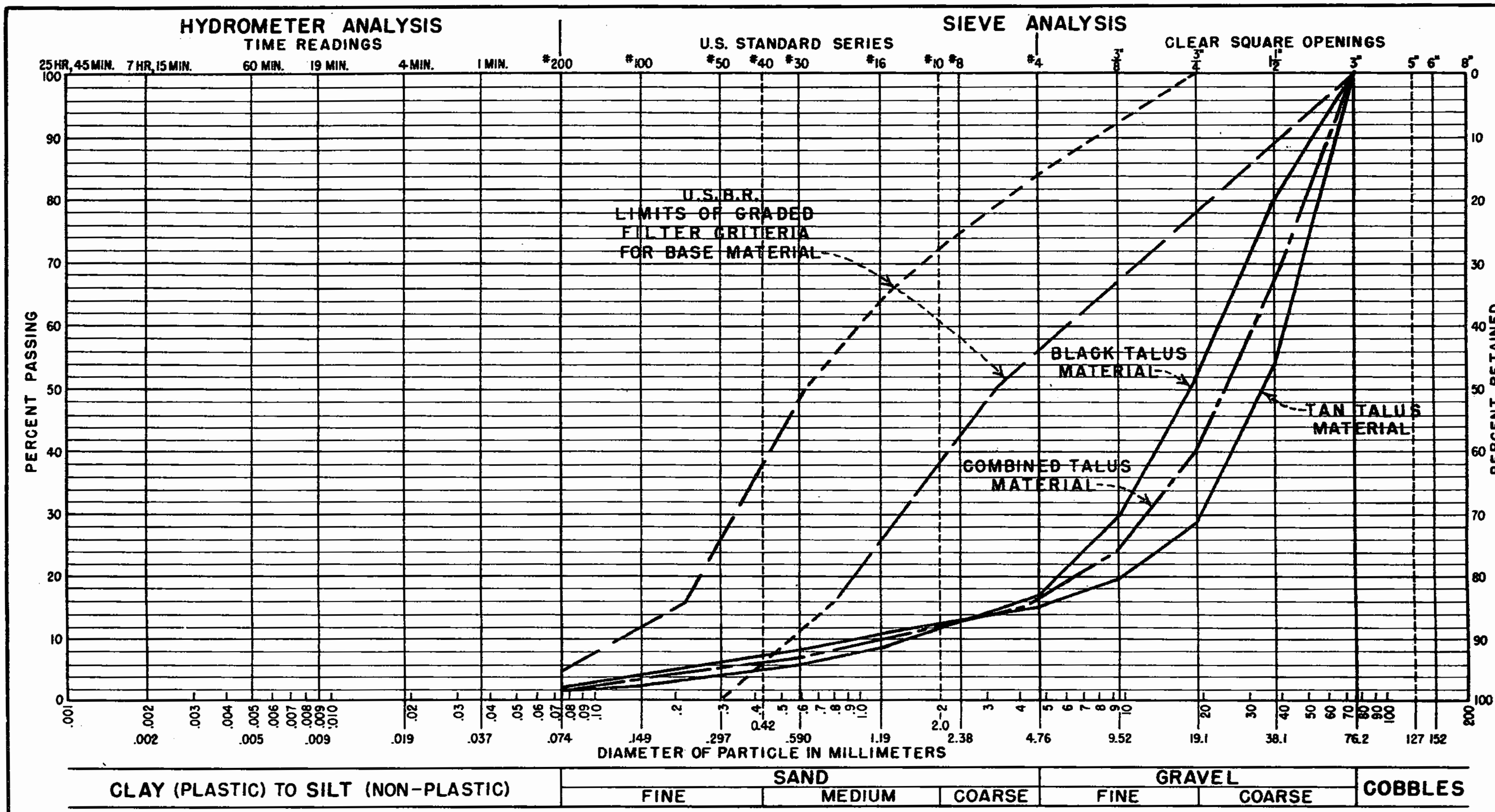


FIGURE 5



NOTES:

GRADATION TEST

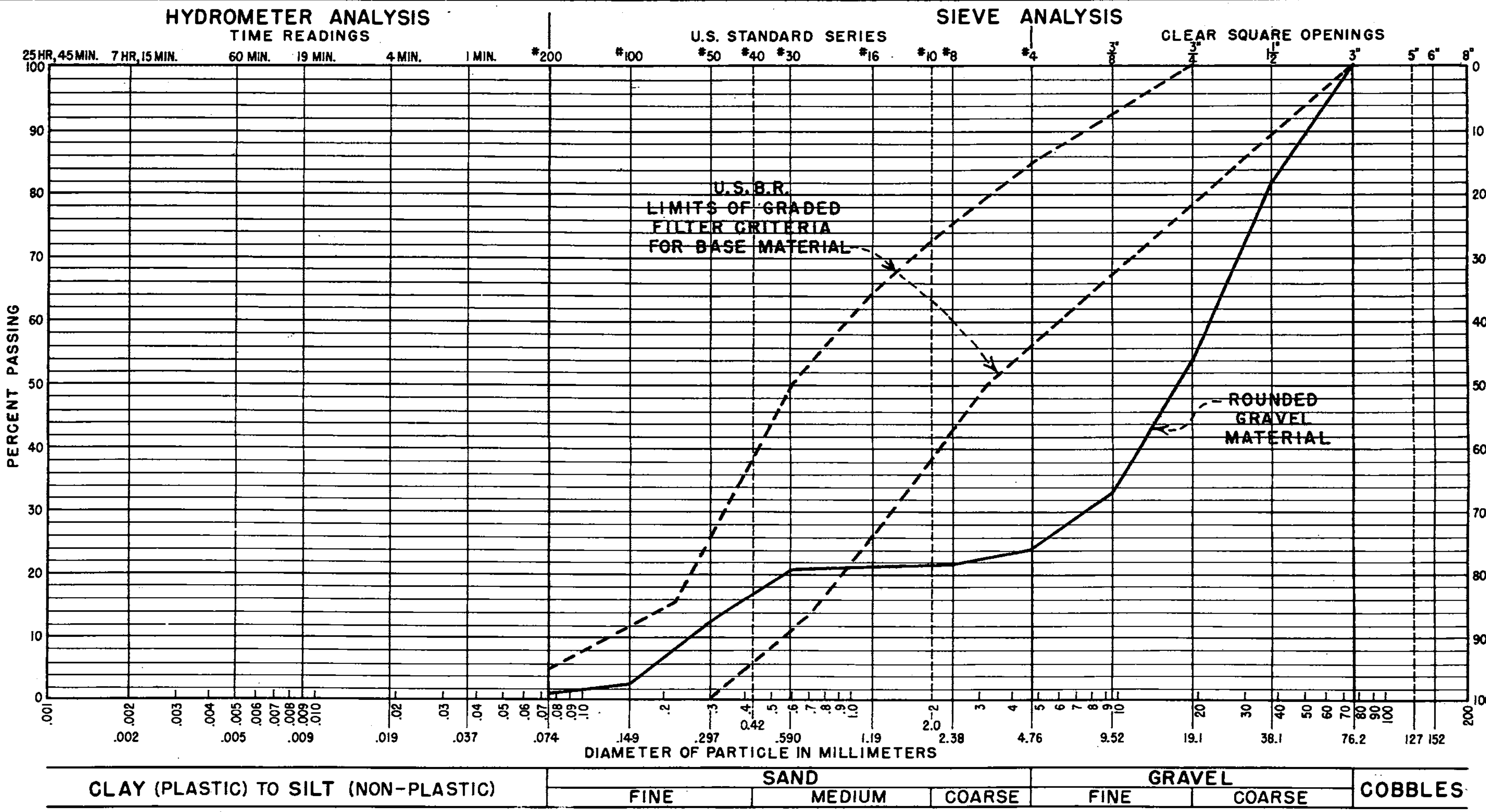
YAKIMA PROJECT—WASHINGTON

KENNEWICK MAIN CANAL

AVAILABLE TALUS BLANKET MATERIALS

LABORATORY SAMPLE No.________ FIELD DESIGNATION________ EXCAVATION No.________ DEPTH________ FT.

