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CIVIL ENGINEERING DEPARTMENT

FRITZ ENGINEERING LABORATORY

HYDRAULICS DIVISION

Project Report No.35

A STUDY OF THE EFFECT OF HORIZONTAL BERM VARIATION ON WAVE RUN-UP UPON A COMPOSITE BEACH SLOPE

A Report for

C.E. 421 - Hydraulic Laboratory Practice

(3 Credit Hours)

by

Robert M. Sorensen

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Submitted to

Professor J.B. Herbich

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Professor William J. Eney is the head of the Civil Engineering Department and the Fritz Engineering Laboratory and Dr. Lynn S. Beedle is the director of the Fritz Engineering Laboratory.

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INTRODUCTION

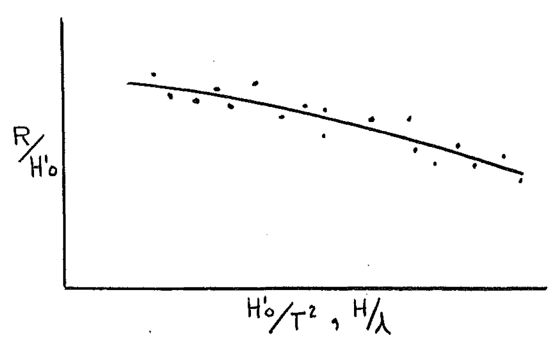
LITERATURE SURVEY

Preface

The purpose of this literature survey is to determine what aspects of the problem of wave run-up upon shoreline structures have been investigated and to review those which pertain to the subject of our proposed study. To this end sources were investigated which related not only to the immediate problem of run-up on composite slopes but also to the more basic problem of run-up on shorelines with uniform slopes. This is not meant to be an all inclusive review but only contains the information from the various sources which it is felt will be of direct significance to the work contemplated.

General Information

It has become standard practice when presenting run-up data for different types of waves to plot the relative run-up (R/H'o) against the wave steepness. A typical plot is shown below.



Relative Run-Up. This dimensionaless term is the ratio of the run-up R (vertical rise of the water on a structure face with respect to the still water level) to the deepwater wave height (H'o). This parameter is of an immediate practical value to the designer because it tells him; for a specified design wave; how much higher than the wave height he can expect the water to rise on the structure.

Wave Steepness. This parameter serves as the identification for a particular wave. The form used by Granthem (1953) is H/L and this is merely the ratio of wave height to wave length. As Saville (1958) points out this designation has several drawbacks from a practical standpoint. (1) It is inconvenience to use wave length as a parameter because it tends to change appreciably with depth for a given wave train. A depth position must therefore be specified with each value given. (2) The wave period in actual practice is usually directly available either from forecasts or from measurements whereas the wave length must generally be computed. The wave period also remains constant regardless of depth variation. Because of this Saville (1958) and Savage (1959) both use the expression $H'o/T^2$ to designate wave steepness. This can be seen to be directly proportional to the more familiar deep water wave steepness H'o/L by the following mathematical manipulation.

$$Ho'/Lo = Ho'/gT^2/2\pi \therefore \frac{Ho'}{T^2} = \frac{Ho'g}{2\pi Lo}$$

$$\frac{Ho'}{T^2} = 5.12\ Ho'/Lo$$

Investigation by K. H. Granthem (1953)

The problem of wave run-up on constant-slope structures was investigated. The primary variables which were found to affect wave run-up were wave steepness, angle of inclination of slope, porosity of structure and relative depth.

Effect of Wave Steepness. A series of waves with H/L varying from .02 to .08 were tested on smooth and permeable slopes of 15°, 30° and 45°. It was found that the relative run-up R/H essentially varied between 1.0 and 2.0 for the entire range of tests on smooth slopes. On permeable slopes (porosity of 28.9% and 32.6%) the relative run-up was markedly reduced to a range which essentially was below 1.0. It is interesting to note that for slopes of 30° and 45° there was an increase in R/H when the wave steepness was increased above .03. For a slope of 15° however, there was a decrease of R/H in the same range.

Effect of Slope Angle on Wave Run-Up. By using a particular wave (constant $\frac{d}{L}$ and H/L) and varying the slope angle it was found that a maximum value of relative run-up occurred in the vicinity of 30° in each case tested. Waves broke on the structure for angles from 15° up to a critical angle of 30° and then above 30° the wave surged up the slope without breaking. This caused a progressive decrease in run-up as the angle was increased to 60°.

Effect of Relative Depth $\left(\frac{d}{L}\right)$ on Run-Up. Tests were run for a particular slope and wave condition for a range of values of d/L (ratio of depth of water to wave length) from a very small value (shallow water) to a value approaching the deep water ratio of .5. In all cases it was found that for increasing values of d/L, there is a simultaneous decrease in the value of the wave run-up.

General Conclusions.

(1) As the wave steepness increases the wave run-up increases.

(2) As the relative depth parameter (d/L) decreases the wave run-up increases.

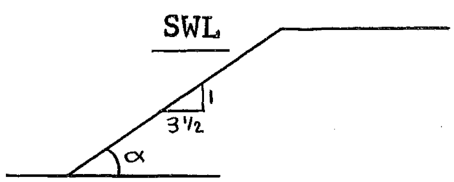
(3) The critical point of side slope angle appears to be approximately 30°. Any variation from this slope, in either direction, probably will decrease wave run-up, other factors being equal.

Summary Report by F. Wassing (1958)

The work that was carried out in the Netherlands considered the influence of many factors on the run-up value. Some of these factors were: the shape of the dike, the character of the dike facing, the direction of wave propogation and the steepness of the wave in front of the dike. The variable that is of particular interest to this report is the shape of the dike.

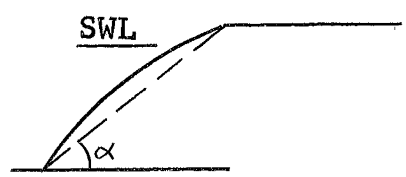
Effect of Dike Shape. The formula for run-up which they developed can, for clarification of the influence of this factor, be rewritten: $R/H = B_1 \left[f\ (\alpha,\ H/L,\ \text{type of facing etc.}) \right]$ The value of B_1 was taken as unity for a straight sloped structure and served as a reference. They divided the shape of the dike into 8 types in order to obtain the influence of shape of dike on run-up, and gave values for B_1 for these.

(A)



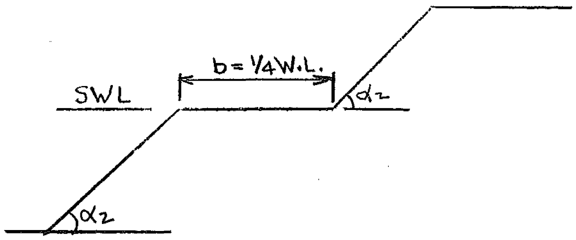
STRAIGHT SLOPE (B_1 = 1)

(B)



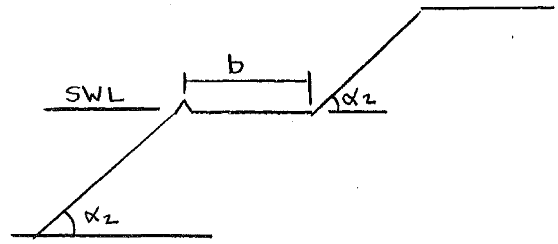
CONVEX SLOPE (B_1 = 0.95)

(C)



BERM DIKE ($B_1 = 0.75$)

(D)



BERM DIKE ($B_1 = 0.65 - 0.70$)
(WITH STILLING BASIN)

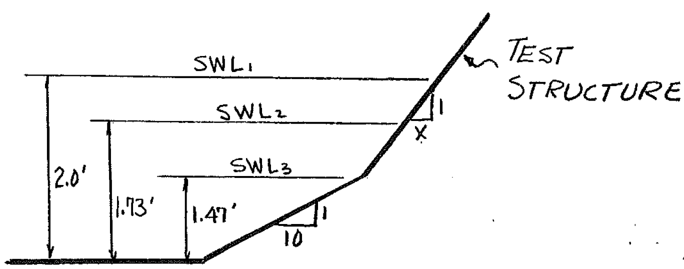
Of the types shown here the one of particular interest is case (C). It is interesting to note that the relative run-up is reduced by a value of 25% by having a horizontal berm section whose width is 1/4 of the wave length of the wave. The report states "From various model tests on berm dikes it was found that a berm has a beneficial influence on the wave run-up if it is placed at approximately storm level and if its width is approximately equal to 1/4 L".

Conclusion. It is briefly noted here that since a reduction factor for run-up is only given for a berm width of 1/4 of the wave length it would be interesting to investigate what this reduction factor would be for other berm widths and perhaps arrive at a point of diminishing returns after which any further increase in berm width would not proportionally decrease the run-up. A second point to be made about the diagrams shown refers to case (D) which is a berm dike with a stilling basin. It will be noted that the "ponding effect" caused reduces the run-up value even more. The effect of this "trapped water" on the damping out of run-up deserves further consideration.

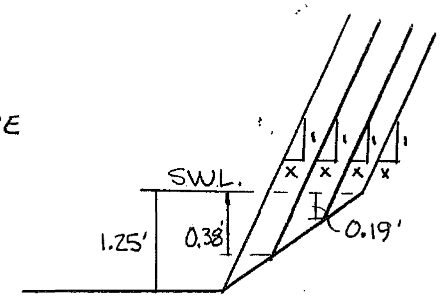
Report by Saville (1958).

This paper considers the work done at the Waterways Experimental Station at Vicksburg, Mississippi, and at the Beach Erosion Board Laboratory. The results of these experimental programs are presented in a form which indicates the effect that the depth of water at the toe of the structure has on the magnitude of the relative run-up. Several notes are also made about experimental procedure which will prove to be helpful in our proposed study.

Types of Structures Tested.



W.E.S. LAB.



B.E.B LAB.

(a) Waterways Experimental Station: As indicated by the diagram three different depths were obtained by varying the depths in the deep part of the tank. All structures were fronted by a 1 on 10 slope. The smooth uniform slopes tested were

1 on 3, 1 on 1-1/2. Tests were also run on a step faced wall and a curved wall and for each type overtopping measurements were also made. The wave heights tested ranged from .17' to .70' and the wave periods were from 63 seconds to 3.64 seconds.

(b) Beach Erosion Board: All the structures were tested in 4 depths of water at the toe of the structure. These were obtained by keeping the water level in the deep part of the tank constant at 1.25' and varying location of structure. Smooth slopes of 1 on 1-1/2, 2-1/4, 3, 4 and 6 (all fronted by 1 on 10 slope) were tested. The 1 on 3 and 1 on 10 slope also were tested with varying depths in the deep part of the tank to determine the effect of this depth on wave run-up. The range of wave heights tested were .03' - .58' and range of wave periods were 0.61 - 4.70 sec.

Notes on Run-Up Readings. At both locations the first 2 to 4 waves were ignored in order to permit a stable condition to become established before measurements were taken. Measurements of run-up were then made on the next 6 - 15 waves or so, but were, in any case, stopped before reflected waves from the structure could travel to the generator and return back to the structure. In the B.E.B. tests actual measurements were taken on each of the six to fifteen waves and these were averaged to obtain a mean value. In the W.E.S. tests only the maximum of the 6th to 15th waves were taken, the water was then stilled and the test repeated several times. Tha maximum values from these tests were then averaged to obtain the value reported.