DRAWN BY ________ CHECKED BY ________ DATE ________



NOTES: Sample 36-94, Pit location S.E. 1/4, Sec. 20-9-27

GRADATION TEST

YAKIMA PROJECT — WASHINGTON

KENNEWICK MAIN CANAL

AVAILABLE GRAVEL BLANKET MATERIAL

FIGURE 4

________ FT.

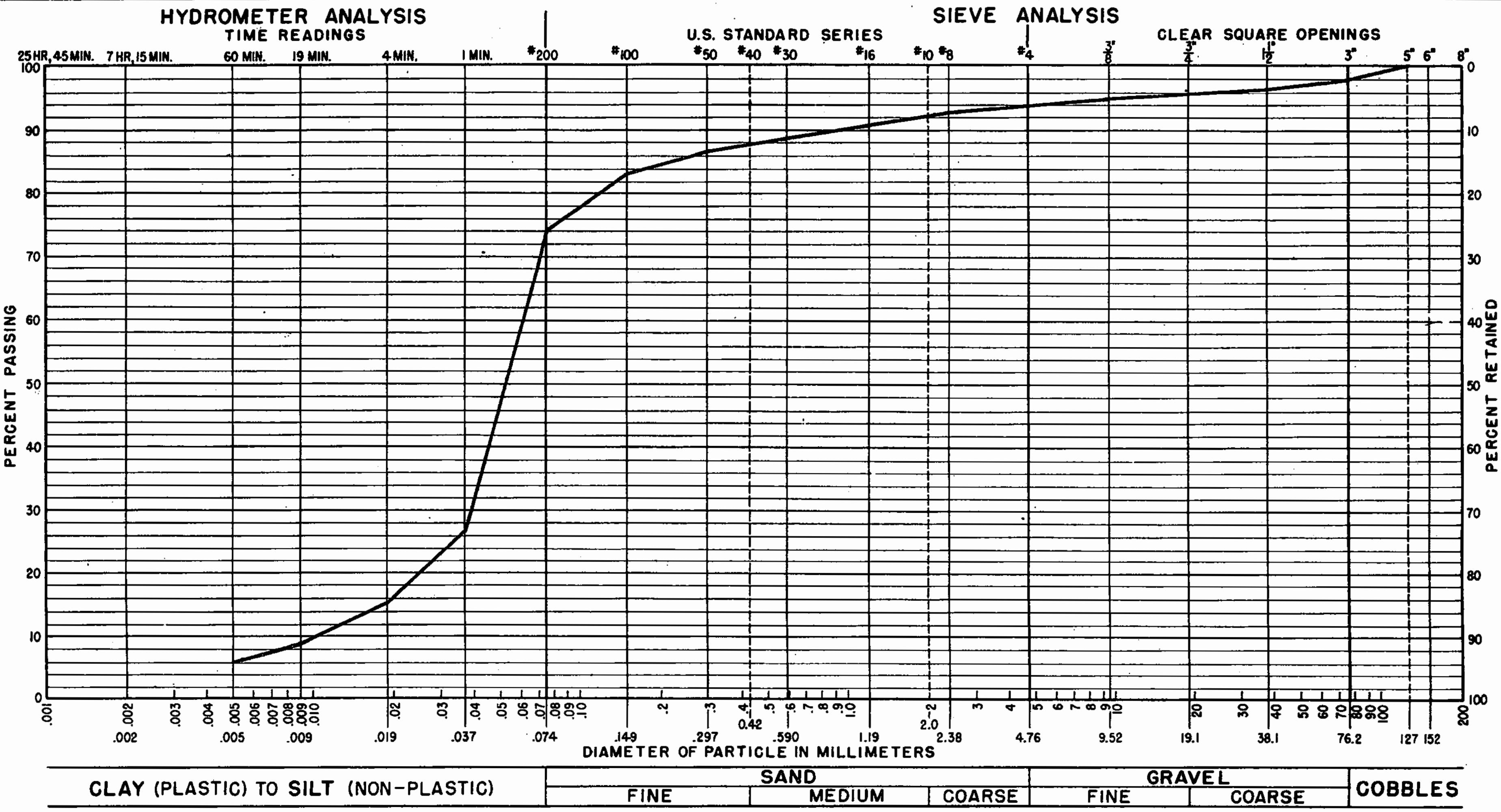


FIGURE 3

NOTES: Sample 36-93, Station 447+00

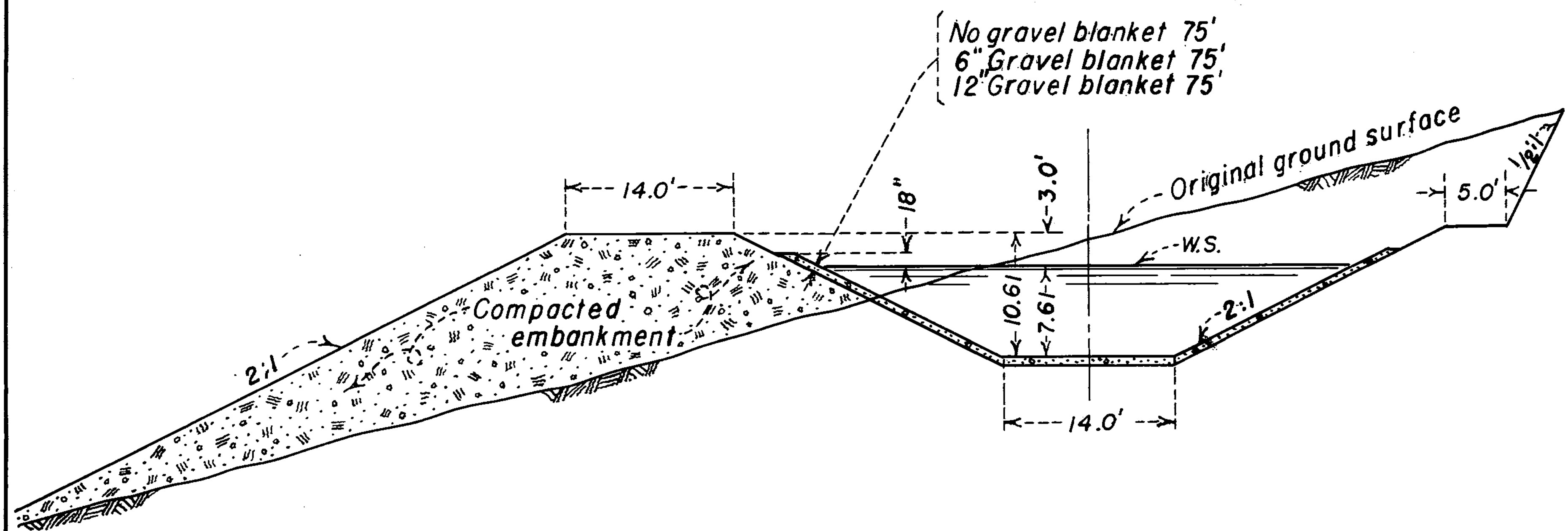
GRADATION TEST

YAKIMA PROJECT — WASHINGTON

KENNEWICK MAIN CANAL

BASE MATERIAL THROUGH WHICH THE CANAL PASSES

LABORATORY SAMPLE No._______ FIELD DESIGNATION_______ EXCAVATION No._______ DEPTH_______ FT.



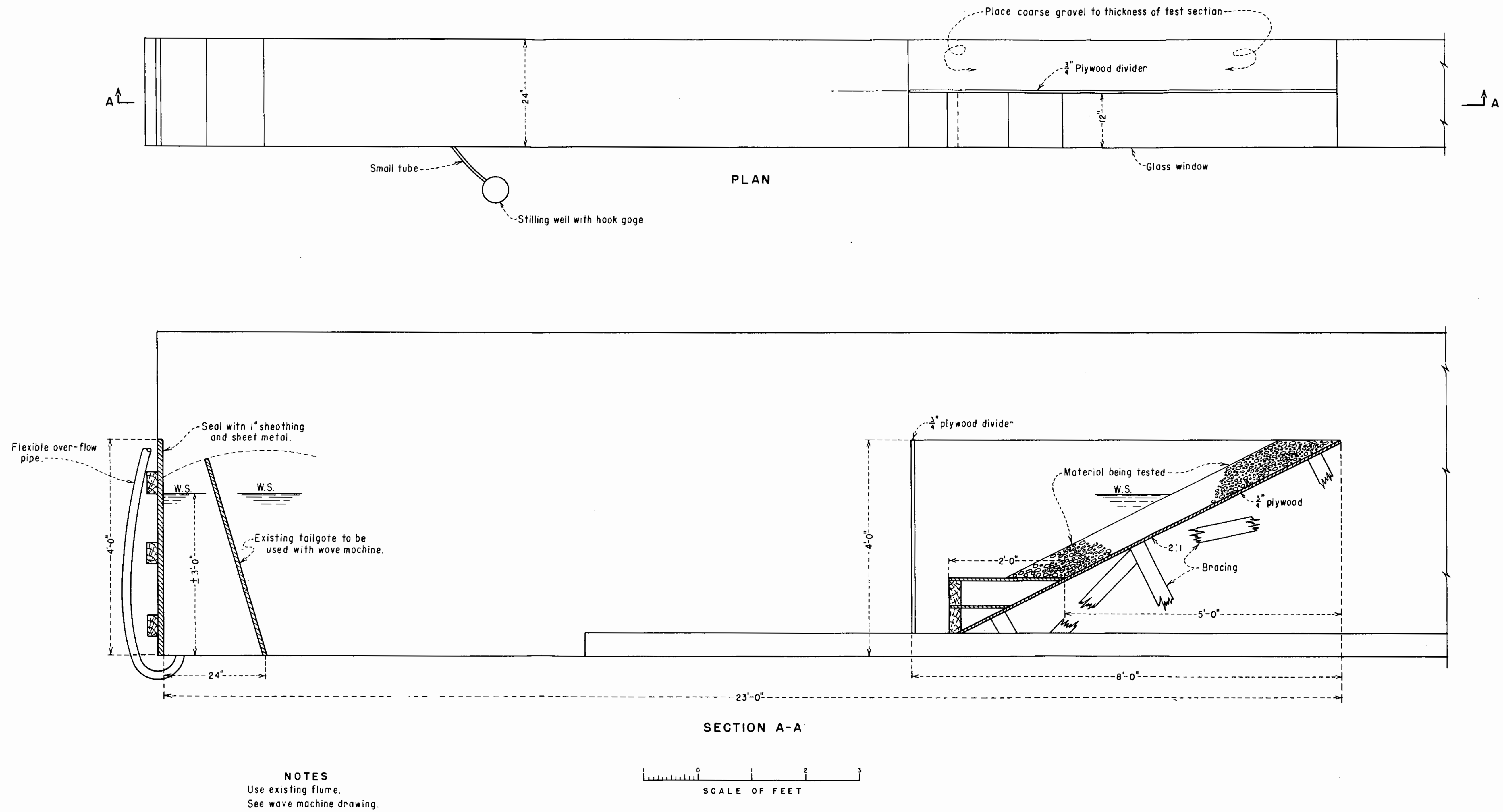
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
YAKIMA PROJECT
KENNEWICK DIVISION- WASHINGTON

MAIN CANAL- STA. 246+75 TO STA. 249+00
TEST SECTION

DRAWN R.H.K. SUBMITTED
TRACED H.D.B. RECOMMENDED
CHECKED F.R. APPROVED
CHIEF DESIGNING ENGINEER

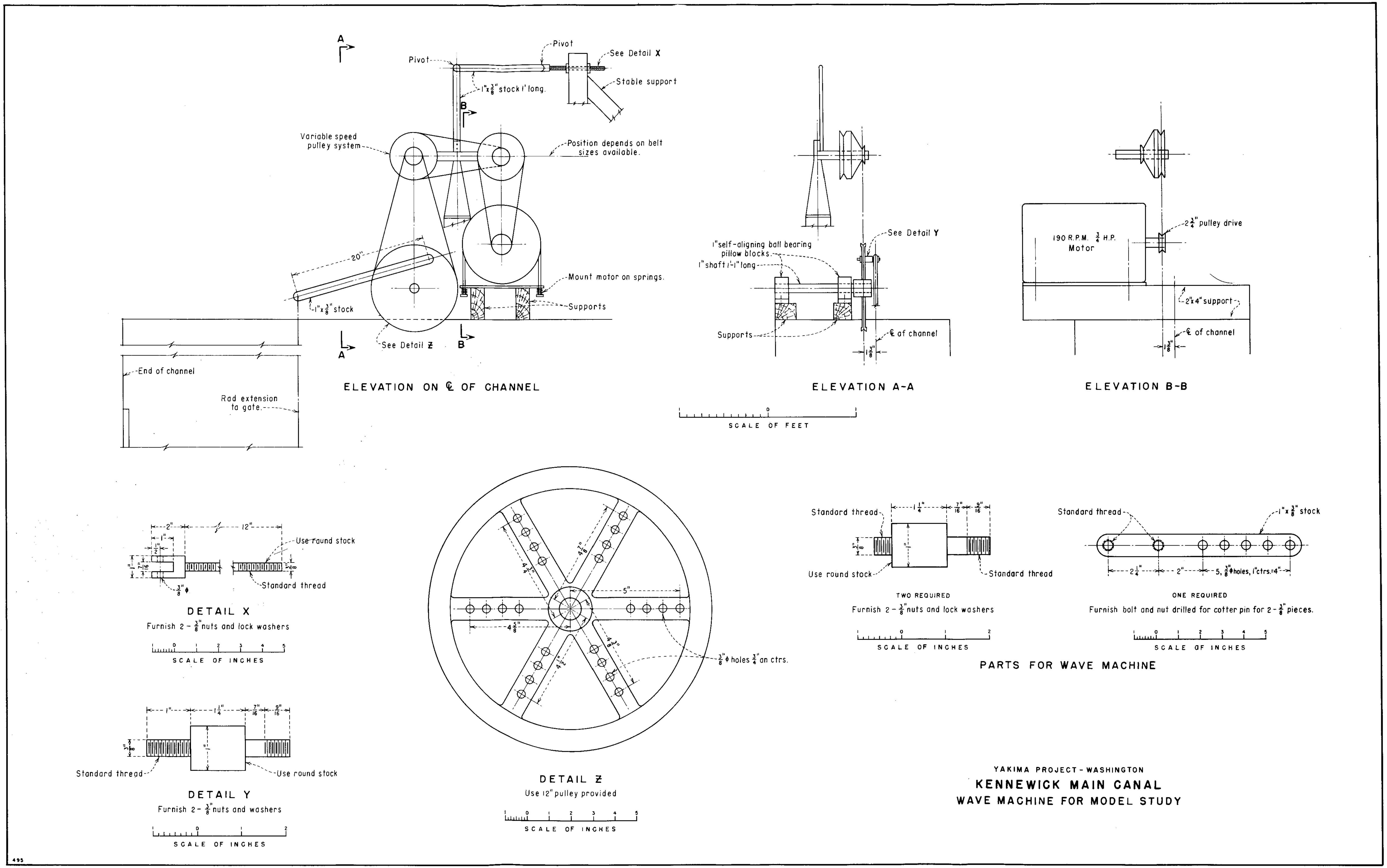
DENVER, COLORADO 7-29-53 | 566-D-202

FIGURE 2
REPORT HYD 381



NOTES
Use existing flume.
See wave machine drawing.