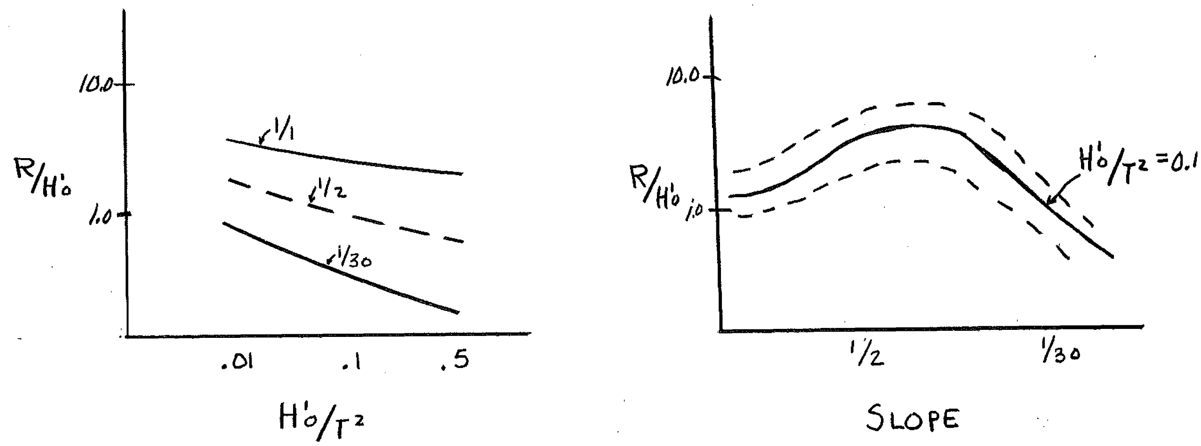
Results and Conclusions. Plots of relative run-up as a function of wave steepness are presented for various values of beach slope (from 1 on 1-1/2 to 1 on 6) as the relative depth d/ho' (ratio of depth of water at the toe of the structure to the wave height) varied from 0 (toe of structure at still water level) to greater than 3. It was found that the run-up increases with the depth of the structure until a depth to height ratio of between 1 and 3 is reached and then apparently decreases somewhat. This apparent decrease as the larger depths are reached appears quite small, particularly in the range of values of Ho'/T^2 of greatest interest to the designer. A general statement could therefore be made that varying the water depth at the toe of the structure has a negligible effect on the relative run-up when the water depth at the toe of the structure is in the order of three times the deep water wave height or greater.

Run-up Report by Savage (1959)

The influence of slope roughness and slope permeability on wave run-up was investigated extensively for constant sloped structures (ranging from 1 on 30 to vertical) in this report. The effect of roughness was tested by covering the smooth slopes (constructed of plywood) with a single layer of material glued to the slope; the effect of permeability was tested on slopes composed entirely of the material to be tested. Curves relating wave run-up to wave steepness, slope roughness and slope permeability were presented.

Curves relating run-up to wave steepness were also presented for the case of smooth slopes. A constant depth of 1.25' was used throughout the tests.

<u>Presentation of Data and Experimental Results</u>. The smooth slope data was plotted in the conventional manner relating relative run-up to wave steepness for each slope. The interesting point about the data presentation however is that from these curves a composite graph was drawn which shows the effect of slope on the relative run-up for isolines of $H'o/T^2$.



Several important conclusions were drawn when the data was presented this way.

(1) For any particular slope, the relative run-up increases as the wave steepness decreases.

(2) For very steep waves the relative run-up is highest for a slope in the order of 1 on 2.

(3) For waves of low steepness the relative run-up is highest for a slope in the order of 1 on 5.

A brief mention is made here of the effect of the other two variables studied. It was found that the effect of slope permeability on wave run-up was more pronounced than the effect of slope roughness. This was because data for the effect of permeability also included the effect of roughness since the surface of permeable slopes was composed of the same roughness materials used in the roughness tests. Both factors however, indicated a marked reduction in run-up when compared to the run-up for smooth slopes. It should be mentioned here however, that the results found are not valid when the depth of water at the toe of the slope is less than three wave heights. In this region ($d/Ho < 3$) the run-up will be affected by the depth at the toe of the slope. This means that d/Ho must be considered as a variable because as Savage mentions: "As the depth of the slope decreases below three wave heights, run-up increases to a maximum value which may be twice the relative run-up for a large water depth at the toe of the slope. From this maximum, the relative run-up decreases as the depth at the toe of the slope decreases further".

Hurricane Project Model Tests by R. Savage (1957)

The wave run-up tests were conducted with an undistorted 1:20 scale fixed bed model of the proposed design. The beach was a composite sloped structure with a 1:20 beach foreshore slope, a horizontal berm section and a 1:10 and 1:5 dune slope respectively. The two prototype widths of berm tested were 50' and 150'. Various depths of water with respect to the berm elevation were also tested. These ranged from a still water depth at the same level as the berm section, to a condition of submergence of the berm to 3' (prototype dimension) below still water level and a condition of elevation of the berm up to 2 ft. above the still water level.

It was found that waves which broke on the 1:20 beach slope and moved across the beach berm caused a layer of water to stand on the berm. In each case the height of this "water set-up at the toe of dunes" was noted and this set-up was added to the "still water depth over the berm" to obtain what was called the "active water depth over the berm at the toe of the dunes".

A definite analysis of the results was not made in order to determine quantitatively how this "active water depth" effected the wave run-up but it appeared from the presentation of the data that its relative effect on run-up as the berm width is increased warrants further study. It also would prove interesting to examine the effect that the still water level above the berm has on the amount of wave set-up. It appears in some cases that when similar waves were tested for both a still water depth over the berm and a still water depth equal to berm height considerable differences in the water set-up at the toe of the dunes and hence the run-up resulted.

Wave Run-up on Composite Slopes, Thorndike Saville (1957)

After a presentation of the method for predicting run-up on composite slopes Saville compares the predicted values of run-up with values obtained experimentally by Savage (1957) for composite slopes with horizontal berms. He makes mention of restricting the comparison to the cases of still water depths over the berm of -2, -1, 0 and 1 feet so that the run-up would be due to the wave breaking on the beach slope rather than to a reformed smaller wave propogating on the water over the berm. This will be an important factor to consider when the tests for the present project of this paper are being run.

Saville found that good agreement existed between his predicted values and those obtained experimentally for all cases except those for the 150 foot berm. Mention is also made of the fact that there is not much difference between the run-up values for the 50 feet and 150 feet berms. Saville then comments "This would seem to imply that after a berm has reached a certain width, further widening has no significant effect in reducing wave run-up -- at least for horizontal berms".

The final sections of the report are concerned with comments about what causes these effects. It is felt that these are sufficiently pertainent to this literature survey to be directly recorded here.

"This reduction in effect of berm width may be because, in the laboratory tests at least, a definite "set-up" of water occurred on the berm. This "set-up" or increase in mean water level is caused by the forward transport of water by the waves and, for these tests, ranged between 0.9 and 2.4 feet with an average value of 1.7 feet and a most frequent value of 1.8 feet. This "set-up" increased the water depth over the berm appreciably, and in many cases the run-up measured may have been due more to reformed waves or surges in this increased depth than to the actual uprush of the wave. This is partially substantiated by the fact that experimental values for the higher berms (at or above still water level) are more nearly approached by the predicted values than are those for the lower berms where a greater water depth is observed. This "set-up" phenomenon appears to be much more apparent for horizontal berms than for sloping berms, where the water pushed forward by the wave may flow back much more readily."

His closing remark about the validity of the run-up prediction method in light of these experimental results is "However, further tests are needed to define those cases where width of horizontal berm becomes great enough to effect the validity of the method".

It should be noted here, at the conclusion of this literature survey, that the above statements in general and the last one in particular served as the original idea and guide for the proposed study of which this literature survey is a part.

SAVILLE'S METHOD FOR PREDICTION OF WAVE RUN-UP

The Beach Erosion Board of the United States Army Corps of Engineers, as part of a broad research program, has developed a method for predicting wave run-up on composite beach slopes. The value of this method comes to light when one considers the consequences of waves overtopping shore structures. There is also the economic consideration as structures of the shore protection type are very costly and considerable savings can be realized by building them only to the extent needed for the particular case.

In order to proceed by this method, the actual composite slope of concern is replaced by a hypothetical single constant slope as shown below. As can be seen in Fig. 1 the new slope is from the breaking depth of the wave to an estimate point that the wave run-up reaches.

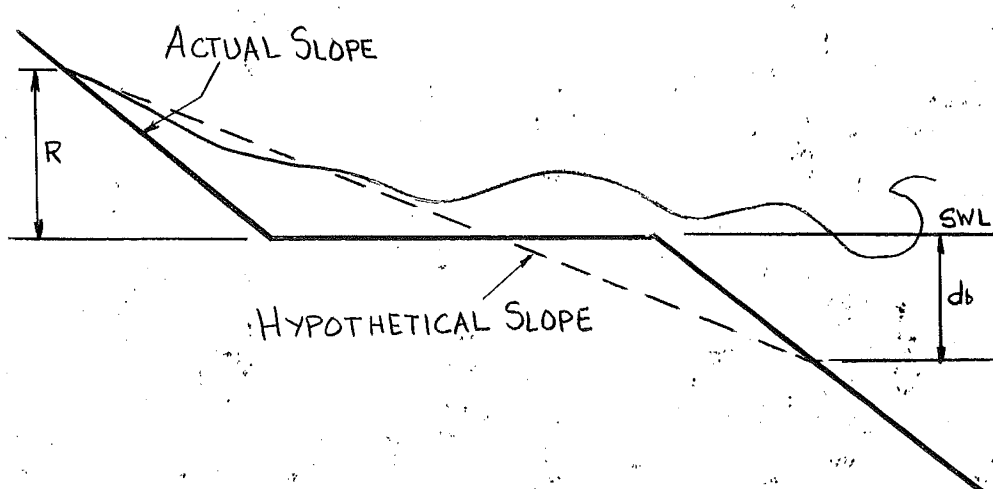


Fig. 1

The values of the equivalent deep water wave height H'o and the period T must be known or estimated. The deep water height value should be corrected for refraction. From these values the breaking depth may be computed by the following equation.

$$d_b = H'_o / 1.5 \left(H'_o / T^2 \right)^{1/3}$$

When the breaking depth has been determined estimate the amount of run-up R that should occur. With these points determine the hypothetical single slope. With the slope and the value of $H'o/T^2$ enter Fig. 61-A and find the value for R/H'o from which R is obtained. This procedure is repeated until the estimated run-up equals the value of run-up from the curves.

The following is an example taken from actual research calculations.

Given: Slopes shown in Fig. 4

Berm width 5 inches.

H'o of 1.94 inches.

Period of 1.07 sec./cycle.

Find: Estimated run-up.

Solution: 1) $d_b = H'_o / 1.5 \left(H'_o / T^2 \right)^{1/3}$

$H'_o = 1.94/12 = 0.162'$

$d_b = .162/1.5 \left(.162/(1.07)^2 \right)^{1/3}$

$d_b = .207'$

$d_b = 2.49''$

2) Assume run-up of 2.6 inches above M.W.L.

3) Calculate hypothetical slope.

$$\text{SLOPE} = \frac{2.60 + 0.96}{18.42} = \frac{1}{5.18}$$

4) Enter Fig. 61-A at slope of 5.18 and line of $H'o/T^2$ of 0.141 and find R/H'o of 1.25.

5) H'o (R/H'o) = R = 1.25 (1.94) = 2.43 inches (estimate was 2.60")

6) Re-estimate a run-up of 2.4 inches.

7) Calculate new slope to be 1/5.24.

8) From Fig. 61-A R/H'o = 1.22 and R = 2.41 inches which is close enough to estimate of 2.40 inches.

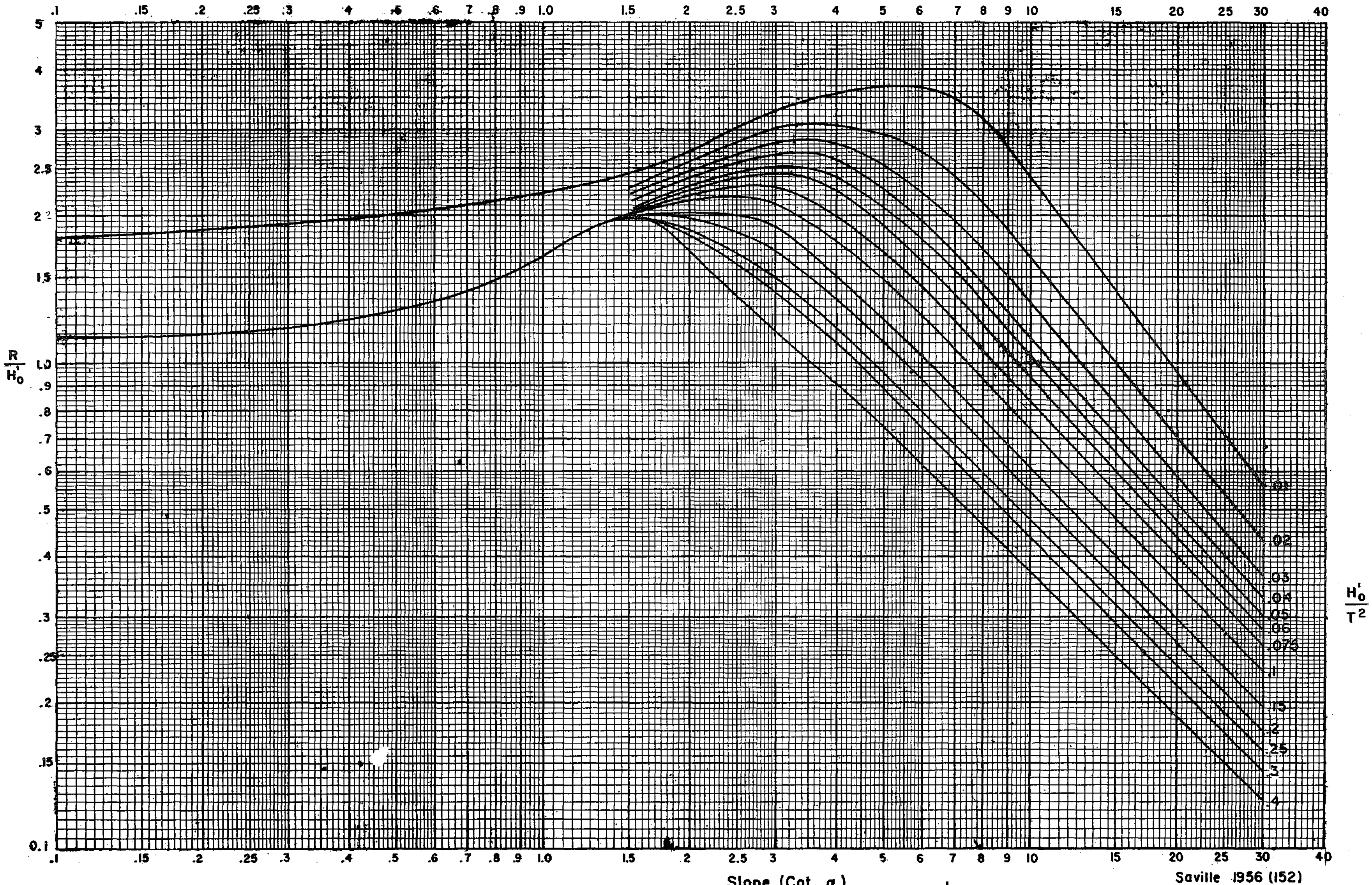


FIGURE 61-A. WAVE RUN-UP FOR SPECIFIC VALUES OF $\frac{H_o'}{T^2}\left(\frac{d}{H_o'} > 3\right)$.

OBJECTIVE OF INTENDED STUDY

This study will involve tests of wave run-up on a composite model beach slope with a variable horizontal berm. The wave characteristics, mean water depth and berm width will be varied and the wave run-up measured. Also, visual observations will be made in an effort to determine what physically occurs to cause the results obtained.

The results will be compared to the work done previously in this area with the idea of confirming, if possible, these results. Also, an attempt will be made to add in general to the information available on the effect of horizontal berms on the wave run-up on a composite beach slope. By previous work done in this area it is meant the work done by Saville at the Beach Erosion Board and the work mentioned by Wassing in his paper published in 1958.

DESCRIPTION OF EQUIPMENT

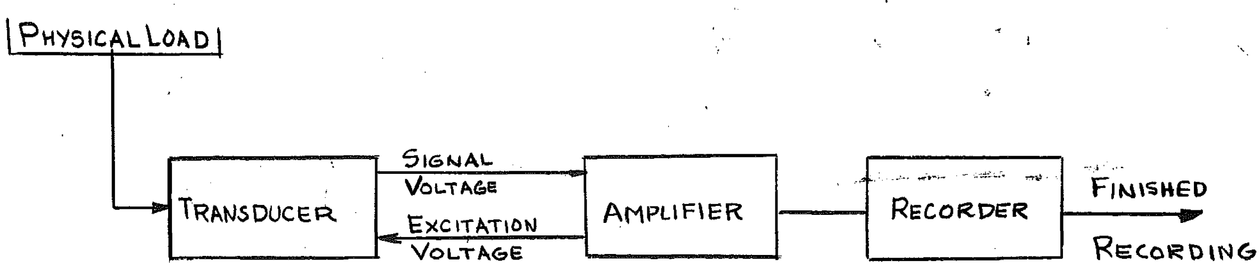
General

The equipment used to conduct the research for this report is located on the second floor of the Hydraulics Division of the Fritz Laboratory. In general it consists of a wave tank with generator and absorbers, a Sanborn recorder and the model composite shoreline. This equipment is further discussed in the following paragraphs.

Wave Recorder

A Sanborn Twin-Viso Recorder (Model 60-1300B) (see figure P-1) which produced a record in rectilinear coordinates was used to obtain the wave profiles. The recording apparatus also included a Sanborn Strain Gage Amplifier (Model 64-500B) (for measuring variation in water level in conjunction with an external sensing element) and a Sanborn Control Panel (Model 60-1600) used with the amplifier.

A block diagram below shows the recording system:



The transducer (used to "sense" variations in water level) was not supplied with the amplifier but was assembled at Fritz Laboratory. Essentially it is a component part of a capacitance bridge. The deflections that were recorded corresponded to the depths of submergence of an insulated wire into the water. This insulated wire acted as a small capacitor whose capacity varied directly with the wetted area of the wire.

The amplifier supplied a 2500 cycle excitation voltage to the transducer. The transducer returned a signal voltage to the amplifier. When a physical load (deflection) was applied to the transducer, the signal voltage had a magnitude and phasing which represented the magnitude and direction of the physical load. The amplifier interpreted the signal voltage in terms of the physical load and moved the stylus up or down on the recording to show the magnitude and direction of the load on the transducer.

It should be noted that a system of this type should have a linear calibration so that accurate wave profiles can be recorded. At one of the water depths tested there was indeed a linear correlation between stylus movement and water height change when it was calibrated. However, at the other test depth it was found that a linear correlation did not exist. This meant that a calibration graph had to be drawn to relate wave height and stylus movement. This condition as mentioned above is undesirable.

The Sanborn Company recommends that a resistance bridge type transducer be used since it is stable, easily calibrated and has adequate sensitivity for most measurements. A capacitance bridge transducer similar to what was used in the experiment is not recommended because although it has an advantage of extremely high sensitivity it requires a phase adjustment and sometimes appears unstable because of its extreme sensitivity.

Wave Tank

The wave tank has an overall length of 67.5 feet, a depth of two feet and a width of two feet. This overall length includes the area reserved for the generator and wave absorbers. The tank is constructed with a steel and aluminum frame, the steel being used primarily for the lower supporting members and the aluminum for the tank itself where it comes in possible contact with the water. The frame is made up of standard channels and girder flange angles while the tank has a steel plate bottom and glass sides.

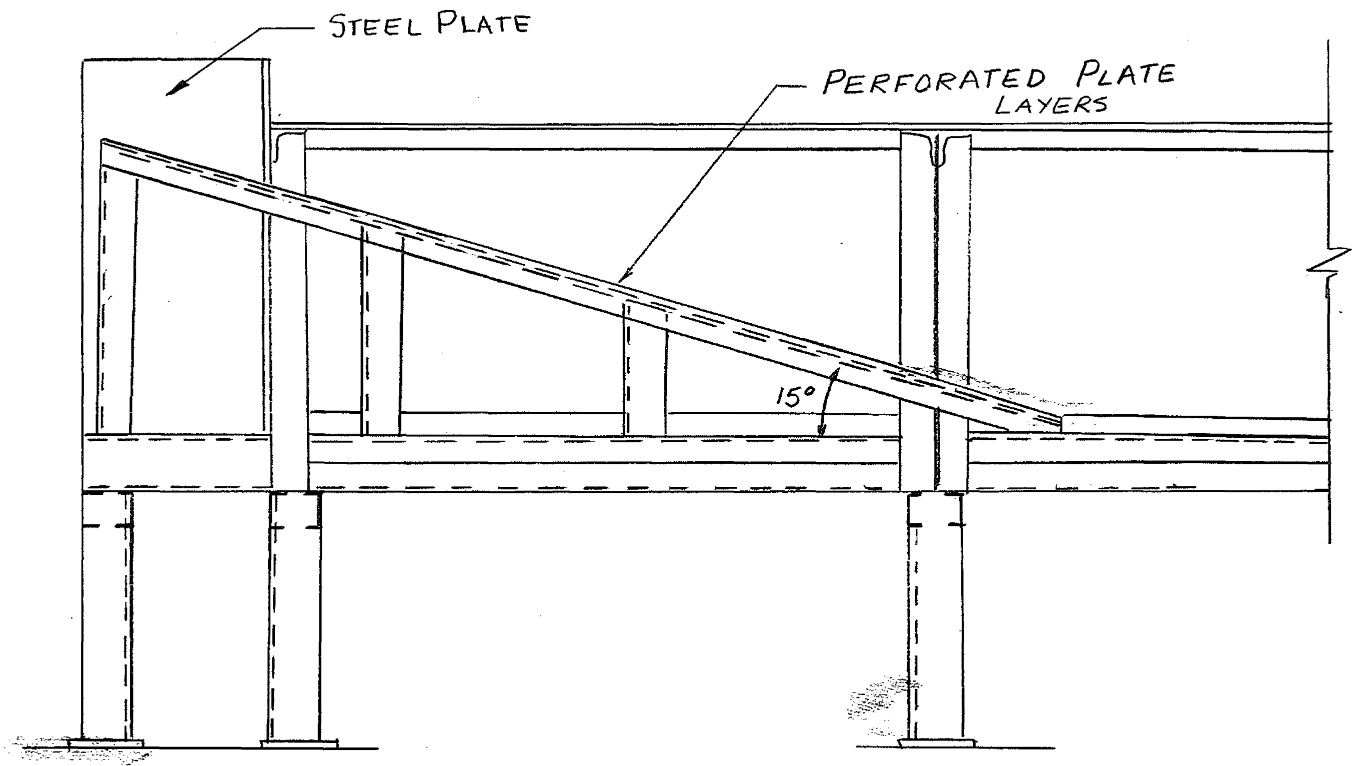
At the west end of the tank is a wave absorber as shown in Fig. 2 The absorber consists of four thin perforated aluminum sheets spaced 1/4 inch apart. These sheets rest on a 5/16 inch aluminum plate. From Fig. 2 it can be seen that the plates are inclined to a 15 degree angle with the horizontal. Also at the west end is a city water tap.

At the east or upstream end is the wave generator and behind this is a wave absorber inclined at 45 degrees and built in a manner similar to the downstream absorber. Fig. 3 is a diagram of the generator and absorber.

There is a track that runs the length of the wave tank and supports a movable carriage. This carriage was used to support the probe from the wave recorder.