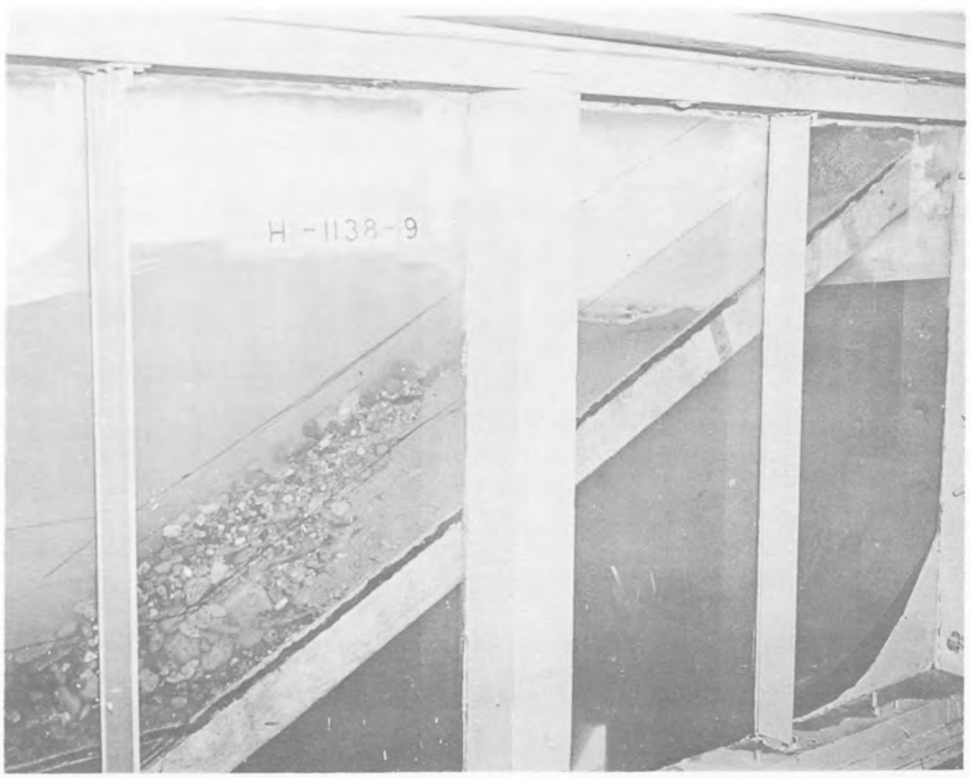
YAKIMA PROJECT—WASHINGTON
KENNEWICK MAIN CANAL
MODEL FOR WAVE STUDIES



YAKIMA PROJECT - WASHINGTON
KENNEWICK MAIN CANAL
WAVE MACHINE FOR MODEL STUDY

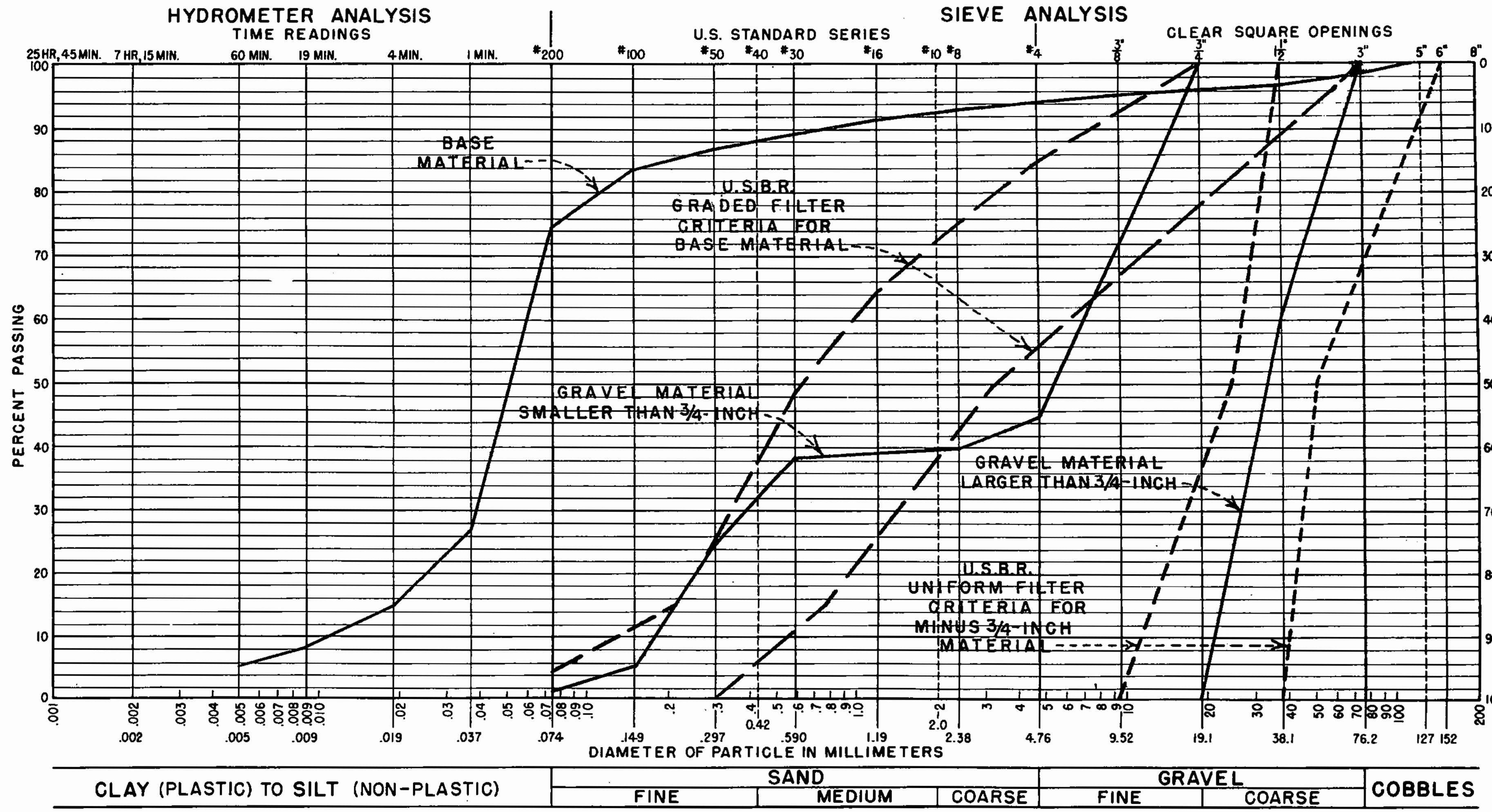
Figure 8

(a) Model prepared for Test 1



(b) Slope failure after 45 minutes of operation at 32 waves per minute - wave height 0.32 ft.

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 1 (GRAVEL MOISTENED AND WELL MIXED)
Model study



NOTES:

GRADATION TEST

YAKIMA PROJECT—WASHINGTON

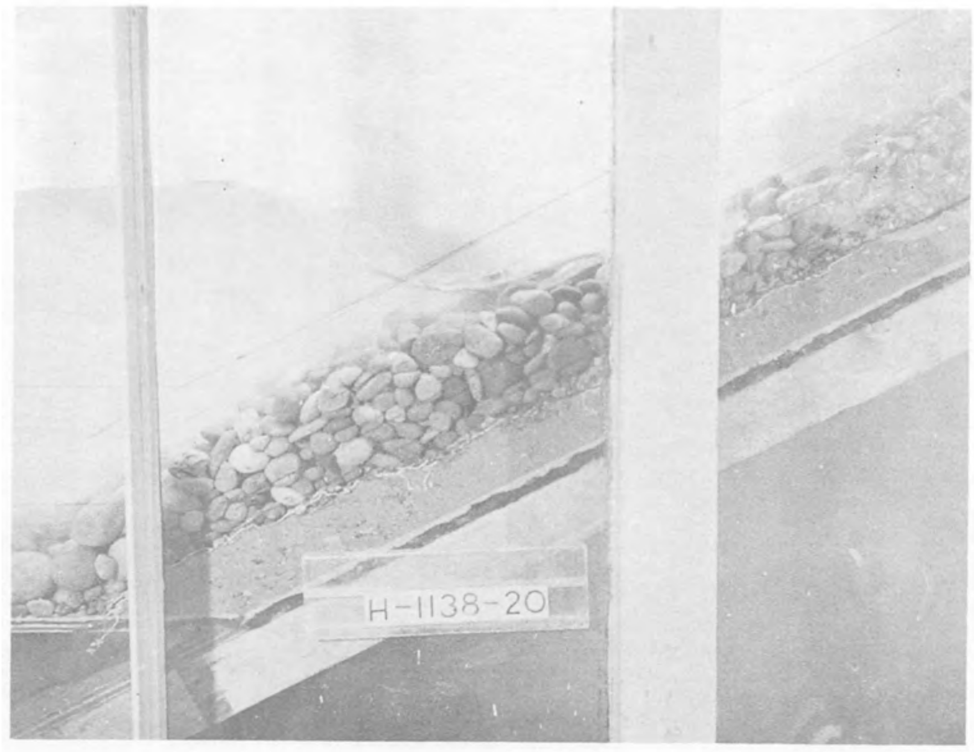
KENNEWICK MAIN CANAL

GRAVEL MATERIAL SCREENED AT 3/4-INCH
BASE MATERIAL — FILTER CRITERIA

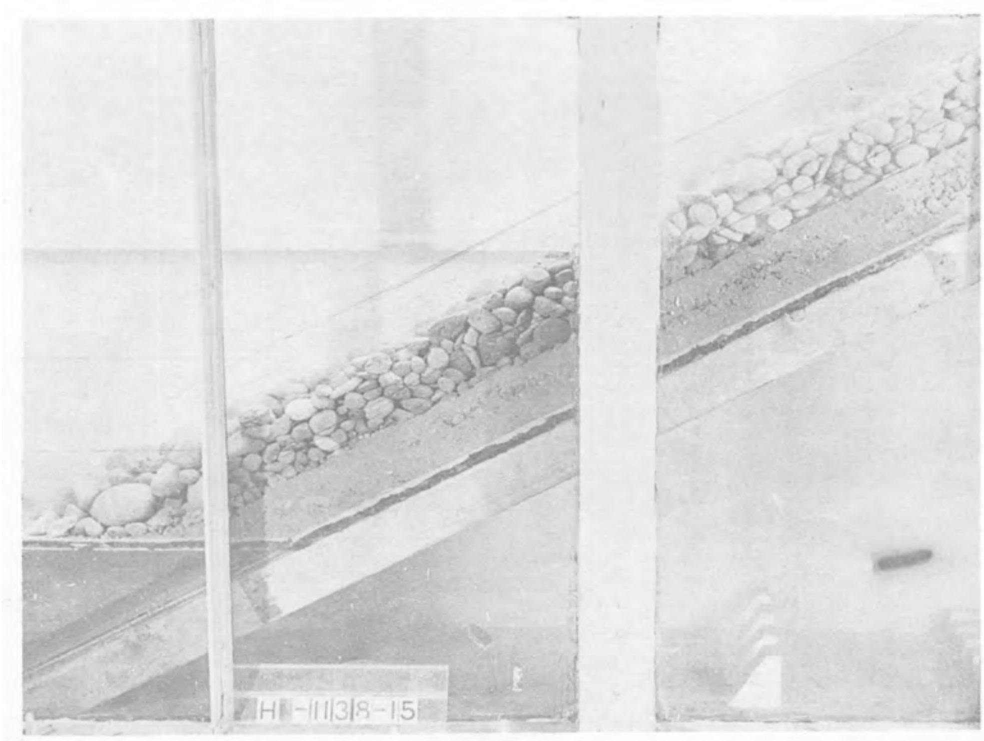
LABORATORY SAMPLE No.______ FIELD DESIGNATION______ EXCAVATION No.______ DEPTH______ FT.