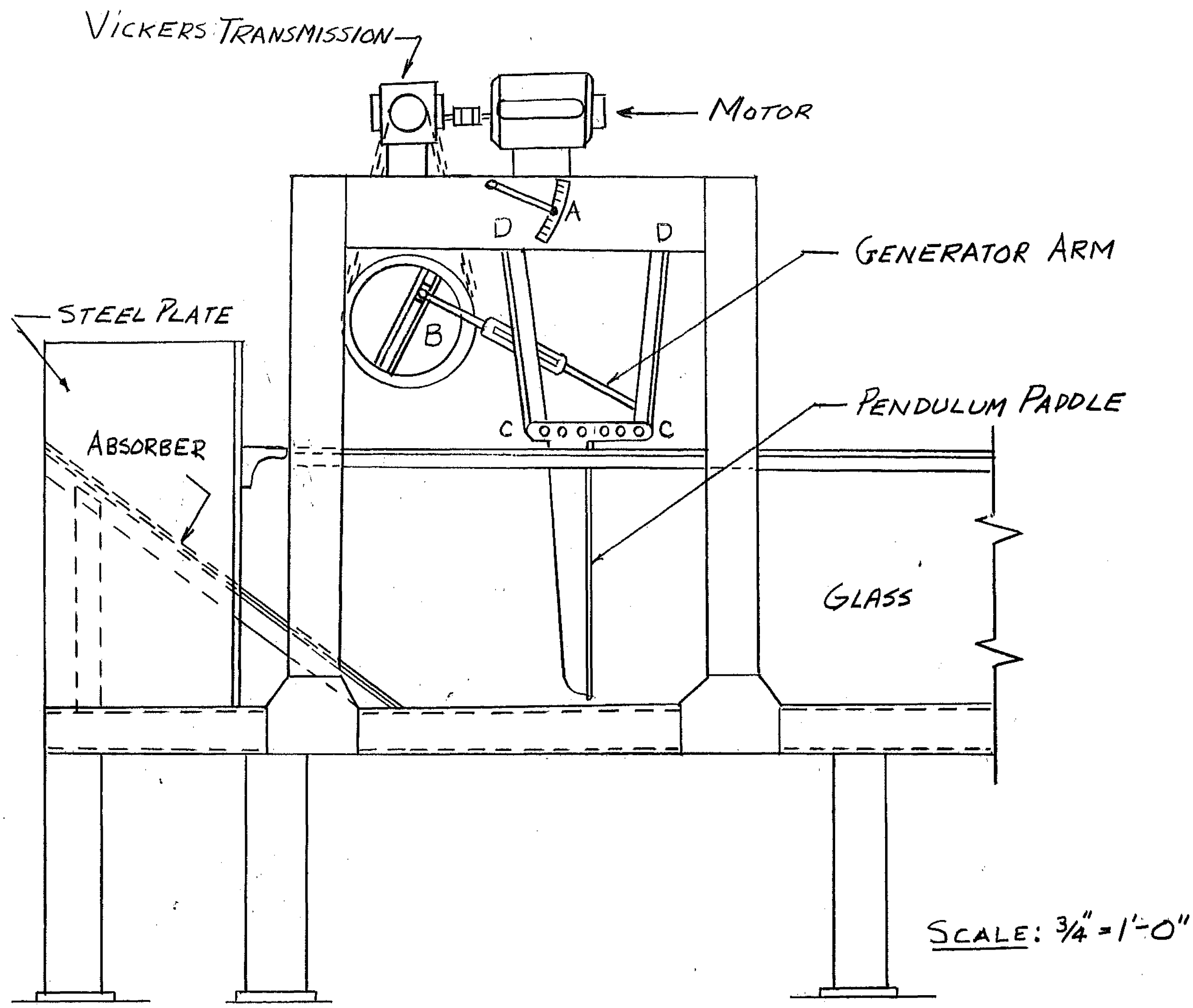
Wave Generator

The generator is of the oscilating paddle variety as seen in Fig. 3 Power for the generator comes from a 3/4 - HP Westinghouse A-C electric motor which operates at a maximum speed of 1725 RPM on 115 volts and 9.4 amps. The motor is coupled to a Vickers transmission which is controlled by lever A in Fig. 3 The power from the transmission goes to rotating disc B by way of a chain drive. At disc B the stroke may be adjusted with a screw that varies the distance from the disc



WAVE ABSORBER

FIG. 2



WAVE GENERATOR AND ABSORBER

FIG. 3

center to the connection between the generator arm and the disc. The generator arm is in turn connected to the paddle. The range of frequencies for the generator may be varied from 0 to about 2.1 cycles per second.

The paddle arms may be adjusted at points C and D. From this the paddle may be set so that it either moves back and forth remaining vertical or so that it swings about a point at the bottom of the tank somewhat like a swinging gate. The generator arm may also be adjusted to increase the stroke but this was not found to be necessary.

There is a main cut-off switch box on the wall near the generator that controls the power to the motor. Also, control buttons for turning the generator on and off are located at approximately 10 foot intervals along the tank.

Figure P-2 shows a photograph of the generator.

Model Shoreline

The primary objective was to construct the shoreline so that the horizontal berm width could be varied at will. Equal inclined slopes were chosen to eliminate these as possible variables. The results obtained by Savage (4) on smooth slopes showed that the highest relative run-up (R/H_o') for steep waves occurred on slopes of the order of 1 or 2 and the highest relative run-up for waves of low steepness (H_0'/T^2) occurred on a slope in the order of 1 on 5. Using this information as a guide for our composite slope structure we designed the model with slopes of 1 on 4 to eliminate large relative errors in estimating run-up as much as possible.

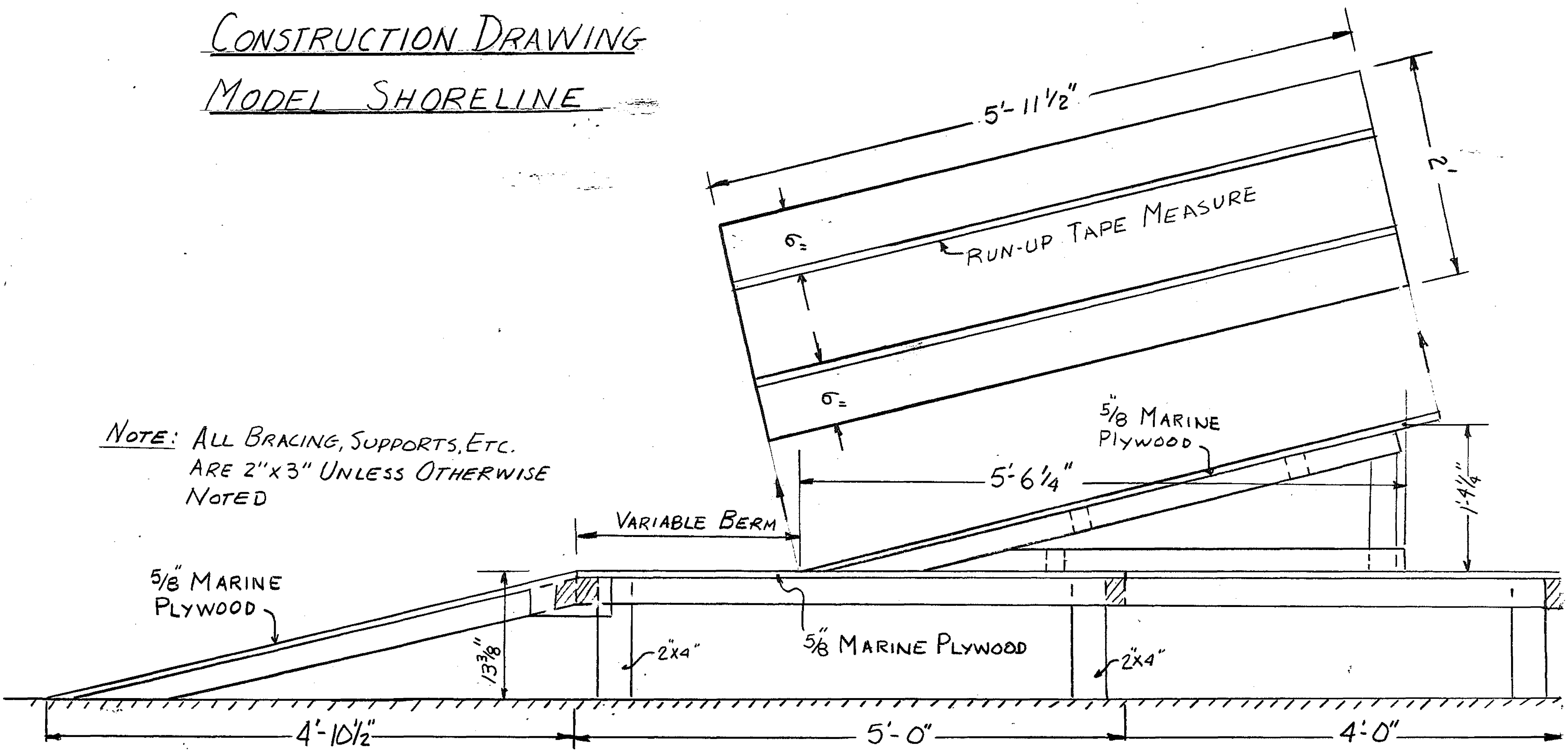
It was decided to perform the testing on a smooth slope rather than a roughened slope for a number of reasons. In the literature review it was found that Saville (3) and others had done quite a bit of work with smooth slopes, which meant that verification of theory and correlation with existing data would be greatly facilitated. It had also been mentioned by Savage (4) that a factor which caused a good deal of scatter in the data for roughened slopes was the increased difficulty in reading the run-up on the slopes as the size of the roughness material increased. Taking all these factors into consideration it was decided that a smooth sloped structure would be used.

The height of the horizontal berm section was largely determined by considering the limitations of depth presented by the size of the wave tank. The height was also chosen on the criteria that the still water level in the vicinity of the berm height gave us the widest possible range of wave heights possible.

A point should also be mentioned here about the actual construction of the shoreline profile. It was designed and constructed at the Laboratory by the authors as the first phase of the work. Marine Plywood was used for all the slopes and for the berm. The supporting members were built from White Pine and the entire structure was given four successive coats of linseed oil before being placed in the water. The structure was kept in place at the end of the wave tank by means of weights placed on lateral struts which connected the column members. It should be noted that even with this considerable dead weight factor the entire structure was found to move very slowly up the wave tank because of the force of the waves. It became necessary several times to move it back several feet to the end of the tank. A drawing of the model shoreline is presented in Fig. 4.

CONSTRUCTION DRAWING
MODEL SHORELINE

NOTE: ALL BRACING, SUPPORTS, ETC. ARE 2"x3" UNLESS OTHERWISE NOTED



SCALE: 3/4" = 1'-0"

FIG. 4

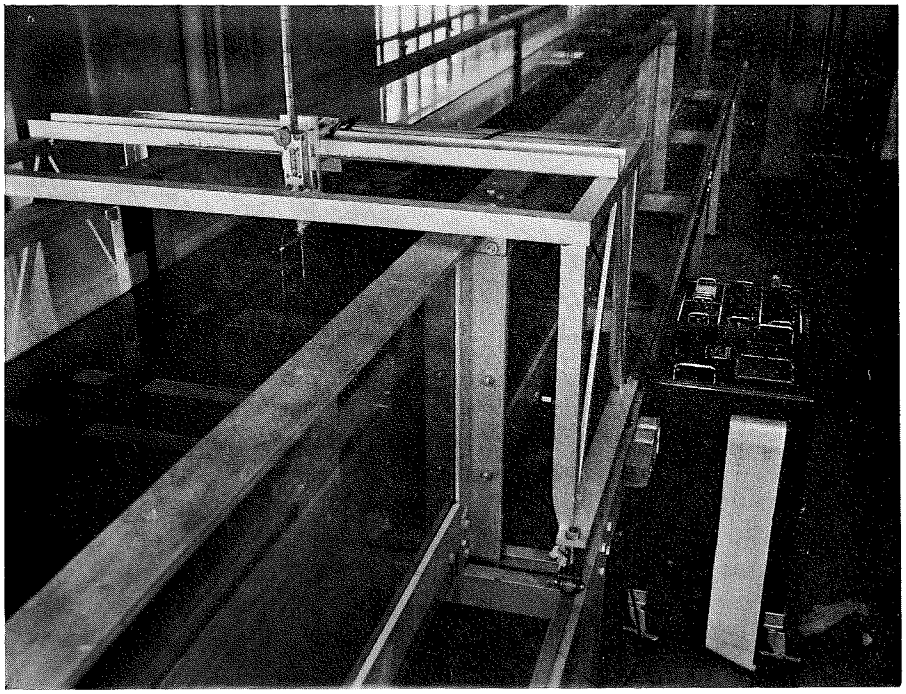


Fig. P-1 Sanborn Recorder

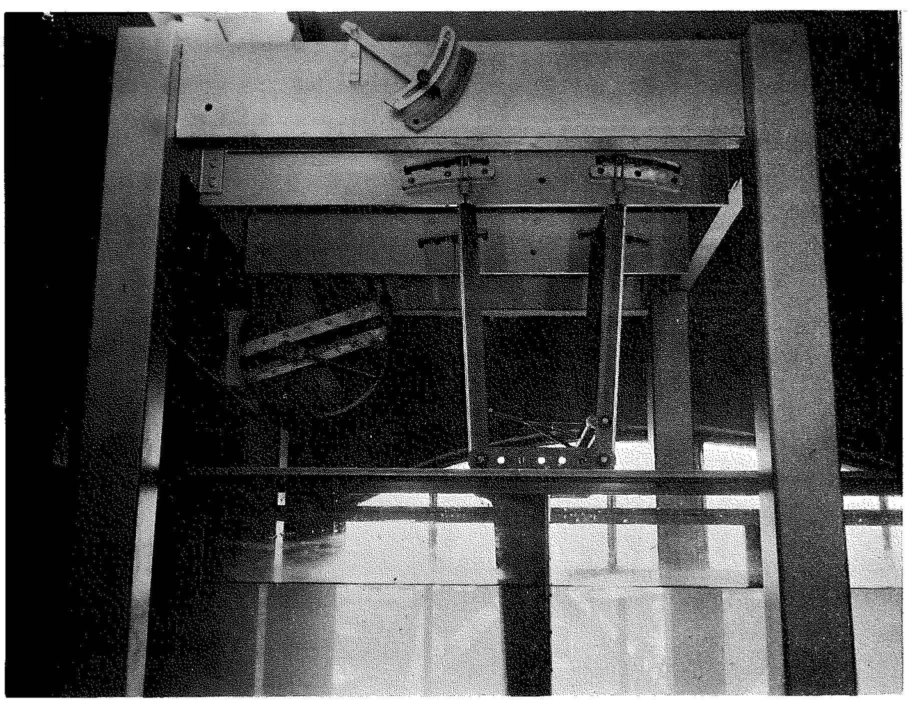


Fig. P-2 Wave Generator

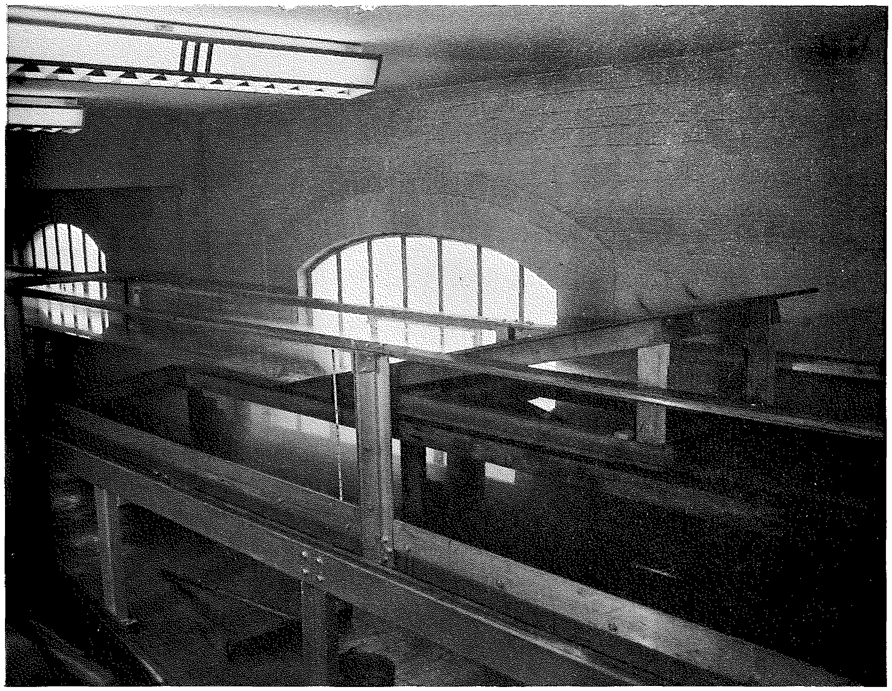


Fig. P-3 Model Shoreline

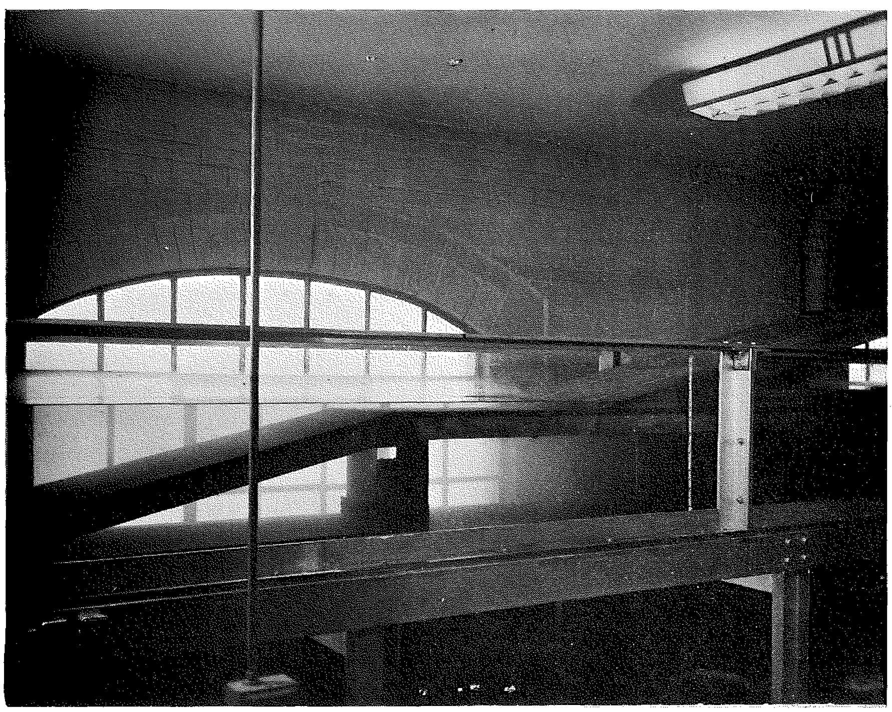


Fig. P-4 Model Shoreline

APPROACH TO TESTING AND COMPUTATIONS

Experimental Measurements

The first step taken in the experimental phase of the work was to determine the wave characteristics for particular stroke and dial settings on the wave generator. With this information known it was then only necessary to reproduce the appropriate setting to achieve a desired wave. This made it possible to concentrate on the shoreline end of the wave tank and determine run-up values without having to simultaneously determine the appropriate wave characteristics.

The wave recorder was used to obtain a record of the wave profile for each setting. The method of determining the characteristics of the wave pattern is outlined below.

Wave Period - This was determined in each case by determining with an electric timer the time required for the pendulum paddle on the wave generator to complete fifty complete cycles of movement. In this way the period in seconds/cycle could be determined.

Wave Height - This property was obtained directly from the recorded wave profile. The recorder had been calibrated prior to testing and it had been found that a drop of one inch in water level corresponded to 6 unit squares deflection by the recorder stylus over the entire range of wave heights to be expected. Since a linear relationship was evident a calibration curve for the recorder was not required.

Wave Length - From a study of available literature it was discovered that it is fairly standard practice to measure the wave period (with a stop watch etc.) and calculate the wave length knowing the period, depth of water and the wave amplitude. The reason this is done is because it is easier to measure the period and it is a fixed quantity whereas the wave length also varies with the depth of water, in which the wave travels.

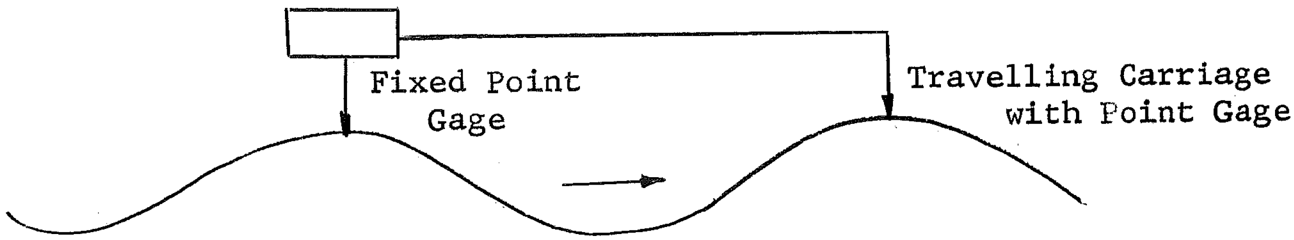
The equation used to find the wave length was Airy's wave velocity expression:

$$V = \sqrt{\frac{g.L}{2\pi} \tanh \frac{2\pi D}{L}} \qquad \text{where } T = \frac{L}{V}$$

For the two depths to be tested (d = 1.4', 1.2') plots relating wave period to wave length for various wave lengths. Thus for the various test values of the period it was only necessary to enter the curve to find the appropriate value of the wave length

An alternate method which was considered but not adopted is one that is mentioned in La Houille Blanche (4). The basic principle involved is the synchronization of electric impulses originating in 2 point gage circuits by means of a

"Magic Eye" radio valve.



The point gages are regulated vertically to barely touch each successive wave crest, this passing of a wave crest is signalled on a sector of the "Magic Eye" by a transient flash. The movable carriage is shifted until flashes in the two sectors are exactly synchronized. There will then be a whole number of wave lengths between the point gages and the wave length can be determined.

Although the accuracy thus obtained may be valuable when model studies are made when field data is given in terms of wave length (Ex: with aerial photographs) it was decided that the formula method was most appropriate and satisfactory in our case.

Criteria for Selection of Test Waves

The main bases for selecting the test waves were that the waves were not so steep that they would break before reaching the slope and that the waves were of a shallow water variety. With a given depth of water, a certain period will give a set wave length. Thus, the period was set so that the wave lengths were at least twice the water depth which gave the desired shallow water wave. Wave lengths were selected so that the smallest wave length was just on the verge of becoming a deep water wave and the largest was about ten feet in length.

With the period set, the stroke on the wave generator was adjusted to give various wave heights. Wave heights were selected over uniform intervals from those that were just under the breaking height to small heights that were still large enough to give results that could be adequately measured.

The paper by Brater, McNown and Stair and the discussion by Herbich brought up the problem of transverse waves. To overcome this problem the wave lengths should be set so that they are not harmonics of the tank width (i.e. one, two, four, eight and sixteen feet etc.) Thus, the wave lengths were selected so that they were of lengths substantially different than the harmonic lengths.

Selection of Water Depth

In conjunction with the selection of the test waves chosen a note should be made about the selection of the water depths. The depths of 1.2' and 1.4' were chosen to insure that the depth at the toe of the structure was greater than three times the wave height in deep water so that this depth would not have an effect on the values of relative run-up.

Run-up Calculation Procedure

The theoretical calculation for the run-up for a particular wave and berm width condition was based on the general procedure developed by Saville and outlined in the Introduction. The initial approximation for each calculation was based on the results obtained experimentally. If this experimental value proved to be in agreement with the value obtained from Saville's method for these particular conditions it was taken as the theoretically predicted value. If the value obtained by Saville's method differed from the experimental value a new approcimation on the basis of the former value was made and this was tried in Saville's method. Using this procedure of successive approximations a value was soon obtained which satisfied Saville's method and this was then noted as the theoretically predicted value. It should be noted here that in most instances the case of zero berm width the experimental value agreed fairly closely with Saville's predicted value. As the berm width increased however, it was found that if the original estimate was based on the experimental value convergence to a value which satisfied Saville's method for these particular conditions was fairly slow. It proved more advantageous therefore to pick an initial assumed value from the general shape that Saville's theoretical curve had taken up to that point. This proved to save a lot of time and effort in completing the calculations. It should also be noted that the original estimate of run-up in no way effects the final value predicted by Saville's method because with any chosen initial value the same value of predicted run-up was always finally converged upon. This was tried on various occasions in the calculations and always proved to be the case. A complete tabulation of all these calculations is in the Appendix.

It was also possible to save time by using a scale drawing of the model shoreline with the second slope drawn in at each berm width of interest. This meant that values for the rise and run of the hypothetical slope used in Saville's method could be taken directly from this drawing for each case. The alternative to this would have been completing a numerical calculation for the hypothetical slope in each case. The method we used was found to be accurate enough for our purposes.

Theoretical values of run-up were obtained for each wave condition at berm widths of 0, 5, 10, 15, 20 and 30". These points were plotted on the same graph as the actual run-up values to facilitate an immediate comparison for determing the accuracy of Saville's predicted values. It was felt that 6 points were sufficient to accurately locate the theoretical curve of run-up versus berm width

Observational Tests

After the major program of run-up testing had been completed and the experimental and theoretical values had been plotted it was decided that a secondary series of observational tests should be run. The reason for these tests was two-fold. (1) To determine in a qualitative way what was physically occurring when the waves hit the shoreline and what changes took place in this physical condition as the berm width was varied. (2) To use this information in some way to help explain why the actual and theoretical values of run-up disagreed after a certain berm width was reached.