FIGURE 9

Figure 10



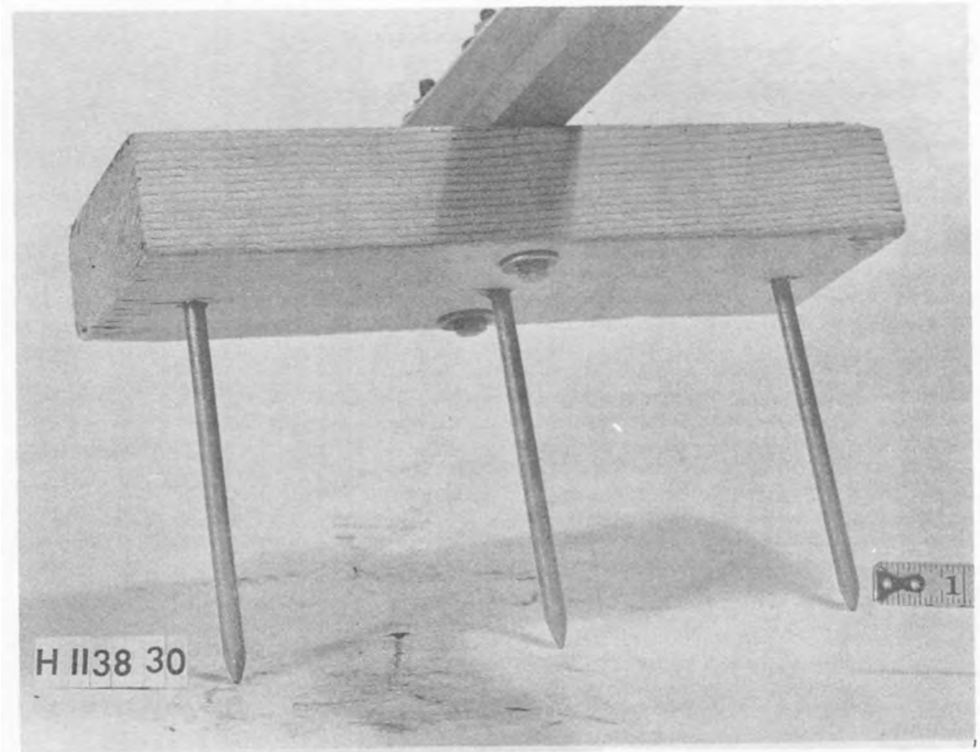
(a) Ready for operation



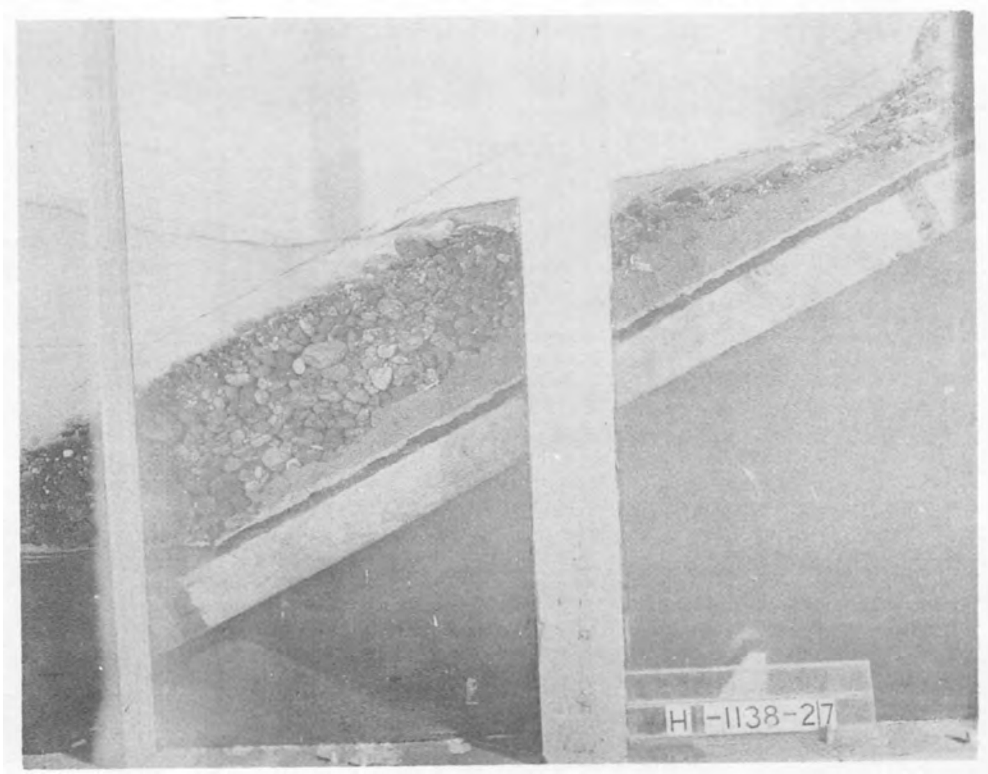
(b) After 23 hours of operation at 42 waves per minute--wave height 0.43 ft.

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 2 (GRAVEL SEPARATED ON 3/4-INCH SCREEN)
Model study

Figure 11



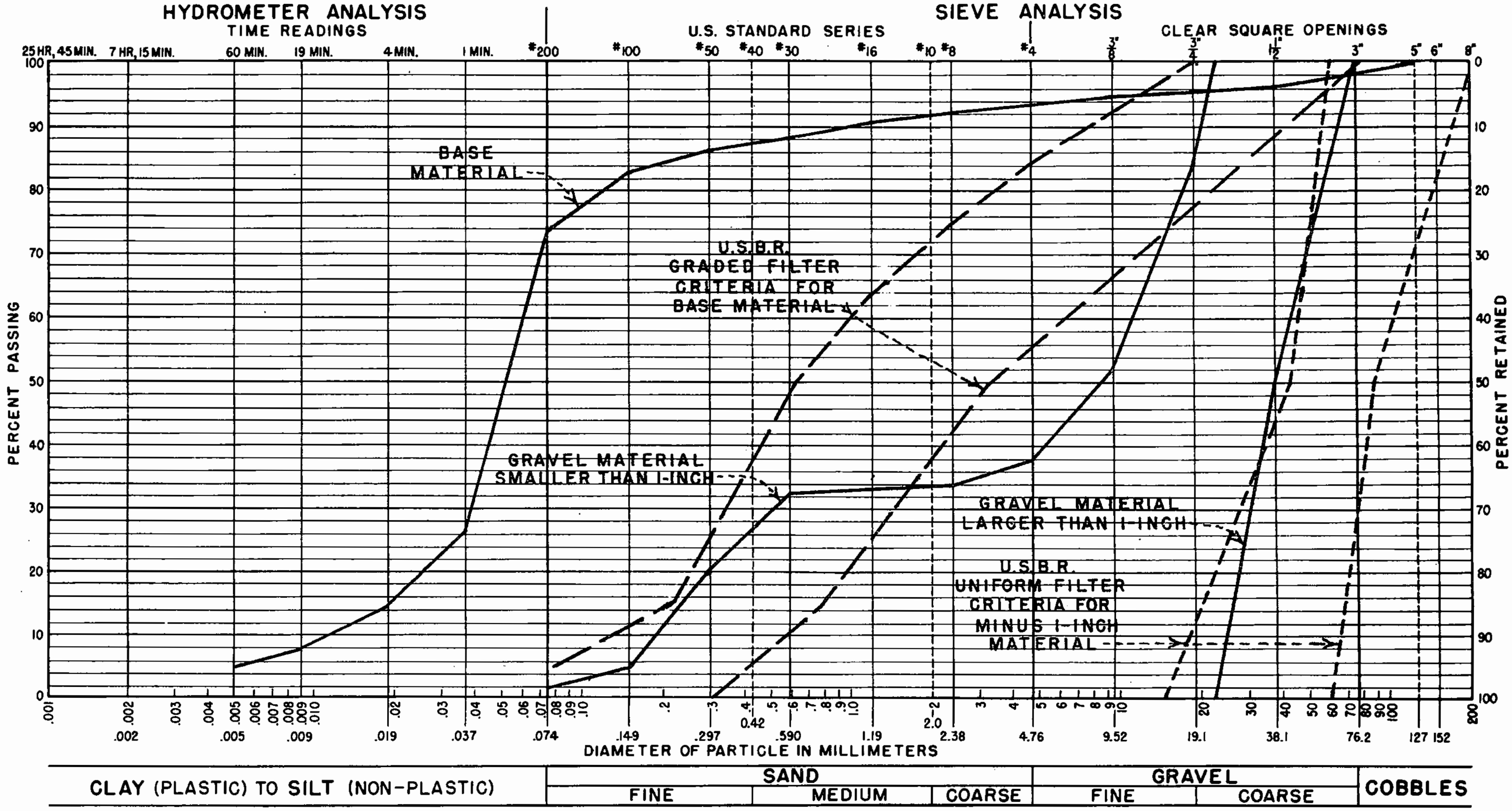
(a) Rake used in Test 3



(b) After 19 hours of operation at 42 waves per minute--wave height 0.43 ft.

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 3 (GRAVEL PLACED DRY AND RAKED)
Model study

DRAWN BY ________ CHECKED BY ________ DATE ________



NOTES:

GRADATION TEST

YAKIMA PROJECT — WASHINGTON

KENNEWICK MAIN CANAL

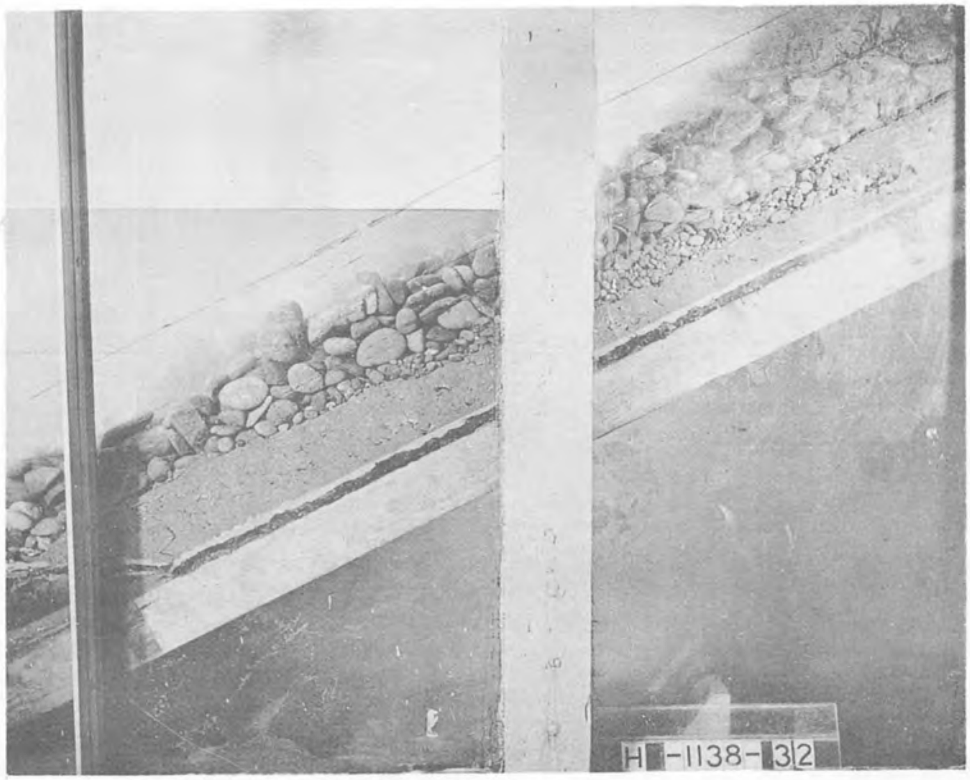
GRAVEL MATERIAL SCREENED AT 1-INCH

BASE MATERIAL — FILTER CRITERIA

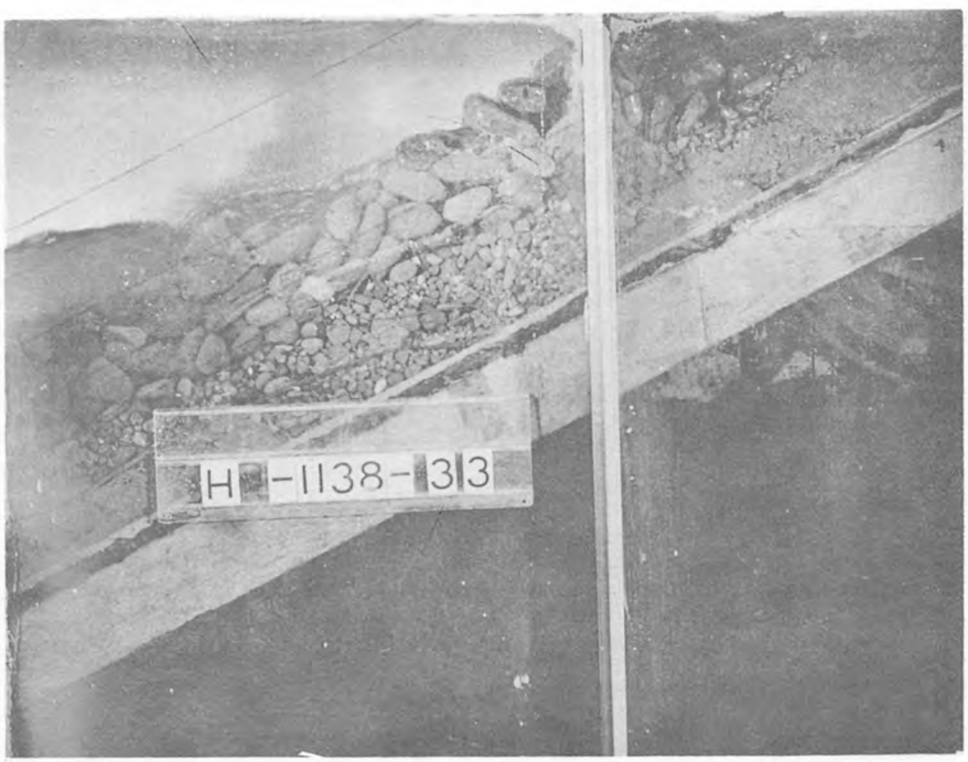
LABORATORY SAMPLE No. ________ FIELD DESIGNATION ________ EXCAVATION No. ________ DEPTH ________ FT.