These tests consisted of observing the physical flow conditions at the berm as its width was varied. Primary attention was directed toward determing when and how a permanent slug of water was "set-up" on the berm and how this slug effected the subsequent run-up readings as the berm width was further increased. The shortest and longest wave lengths were so tested to observe what physical changes occurred due to this factor. Small particles of paper dropped in the water on the berm added considerably in clarifying what the actual flow pattern in this "slug" was.

Finally an attempt was made to photograph these varied conditions to obtain a permanent record of the observations.

DISCUSSION OF RESULTS

Curves on Run-up Versus Berm Width

The appendix contains a series of twenty plots of wave run-up versus berm width as found experimentally and as predicted from the ideas put forward by Saville. The first set of curves (Series 1 to Series 12) is for a depth of water that covers the berm (i.e. 1.4 feet) while the remainder of the curves concern the case where the berm is above mean water level. Considering the first set of curves, it can generally be seen that Saville's method predicts run-up values that compare favorably to the experimental values when the berm width is small. As the berm width increases the experimental run-up levels off more than the run-up predicted by Saville. In some cases the experimental run-up became roughly constant as the berm width increased.

For series number one no theoretical run-up was calculated. Although the wave was seen to have broken on the first slope, the computed breaking depth was less than the depth of water on the berm by a very small amount meaning that computations showed the wave not breaking before the berm. Since it did, theoretical wave run-up calculations would have been meaningless. The discrepancy was probably due to the tolerance in measuring H'o and T. These values affect the computed breaking depth.

The curves for series number six follow the same general trend as do the other curves in this set except for the fact that the experimental curve is somewhat higher than the theoretical curve. This is most likely due to an error in the determination of H'o since the period (which is the other independent variable in computing run-up) is the same for series numbers four, five and six and four and five do not show this discrepancy.

A close look at the first set of curves also shows that the scatter of the run-up readings increases with wave height for a given wave length and with the wave length in general. This would be due to the fact that the run-up is higher in these instances causing the absolute scatter to be larger. Also, at larger wave lengths, the wave has more energy. This leads to a more violent condition when the waves break causing more scatter in the readings and making the readings harder to take.

The approximate point at which the observed and theoretical run-up values start to disagree seem to be a function of the berm width divided by the wave length (i.e. x/λ).

This approximate point occurs over a range of x/λ from 0.13 to 0.21 with most values around 0.15 to 0.16. For a given wave length, x/λ seems to increase as the wave height increases. This would seem reasonable as with a larger wave height the set up should be larger and occur sooner than it would with a smaller wave height. This set up is the primary cause of the discrepancy between the two sets of values.

The second set of curves (series numbers thirteen to twenty) are for a depth of 1.2 feet (i.e. below the berm). The majority of these curves show a startling difference from the first set of curves. As in the first set, the curves diverge after a certain point, the experimental curves tending to level off. However, in this set, the curves have a small "dip" in them and then they rise to the point at which they level off. This was found to be so in five of the eight cases. The other three cases behaved in a manner similar to the first set. When this "dip" did occur, the approximate point of disagreement (x/λ) was about 0.07 to 0.09 while without the "dip" this point was at a x/λ of 0.13 to 0.18 as in the first set. In the discussion of the observations, an attempt is made to explain this "dip".

The scatter in the observed run-up readings increases with wave height and wave length and the curves in series numbers thirteen and fifteen are some what separated. The causes for these happenings would be the same as those mentioned for the first set of curves.

In series numbers fourteen and sixteen, the curve of predicted run-up is intercepted by a line titled berm height. Beyond this point the curve of predicted run-up extends below the berm height meaning that the run-up has not reached the berm and is only on the first slope (this was not the experimental observation). It is believed that at this point, Saville's method breaks down. Considering the calculations for series number fourteen (page A-35) we see that the hypothetical slope decreased from 4.27 to 7.6 as the berm width increased from zero to ten inches. During this time the predicted run-up was on the second slope. When the berm width increased beyond 10 inches, the run-up predicted was less than the berm height (i.e. on first slope) which means that the slope would revert back to what it was at zero berm width (i.e. 4.27). This slope gives a run-up value of 2.05" as for zero berm width which can not occur on the first slope. Thus the theory breaks down.

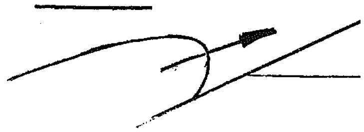
For this reason, no theoretical run-up values were determined beyond this point.

Observation Tests

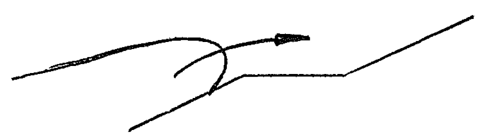
A series of observational tests were performed in an attempt to determine what physically took place as the waves broke on the composite beach slope. After this study was completed some general statements about what effect berm width variation had on the flow characteristics were formulated and are presented below. A series of photographs would have greatly clarified these statements but it was not possible to take or include these photographs in the report. It should be noted here that whereas all other sections of this discussion are based on experimental fact the following is based on observations and suppositions and hence may be open to dispute.

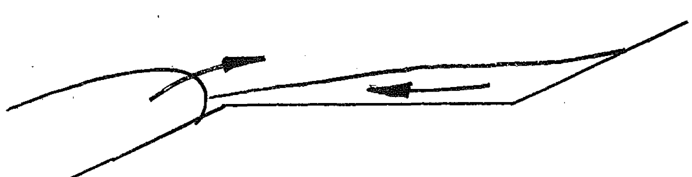
The following are from observations made on Runs #13-#20 which were made with the berm "perched" above the still-water level. The steps which are outlined below were more apparent for this situation so are presented first.

CASE A



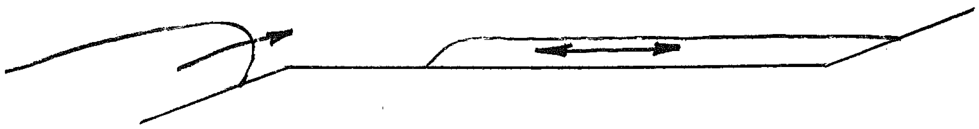
CASE B





CASE C

CASE D



CASE E

Case A

Shore structure has no berm so wave breaks on structure, runs-up on slope and then washes back down.

Case B

With a very small berm as shown the wave breaks on lower slope and proceeds to run-up the upper slope. This water then has an opportunity to wash back down again before the next wave breaks and begins to run-up. Hence there isn't any opportunity for water to remain on the berm.

Case C

When the berm width has increased to a large enough value the water coming down from the top slope no longer has a chance to completely run off the berm before the next wave has broken on the lower slope and is running up. Because of this a slug of water remains on the berm to offer resistance to the oncoming uprush. It probably could be thought of as a mild sloped slug of water which changes the conditions which the water running up must overcome.

Case D

As the berm width is further increased a permanent oscillating slup develops with no part of leaving the berm. This is evidenced by a "dry area" at the forward part of the crest as illustrated in the diagram. The approaching wave must now in effect "climb over" this fairly horizontal slug which is now merely oscillating back and forth.

Case E

After a point as the berm is further increased the length of the slug tends to remain fairly constant thus always presently similar conditons to the approaching waves.

As can be seen by the plots of experimental values for Run #13-20 there is a fairly sharp decrease in run-up as the berm width is initially increased but that a fairly constant value of R/H'o is soon arrived at as the berm width is increased. It is felt that this is due to the fact that as mentioned above a permanent slug develops on the berm after a sufficient berm width is reached and after that the run-up is merely due to the oscillation of this slug of water caused by the force exerted on it as it meets each successive wave. Since there isn't a further change of flow conditions after this point a further change in R/H'o should not be expected.

Saville's method however, does not take this physical factor into account so that his predicted curve continues to show a progressive decrease in R/H'o as the berm width is further increased. This results in the separation of the actual curve and the predicted curve after a certain berm width.

It will also be noticed that in runs #17-#20 there is a characteristic dip in the run-up curves after the berm width has increased a small amount (berm width of about 5 inches). It is felt that this is due to a change in flow conditions from Case B and Case C in each case. This fact is also not indicated by Saville's predicted curve, although it is quite apparent from the curves that some basic physical factor must have been altered to produce such a discontinuity. It is also apparent that each curve "levels out" after a certain point which tends to indicate that Case E has finally been reached. This dip does not appear in the curves for runs # 13-16 and this may be due to the fact that these are for waves of smaller wave lengths than others.

In the case of runs # 1-#12 where the berm is submerged essentially the same conditions exist as in the above-mentioned cases except that the effects are not immediately obvious. There is better agreement between the predicted curves and the experimental ones and this is probably due to the fact that the water that is "perched" on top of the berm by virtue of the still water level tends to cause this "permanent slug" with the "dry areas" visible to occur only at a much larger berm width.

In some cases for the longer wave length waves this existance of a permanent slug does not occur at all for the range of berm widths we tested.

Plots of R/Ro Versus x/λ

An attempt was made to reinterpret the data for Runs # 1-12 by plotting the ratio of the run-up at a particular berm width over the run-up at zero berm width as a function of the berm width divided by the wave length. It was felt that a plot of this type would indicate the point of diminishing returns mentioned in the previous section and also readily convey the percent run-up expected (as related to the run-up for a smooth sloped structure) for a berm width which was any particular fractional value of the wave length of the oncoming wave. A plot of this sort would also be valuable from another stand point because it would allow a comparison between the results of this report and the work which was presented by the Dutch[2] in which they said that the run-up would be decreased to 75% of that of a uniform slope if the berm width was equal to 1/4 of the wave length.

From the figure on page A-47 of the appendix it will be seen that although there appears to be quite a wide band into which the values fall some very definite statements can be made. If the "average" curve is first considered it will immediately become apparent that after a berm width of a certain fraction of the wave length is reached the succeeding reduction in the run-up ratio is negligible.

From the curve it will be seen that this value appears to occur at a berm width whose value is between 1/4 of the wave length and 3/8 of the wave length. This is partially illustrated by the fact that the run-up ratio for a berm width of 3/8 the wave length is 0.58 and for a berm width of 3/4 of the wave length it is 0.54. Thus it appears that increasing a berm width to greater than 3/8 the wave length of the average waves approaching that part of the shore could not be economically justified.

To facilitate further comment the pertainent values found from the curve are re-stated below:

Berm Width	Run-Up Ratio
$1/8\lambda$	.74
$1/4\lambda$	.63
$3/8\lambda$	.58
$1/2\lambda$	.55

First it can be seen that these results prove without a doubt that the existence of a berm has a considerable influence on the value of the run-up. A berm width which is as small as

1/8 of the wave length will, as seen in these results, reduce the run-up value by 25 percent.

This result tends in some way at least to disagree with the findings of the Dutch because they felt a berm width of 1/4 of the wave length would be needed to produce this reduction. Although the authors are not acquainted enough with the test procedures and equipment used in Holland to be able to find a source of discrepancy by examining the differences in this area one important point can be made.

Conclusions were arrived at in the above discussion by considering the "average curve". If we examine the band of values shown in the diagram however, an interesting point develops. It appears that the % reduction value for a berm width which is a particular fraction of the wave length depends directly on the wave length. This can be illustrated by noting that for a berm width value of 1/4 of the wave length, the run-up ratio is about .80 for a wave with a wave length of 27.7" while it is about .58 for a wave with a wave length of 118.1". Thus it appears that the percent reduction is greater for longer wave length waves.

If this point is considered it will be noted that for the shortest wave length wave (27.7") the reduction ratio at a berm width of 1/4 of the wave length is in close agreement with the findings of the Dutch.

In a qualitative way at least these results of this study do concur with their conclusions because it definitely appears that:

(1) A berm width of 1/4 of the wave length is still more preferable than one of 1/8 of the wave length because it is seen that at this value the "average" curve shows a run-up ratio which is down to a value of .63.

(2) The motive for extending the berm width much beyond this $1/4\,\lambda$ value must be considered questionable because the additional run-up reduction is small.