FIGURE 12

Figure 13

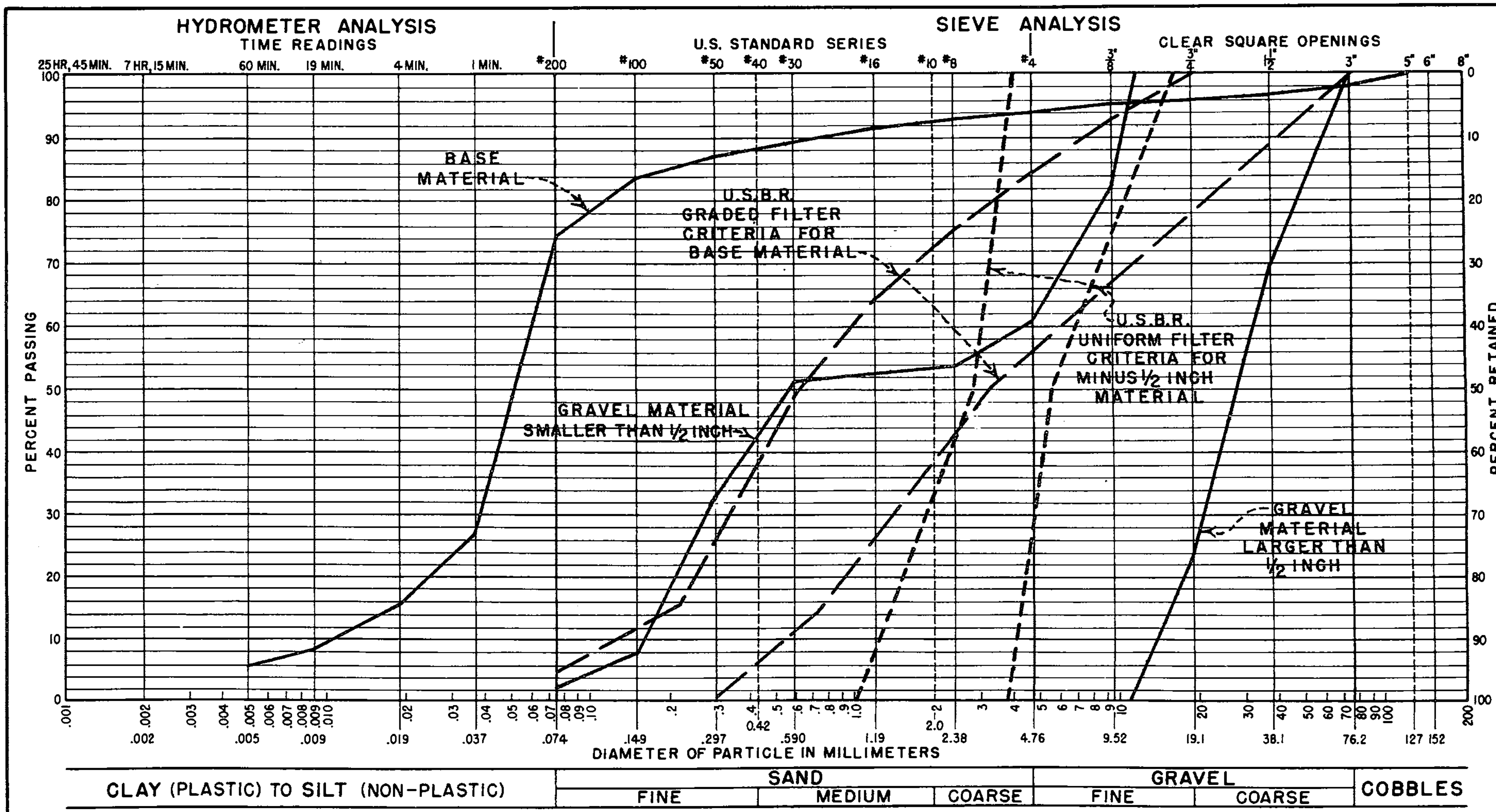


(a) After 45 minutes of operation--
2.7 ft. depth--42 waves per
minute--wave height 0.43 ft.



(b) After 20 more minutes of
operation--3.2 ft. depth--
42 waves per minute--
wave height 0.5 ft.

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 4 (GRAVEL SEPARATED ON 1-INCH SCREEN)
Model study



NOTES:

GRADATION TEST

YAKIMA PROJECT—WASHINGTON

KENNEWICK MAIN CANAL

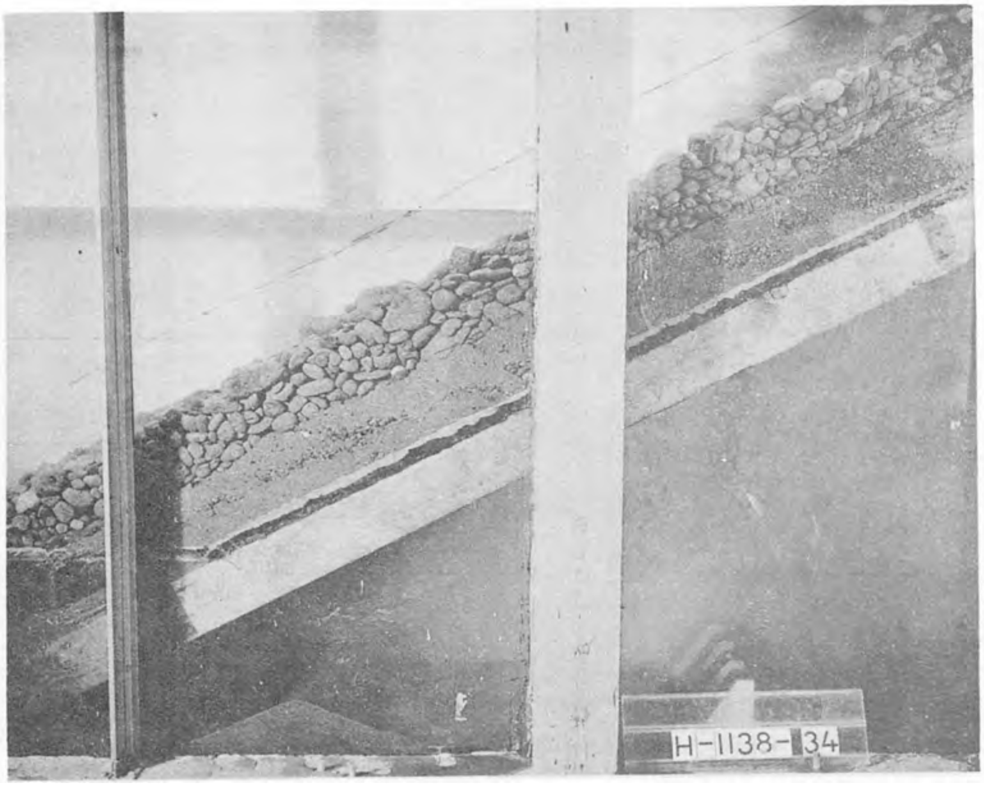
GRAVEL MATERIAL SCREENED AT 1/2 INCH

BASE MATERIAL—FILTER CRITERIA

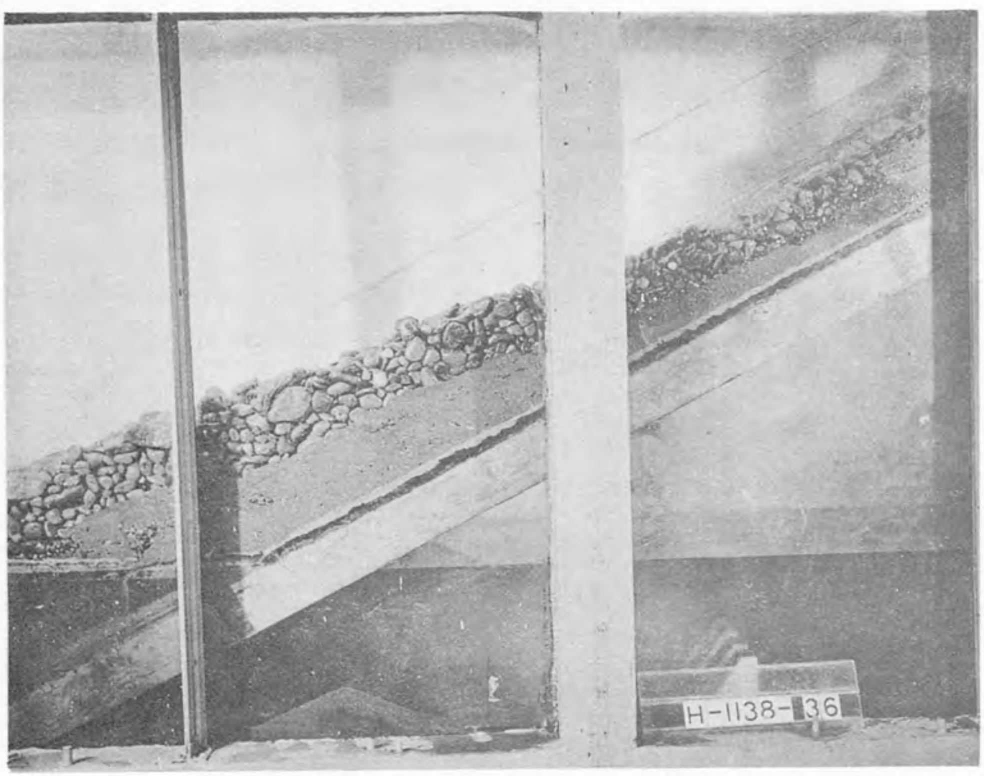
LABORATORY SAMPLE No.______ FIELD DESIGNATION______ EXCAVATION No.______ DEPTH______ FT.

FIGURE 14

Figure 15



(a) Ready for operation



(b) Slippage that occured immediately
after test started

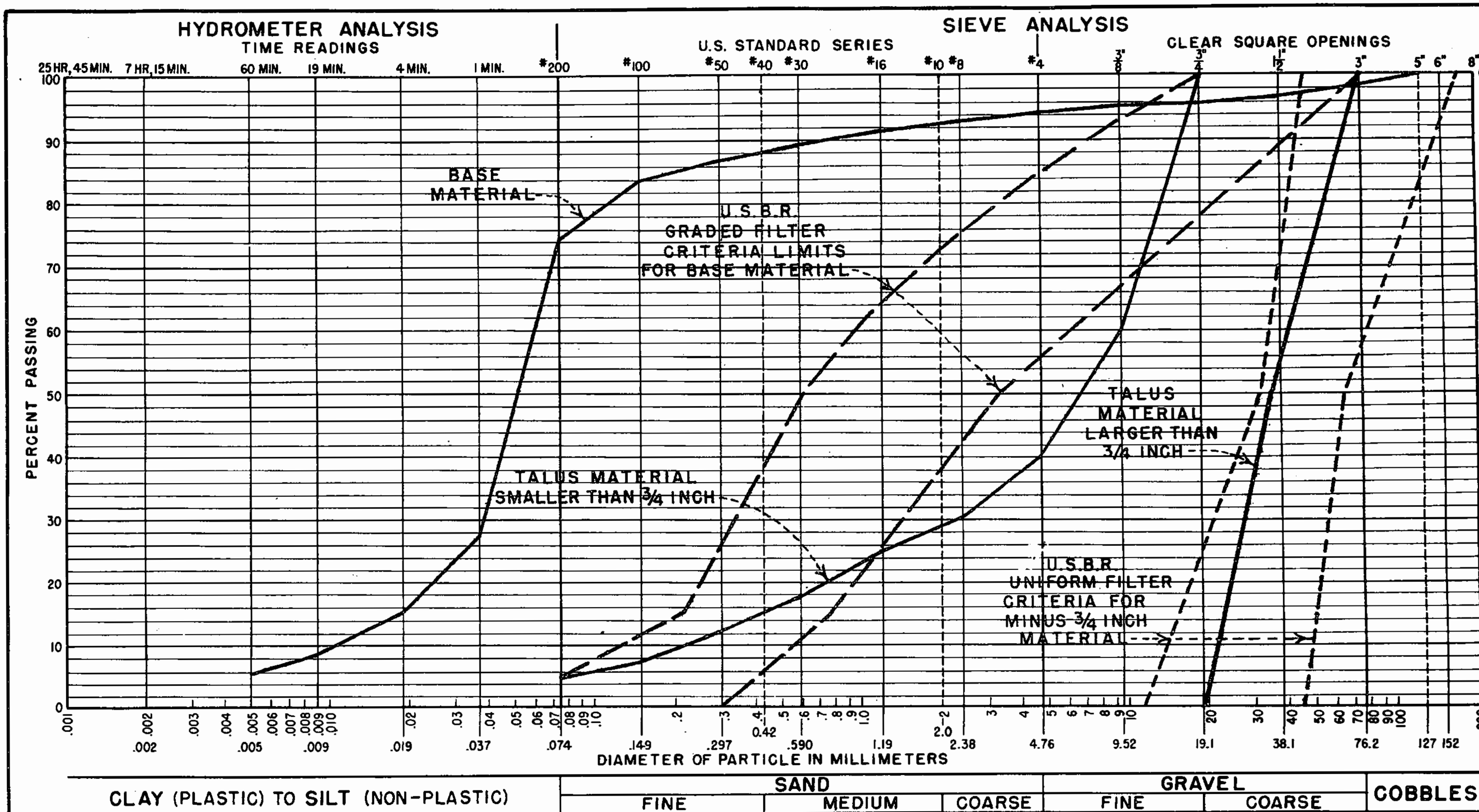
Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 5 (GRAVEL SEPARATED ON 1/2-INCH SCREEN)
Model study

Figure 16

(a) Test 6--After 23 hours of operation
2.7 ft. depth--42 waves per minute--
wave height 0.43 ft.

(b) Test 9--Prepared for operation--
Recommended cover - talus
separated on 3/4-inch screen

Yakima Project - Washington
KENNEWICK MAIN CANAL
TESTS 6 and 9
Model study



NOTES:

GRADATION TEST

YAKIMA PROJECT — WASHINGTON

KENNEWICK MAIN CANAL

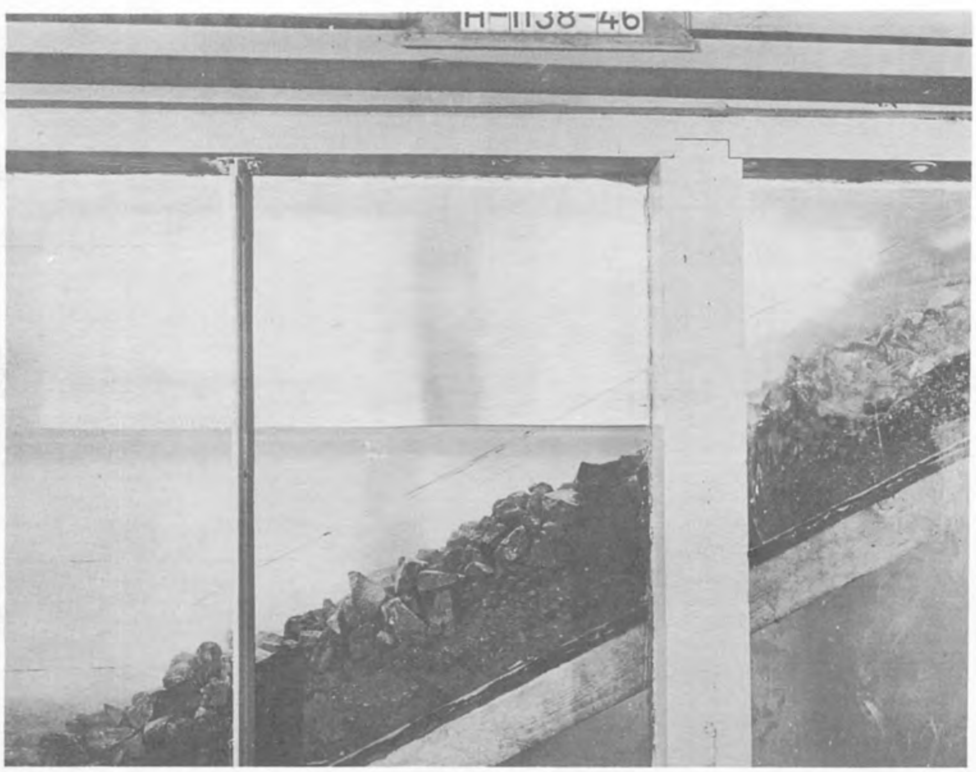
TALUS MATERIAL SCREENED AT 3/4 INCH (RECOMMENDED FOR COVER BLANKET)

BASE MATERIAL — FILTER CRITERIA

LABORATORY SAMPLE No.______ FIELD DESIGNATION______ EXCAVATION No.______ DEPTH______ FT.

FIGURE 17

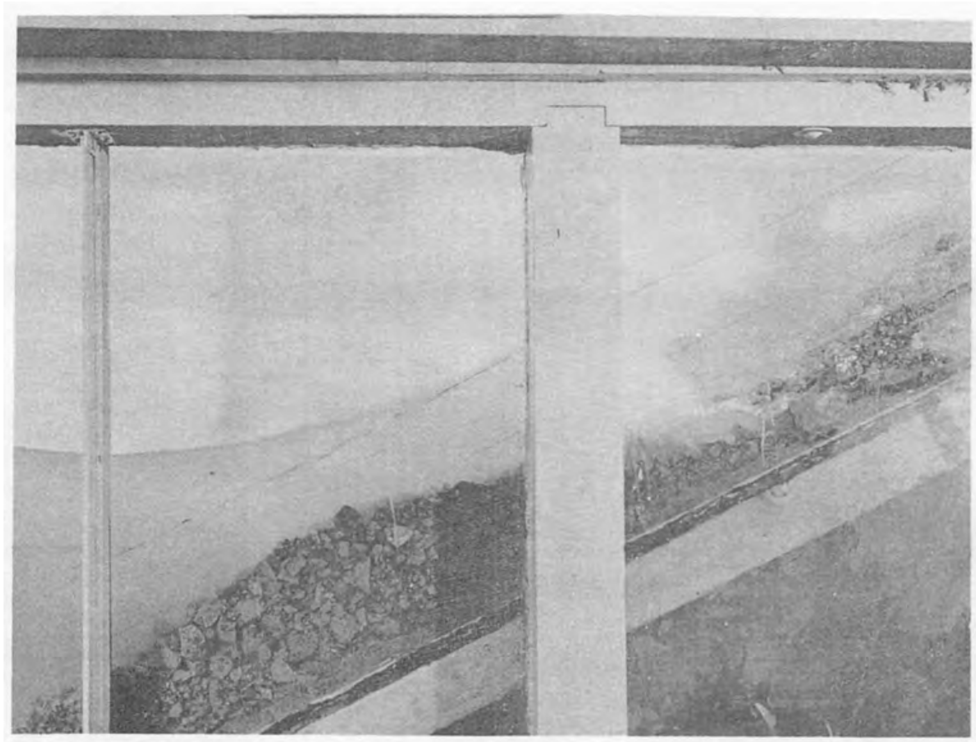
(a) A 0.5 ft. wave approaching the 2:1 slope



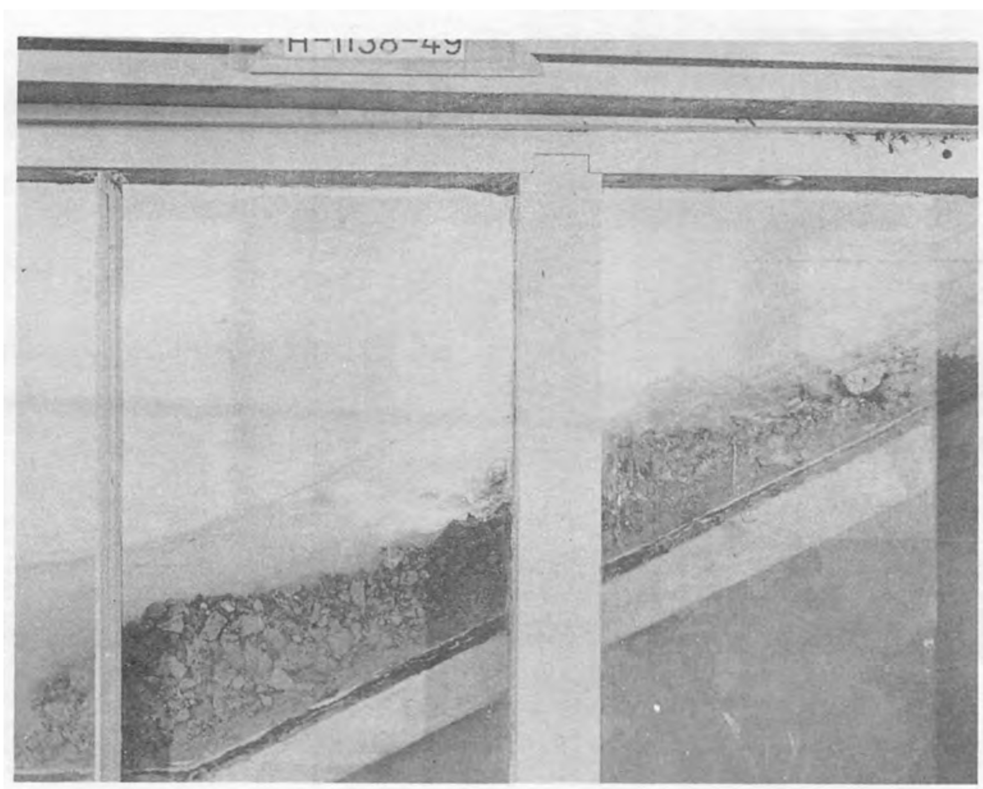
(b) Slope after 5 hours of operation at varying wave heights and frequencies

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 9 (RECOMMENDED COVER - TALUS SEPARATED ON 3/4-INCH SCREEN)
Model study