Thus it appears that the point of diminishing returns appears to exist somewhere between 1/4 and 3/8 of the wave length.

An examination of the run-up curves for runs # 13 - # 20 seem to indicate that for the case of the elevated berm the run-up ratio values will tend to be higher for any particular berm width. This is only mentioned here because an analysis of the data for these runs was not made so cannot be further commented on at this time.

Plots of R/H'o Versus $H'o/T^2$.

The plot of R/H'o versus $H'o/T^2$ for various berm widths (page A-50 of the Appendix) was prepared for runs # 1-12 (berm submerged, depth of water = 1.4') in an attempt to clarify the effect that berm width variation had on relative run-up. It should be noted that the values of $H'o/T^2$ range from .055 to .48. This puts them in the range of greatest practical interest since as Saville(3) points out, actual waves have values of $H'o/T^2$ which are usually greater than 0.1 and probably never less than an $H'o/T^2$ of 0.05.

The first plot of interest is Curve I which is for a condition of zero berm width, in other words a curve for a smooth uniform slope. A straight line of best fit was drawn through the series of test points rather than attempting to draw a curve through these points. After this had been done the data presented by Saville(3) was examined for the case of 1 on 4 smooth uniform slope with $d/H_o' > 3$ hence obtaining agreement with our test conditions and five points were taken off this curve and superimposed on our data as shown. It can be seen that there was only a very small discrepancy in the two curves and this probably was due to the choice of the curve of best fit. It should also be noted here that the portion of Saville's curve which falls within the range of H_o'/T^2 of this report was also drawn as a straight line. Since these results agree very closely with Saville's little need be said about them except to state again that as the value of H_o'/T^2 increased the relative run-up R/H'o decreased. The value of R/H'o varied from a little less than 3.0 for the smallest value of $H'o/T^2$ down to a value of about .72 for the "steepest" wave.

Curve II, which is for a condition of berm width equal to 10" can now be examined. As shown in the figure the line of best fit is approximately parallel to Curve I but "shifted down" a relatively large distance from it. This would tend to indicate that increasing the berm width to 10" has the effect of causing a sizeable decrease in the relative run-up for the entire range of wave steepness values tested. It appears that the value of R/H'o now varied from a little greater than 2.0 for the smallest value of Ho'/T^2 equal to 0.5 which is the steepest wave tested. It could therefore be stated that a prototype beach slope which contained a berm properly scaled up from the 10" berm of the model would produce a sizeable reduction in run-up values.

An analysis of Curve III which corresponds to a berm width of 20" however, does seem to warrant such equally optomistic statements. It appears that for the lower values of H_o'/T^2 there is a further reduction in relative run-up from Curve II but the magnitude of this "advantage" over the 10" berm relative run-up steadily decreases as the value of H_o'/T^2 increases until the range of highest wave steepness values ($.3 < H_o'/T^2 \leq .5$) there does not seem to be any advantage in going to the additional expense of providing the prototype beach with a berm whose width corresponds to 20 inches.

Curve IV which corresponds to a berm width value of 30 inches seems to illustrate this trend even more significantly. This curve roughly parallels Curve III but it has not been shifted a relatively great distance below it. The additional expense of providing and maintaining a beach with a prototype berm corresponding to 30 inches as opposed to one with a 20" berm probably could not be justified because the resultant decrease in relative run-up does not appear to be that significant. When compared to the curve for a 10" berm width it is seen that there is a significant reduction in run-up for the waves of lower H_o'/T^2 values but that as the value of $H'o/T^2$ is progressively increased this reduction decreased until a value of $H'o/T^2$ of 0.5

it is a negligible amount. The values of R/H'o in fact range from a little less than 1.5 for the smallest value of $H'o/T^2$ down to a value of .47 for the "steepest" wave.

From these curves it therefore appears that a point of diminishing returns is reached, from which a further increase in the berm width will not results in an equally favorable further decrease in the value of the relative run-up. From these curves it appears that this point lies somewhere in between a berm width of 10" and one of 20". These curves however, do not allow us to further pinpoint this berm width so it was found necessary to interpret this data from another angle in order to come up with some more conclusive evidence. This has been done and will be discussed in the following section.

It should be noted here that similar plots for cases 13-20 (berm width above MWL) were not completed but it appears that somewhat similar results will be found. This point among others will be further explored later in this report discussion.

General

The Sanborn recorder reading charts are presented for the first twelve series only. This was done in the interest of reducing the volume of this report. They are still sufficient to give an indication of the wave forms concerned. From these readings it can be seen that the waves are not truly symetrical in shape. The trough of the wave is flattened in some cases. This is due to the Sanborn recorder.

Rather than rigidly attach the model shoreline to the wave tank it was decided to weigh it down with metal blocks. With this, the model still moved ever so slightly as each wave broke on it. By moving, the model shoreline was thus absorbing some of the waves energy (especially with a large wave length). This could have an effect on the results obtained.

Suggestions for Future Work

The plots of R/H_o' versus $H'o/T^2$ and R/Ro versus x/λ were completed and analyzed only for series numbers one to twelve (as mentioned). As they were very informative, it would be valuable to plot them for the remainder of the tests.

In addition to the two depths considered, further tests should be run at different depths of water. Of special interest would be a series of tests with the mean water level at the berm elevation. Another variation of interest is that of running tests with different fore and after slope angles. Granthem and Savage feel that maximum run-up occurs with a slope of 30°. This could also be checked for the case of a composite slope in the process of running these tests.

It would also be wise to test the effect of slight angled berms as the angle of the berm would effect the surge setting up and thus the amount of run-up. Perhaps it would be possible to determine the berm angles at which the surge is great enough to effect the theoretical run-up predictions from Saville. A knowledge of this fact would be of great interest in design as it would limit the smallest angle a berm could have and still be effective in reducing run-up.

The permeability of a beach effects the size of the surge that will set up, which in turn effects the amount of run-up. It would be interesting to compare the run-up of waves on a very permeable beach slope with the run-up on a non-permeable slope (as in the present study). Also, the roughness of the berm will effect the surge on the berm (retarding it) and thus the run-up. It would also be interesting to compare the results of a roughened berm with the results of these tests (smooth slope).

As an aid to analyzing what takes place on the model slope, photographic studies could be run. Moving pictures could possibly lead to a more specific statement of what physically occurs when the wave runs up on a composite beach slope.

CONCLUSIONS

Listed below are general conclusions based on the work in this report which is concerned with composite beach slopes with variable horizontal berms.

(1) The experimental results and Saville's predicted values for wave run-up agree at lower x/λ ratios; but, at x/λ from about 0.15 on, they disagree, the experimental run-up remaining approximately constant while the predicted values decrease. In certain specific instances the experimental values "dip" and the disagreement occurs near x/λ of 0.08.

(2) The results obtained by the observational tests seem to indicate that the actual value of the run-up depends to a large degree on whether or not a slug of water has "set up" on the berm, and to what extent this slug of water interferes with the breaking wave.

(3) From the results obtained it appears that a point of diminishing returns is reached as the berm width is increased, beyond which a further increase in the berm width will not result in an equally

favorable further decrease in the value of the relative run-up. From the curves of R/H'o versus $H'o/T^2$ it appears that this point lies somewhere between a model berm width of 10 inches and 20 inches. From the curves of R/Ro versus x/λ it appears that this point lies somewhere between a berm width of 1/4 of the wave length of the approaching waves and 3/8 of the wave length.

(4) Much work remains to be carried out in respect to the effect of horizontal berms on wave run-up. The effects of permeability and roughness of the berm and change in slopes and water elevation should be considered. Photographic studies would also materially add to the knowledge of physical occurrences in wave run-up on a composite slope.

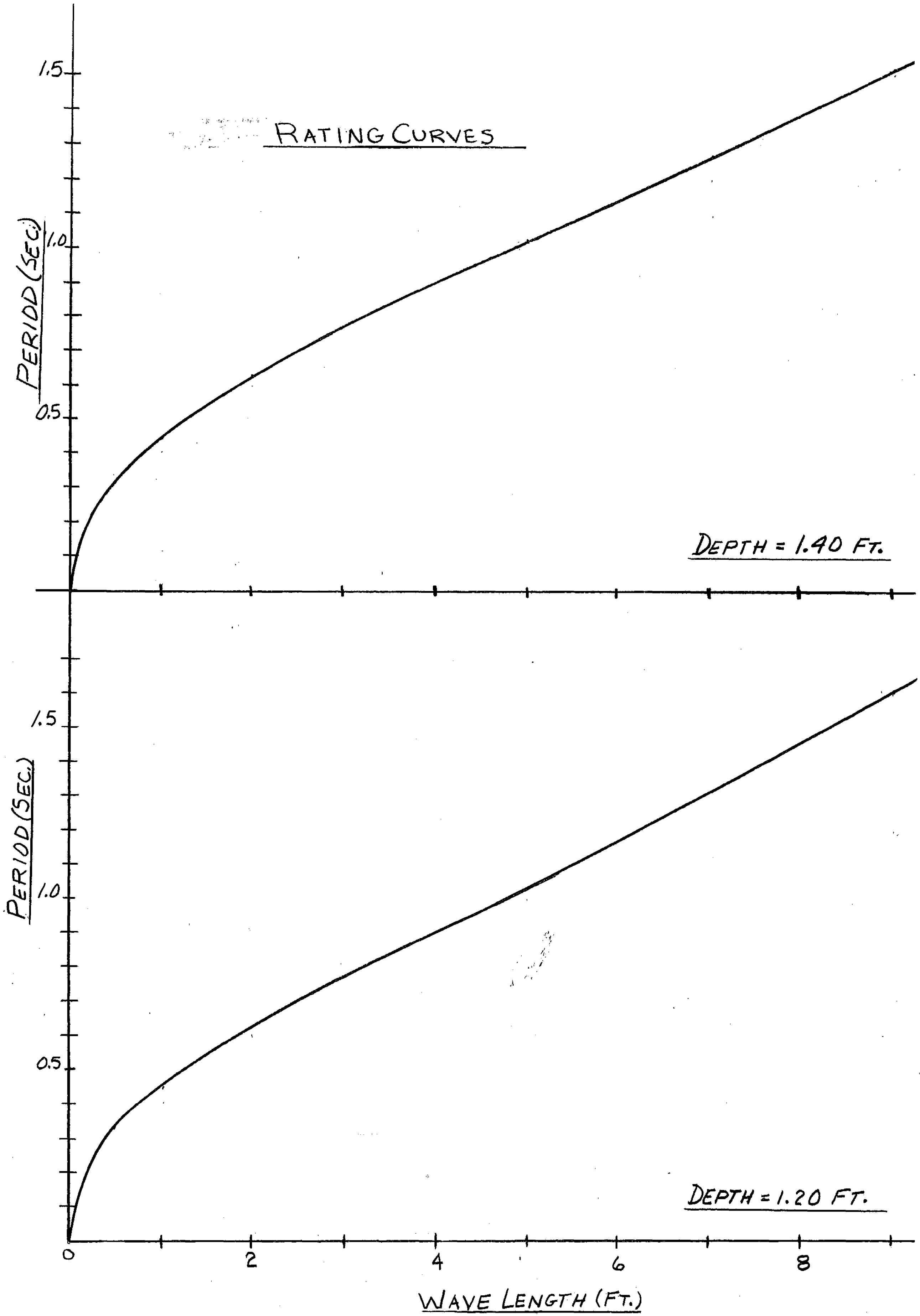
APPENDIX

<u>Wave Characteristics</u>

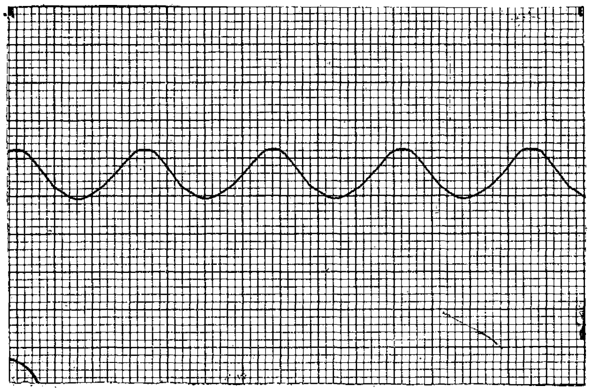
Run Number	Period		Wave Length	Stroke Setting	H'o	Depth	H'o/T^2	Breaking Depth
	Sec./cycle	setting	ft.		ft.	ft.		in.
1	0.67	12	2.31	3.0	0.090	1.40	0.200	1.23
2	0.67	12	2.31	2.8	0.152	1.40	0.339	1.74
3	0.67	12	2.31	2.6	0.215	1.40	0.479	2.19
4	1.00	8	4.82	2.8	0.146	1.40	0.146	2.22
5	1.00	8	4.82	2.4	0.236	1.40	0.236	3.06
6	1.00	8	4.82	2.0	0.340	1.40	0.340	3.90
7	1.31	6.5	7.31	2.4	0.167	1.40	0.097	2.82
8	1.31	6.5	7.31	2.0	0.250	1.40	0.146	3.78
9	1.31	6.5	7.31	1.6	0.320	1.40	0.186	4.48
10	1.67	5	9.85	2.2	0.153	1.40	0.055	3.24
11	1.67	5	9.85	1.8	0.208	1.40	0.074	3.99
12	1.67	5	9.85	1.5	0.264	1.40	0.094	4.65
13	0.81	10	3.28	2.4	0.251	1.20	0.383	2.75
14	0.81	10	3.28	2.8	0.137	1.20	0.209	1.82
15	1.07	7.5	6.24	2.0	0.274	1.20	0.239	3.53
16	1.07	7.5	6.24	2.5	0.162	1.20	0.141	2.49
17	1.35	6	7.28	1.6	0.270	1.20	0.148	4.07
18	1.35	6	7.28	2.1	0.189	1.20	0.104	3.22
19	1.67	5	9.37	1.6	0.233	1.20	0.084	4.25
20	1.67	5	9.37	1.2	0.269	1.20	0.096	4.69