Figure 19



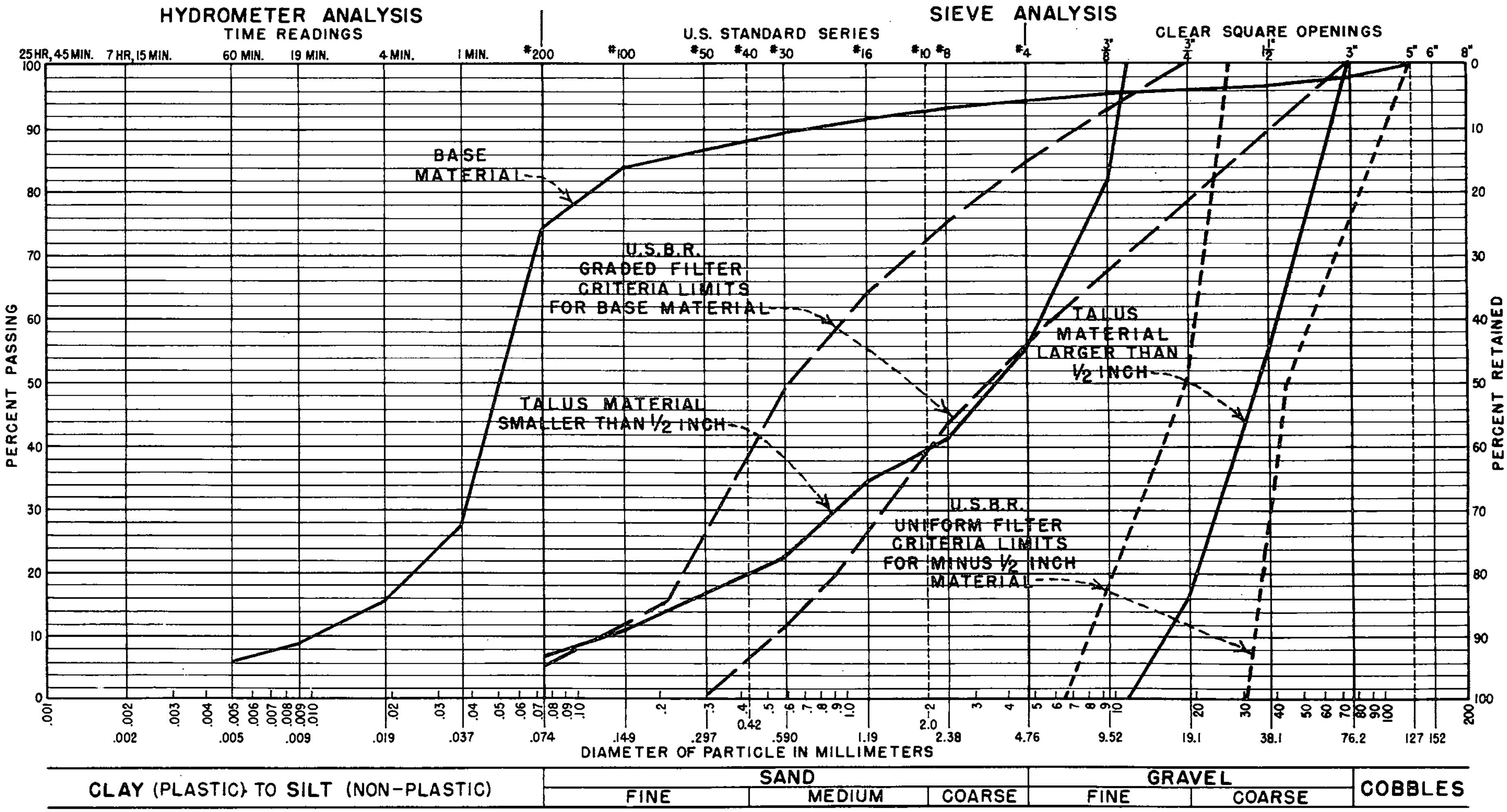
(a) After 3 hours operation at various wave heights and frequencies



(b) After 5 hours operation with various waves and depths

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 10 (TALUS MOISTENED AND WELL MIXED)
Model study

DRAWN BY ____________ CHECKED BY ____________ DATE ____________



NOTES:

GRADATION TEST

YAKIMA PROJECT – WASHINGTON

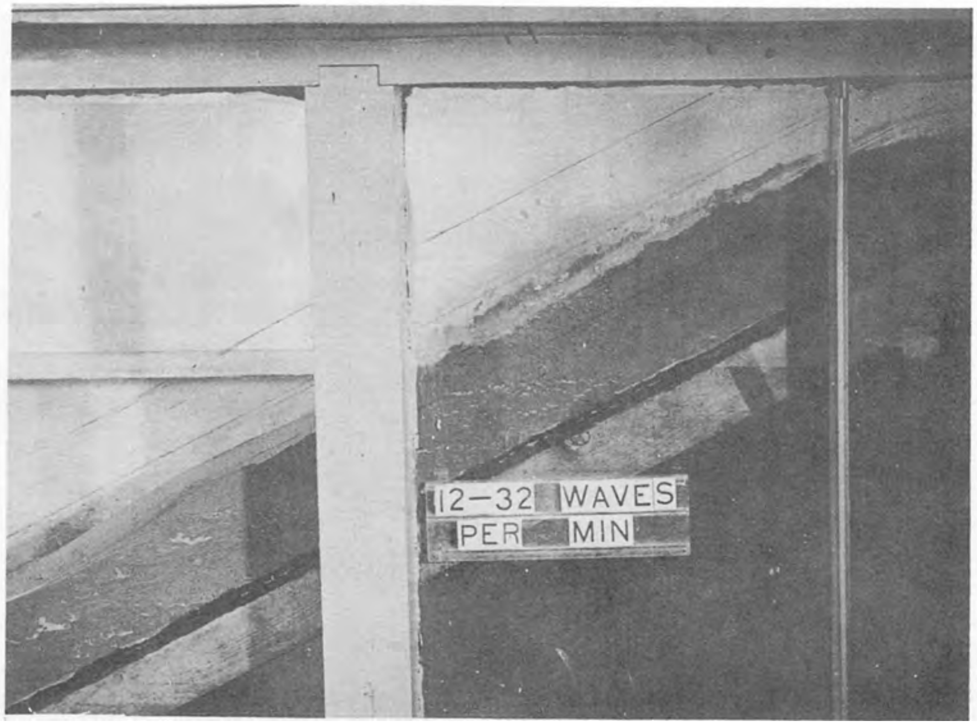
KENNEWICK MAIN CANAL

TALUS MATERIAL SCREENED AT 1/2 INCH
BASE MATERIAL — FILTER CRITERIA

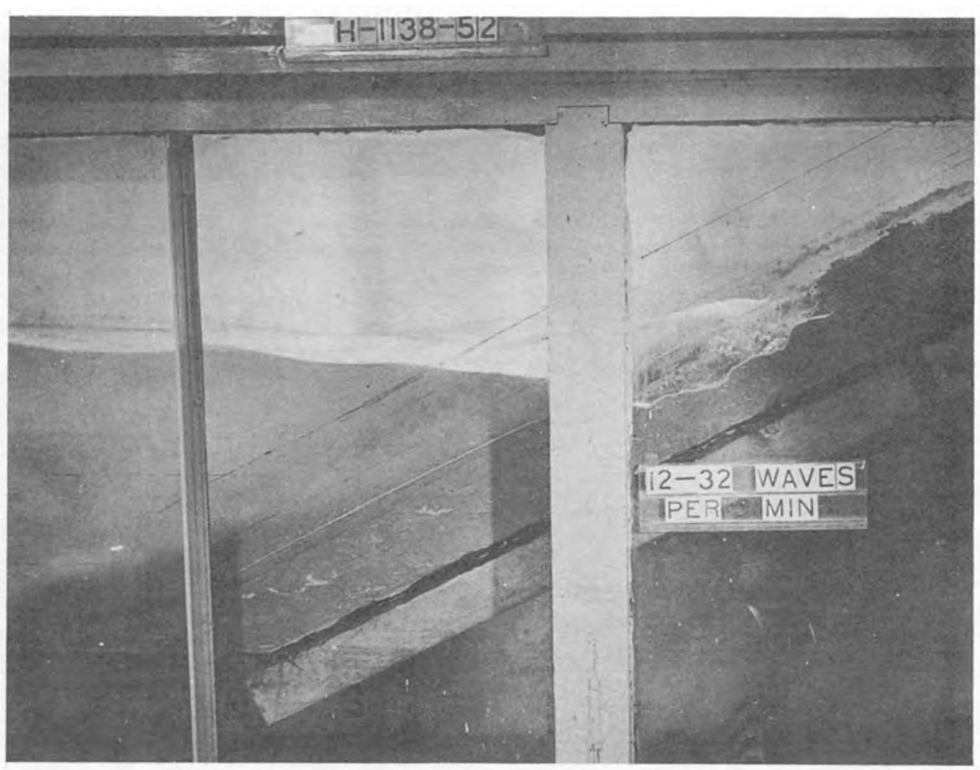
LABORATORY SAMPLE No. ____________ FIELD DESIGNATION ____________ EXCAVATION No. ____________ DEPTH ____________ FT.

FIGURE 20

Figure 21



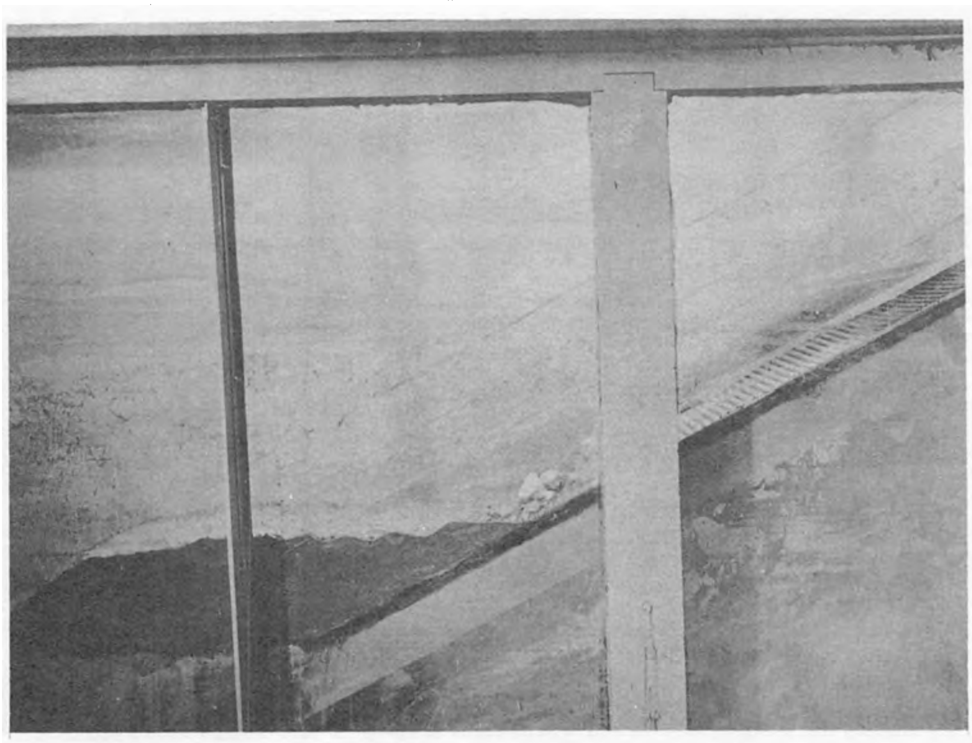
(a) Ready for operation



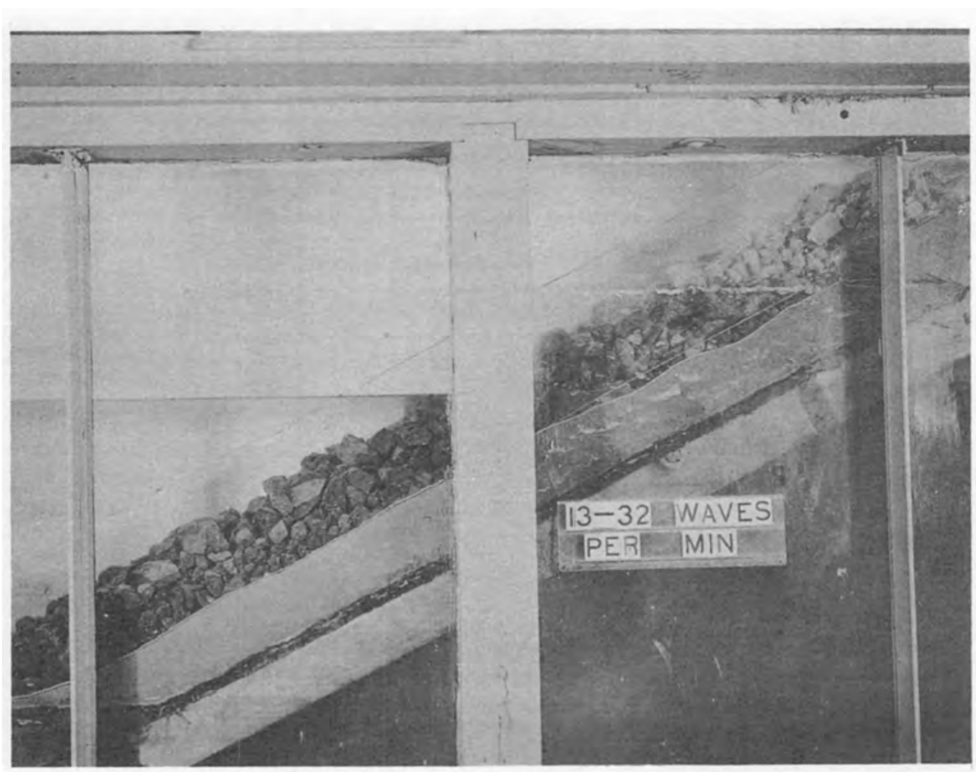
(b) Two minutes after operation started at 2.7 ft. depth and 32 waves per minute--wave height 0.26 ft.

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 12 (FINE BASE MATERIAL)
Model study

Figure 22

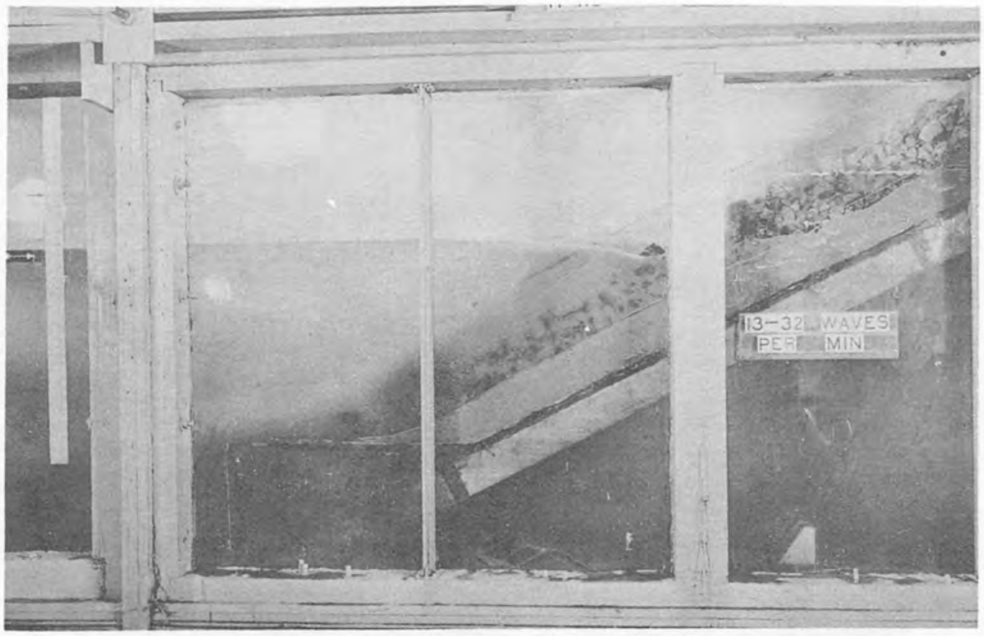


(a) Test 12--after 1 hour of operation at 2.7 ft. depth--32 waves per minute--wave height 0.26 ft.



(b) Test 13--ready for operation. Base material covered with plus 1/2-inch talus

Yakima Project - Washington
KENNEWICK MAIN CANAL
TESTS 12 and 13
Model study



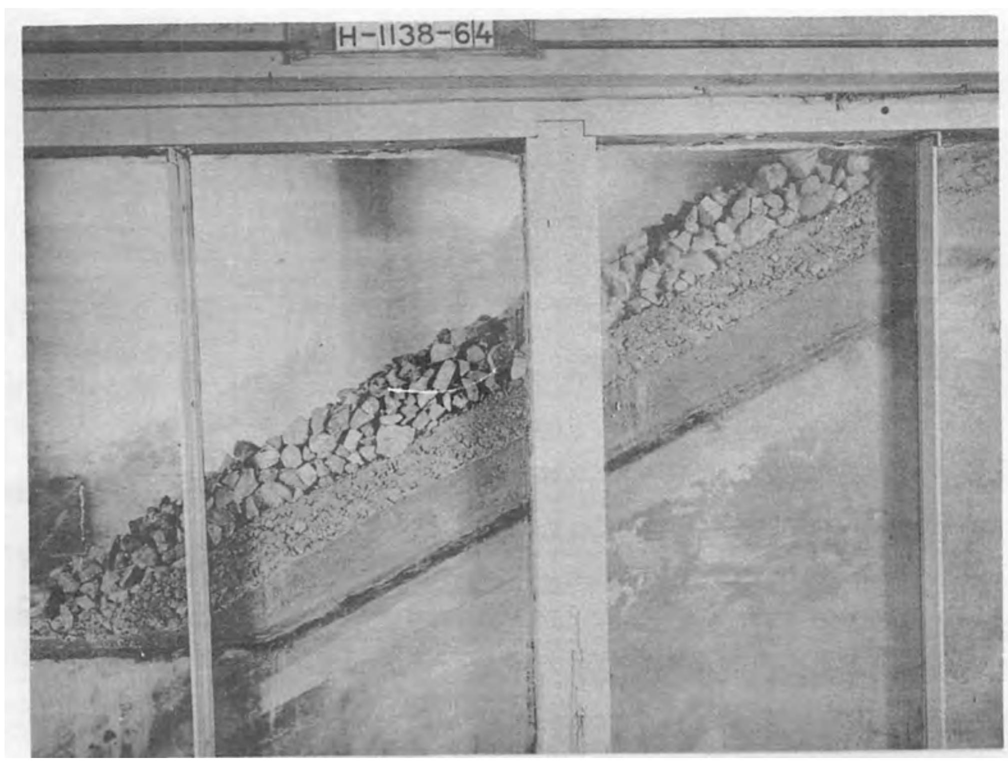
(a) After 7 minutes of operation at 32 waves per minute--depth 2.7 ft.--wave height 0.26 ft.

(b) After 90 minutes of operation at 32 and 42 waves per minute leaching of base material progressed as shown by lines on the photograph

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 13 (BASE MATERIAL AND PLUS 1/2-INCH TALUS MATERIAL)
Model study

Figure 24

(a) Test 13--after the model was left running all night at 42 waves per minute. Base material completely leached out in area near water surface



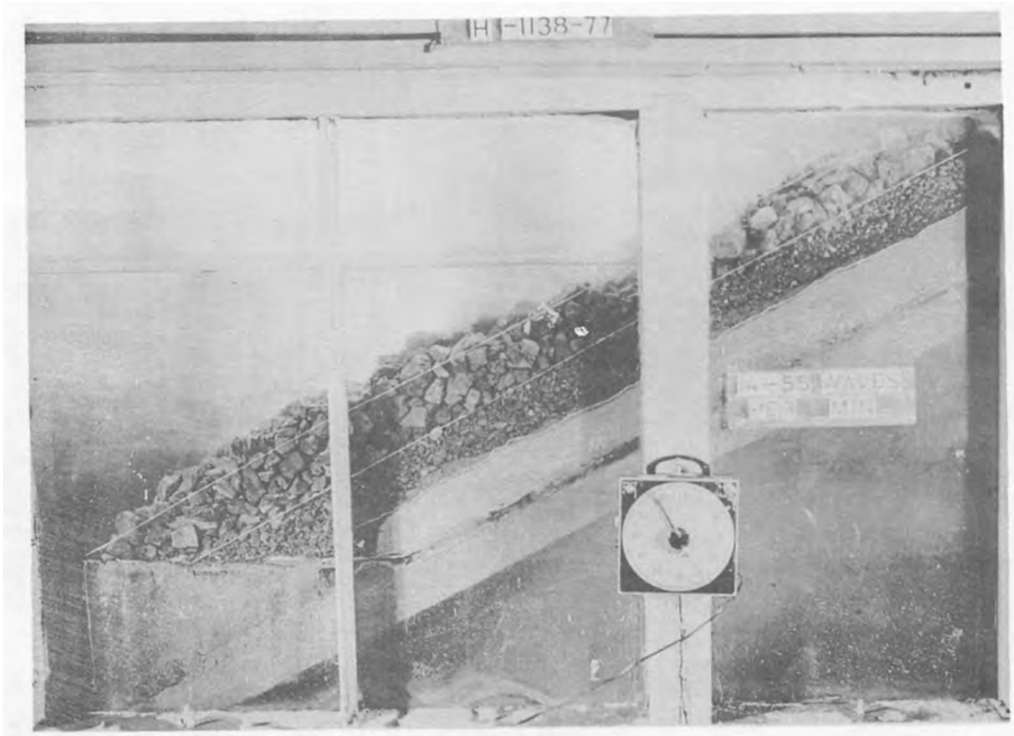
(b) Test 14--ready for operation. Base material covered with talus separated on 3/4-inch screen - recommended cover

Yakima Project - Washington
KENNEWICK MAIN CANAL
TESTS 13 and 14
Model study

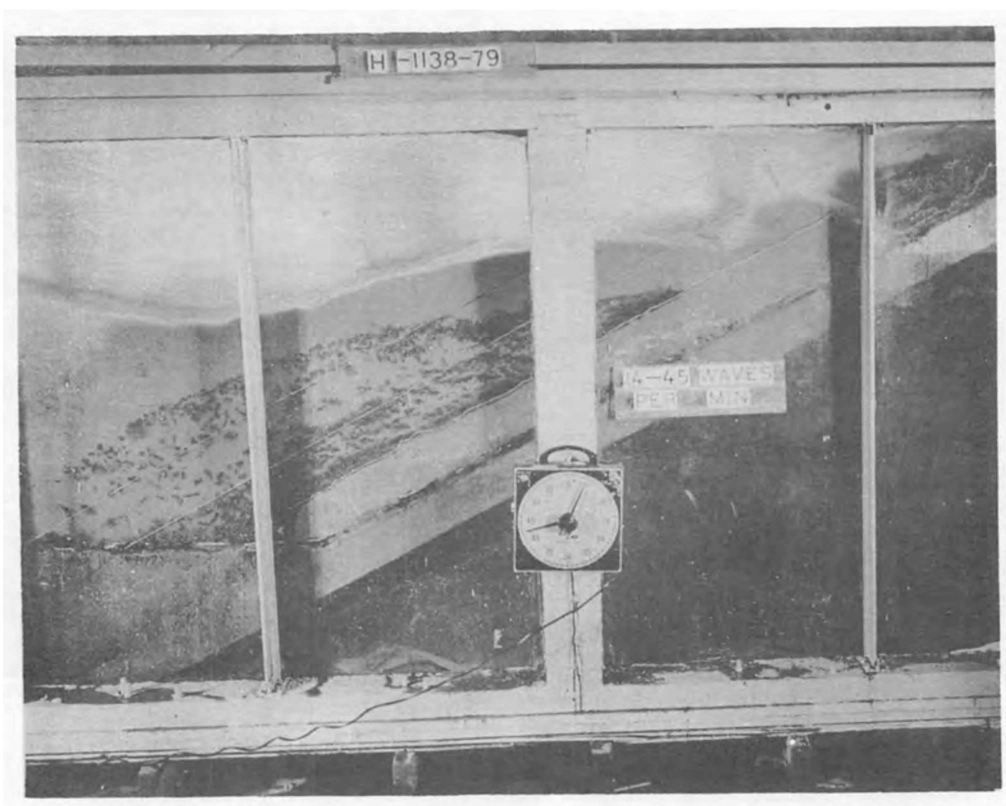
Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 14 (RECOMMENDED COVER) AFTER 28 HOURS OF OPERATION
AT 42 WAVES PER MINUTE--2.7 FT. DEPTH--WAVE HEIGHT 0.43 FT.
Model study

Figure 25

Figure 26



(a) After 128 hours of operation at various depths, wave heights and frequencies



(b) Failure of slope from waves 0.75 ft. high and 45 per minute--approximately 12 minutes after final test started

Yakima Project - Washington
KENNEWICK MAIN CANAL
TEST 14 (RECOMMENDED COVER)
Model study

GPO 835-603