CALCULATIONS FOR WAVE LENGTH VERSUS WAVE PERIOD RATING CURVES

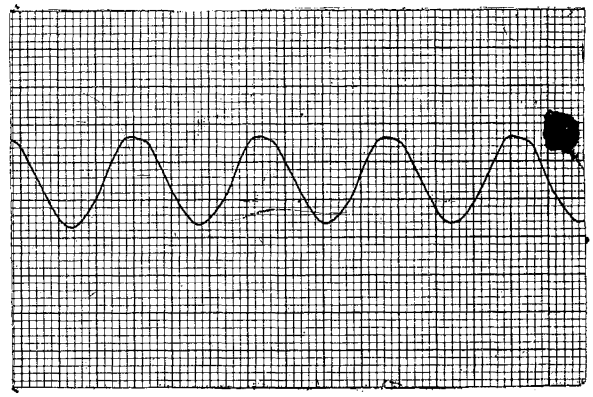
Depth	Wave Length (L)	$gL/2\pi$	$2\pi d/L$	tanh $2\pi d/L$	$gL/2\pi$ tanh $\frac{2\pi d}{L}$ (A)	$\sqrt{(A)}$	T (Period)
1.4	0.5	2.56	17.58	1.00	2.56	1.60	0.312
	1.0	5.12	8.79	1.00	5.12	2.26	0.443
	1.5	7.68	5.86	1.00	7.68	2.77	0.542
	2.0	10.24	4.40	1.00	10.24	3.20	0.625
	2.5	12.81	3.52	1.00	12.81	3.58	0.698
	3.5	17.93	2.51	.99	17.75	4.21	0.832
	5.0	25.61	1.76	.94	24.07	4.90	1.021
	6.0	30.73	1.47	.90	27.66	5.25	1.141
	7.0	35.85	1.25	.85	30.47	5.50	1.271
	8.0	40.98	1.10	.80	32.78	5.72	1.397
	9.0	46.10	0.97	.75	34.65	5.88	1.528
1.2	0.5	2.56	15.07	1.00	2.56	1.60	0.312
	1.0	5.12	7.53	1.00	5.12	2.26	0.443
	1.5	7.68	5.02	1.00	7.68	2.77	0.542
	2.0	10.24	3.77	1.00	10.24	3.20	0.625
	2.5	12.81	3.02	1.00	12.81	3.58	0.698
	3.5	17.93	2.15	0.97	17.39	4.17	0.839
	5.0	25.61	1.51	0.91	23.31	4.83	1.035
	6.0	30.73	1.26	0.85	26.12	5.11	1.174
	7.0	35.85	1.07	0.79	28.32	5.32	1.316
	8.0	40.98	0.94	0.74	30.33	5.51	1.452
	9.0	46.10	0.83	0.68	31.35	5.60	1.607


RATING CURVES
PERIOD (SEC.)
1.5
1.0
0.5
DEPTH = 1.40 FT.
PERIOD (SEC.)
1.5
1.0
0.5
DEPTH = 1.20 FT.
0
2
4
6
8
WAVE LENGTH (FT.)

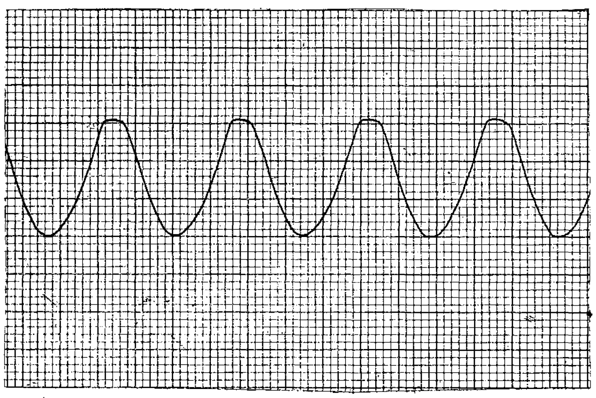
SANBORN RECORDER READINGS



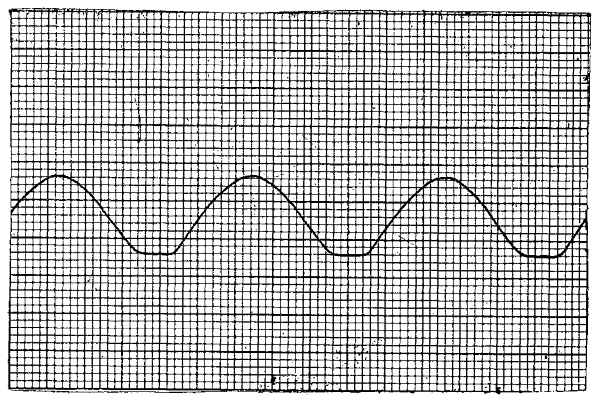
Series 1



Series 2



Series 3



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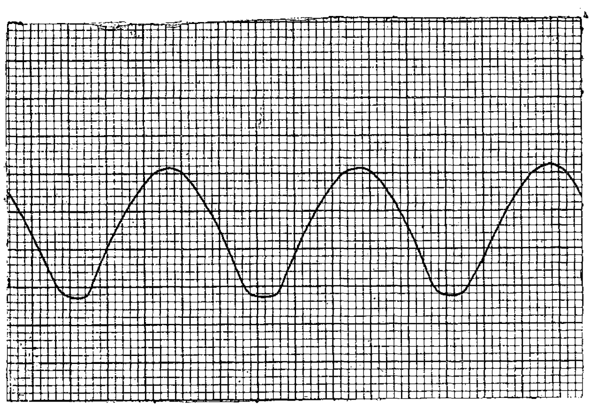

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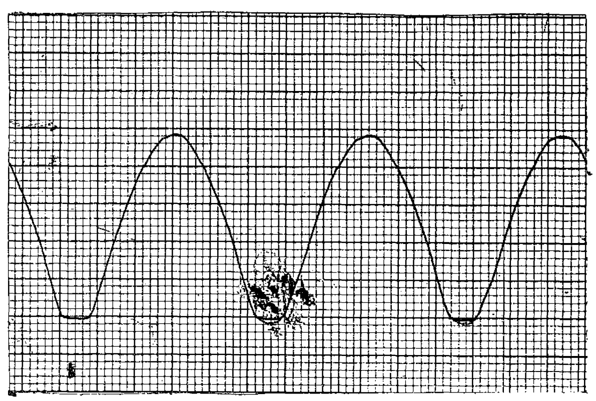
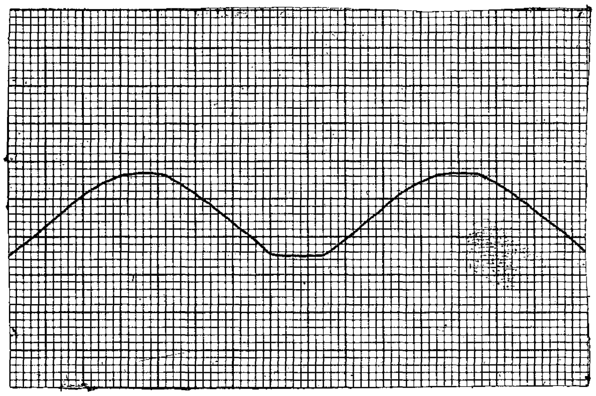
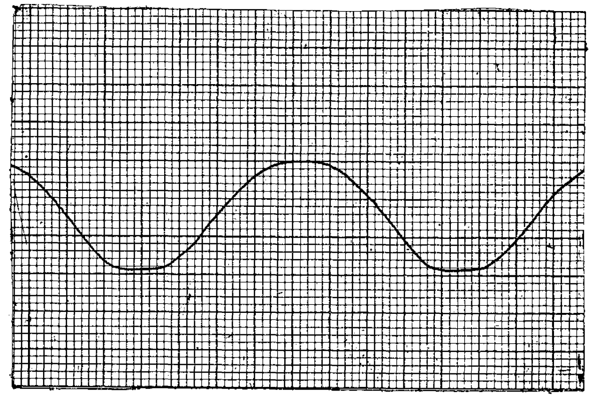


Series 6

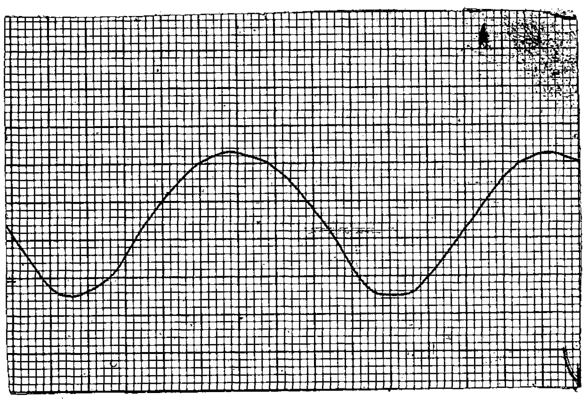
SANBORN RECORDER READINGS



Series 7



Series 8



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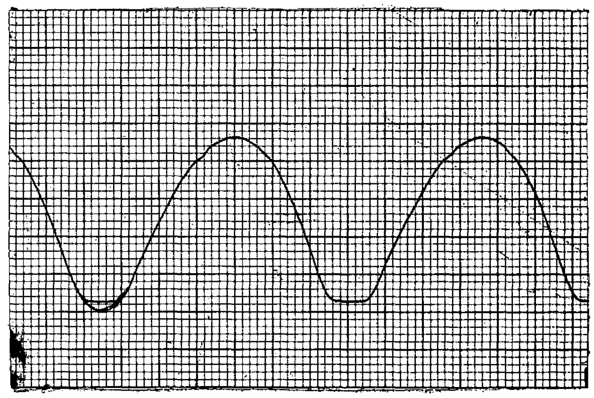
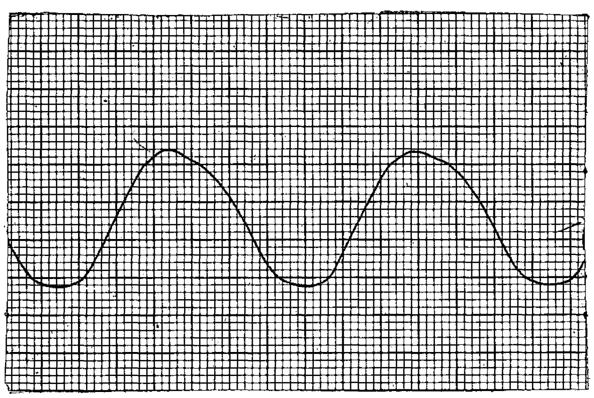


Series 10



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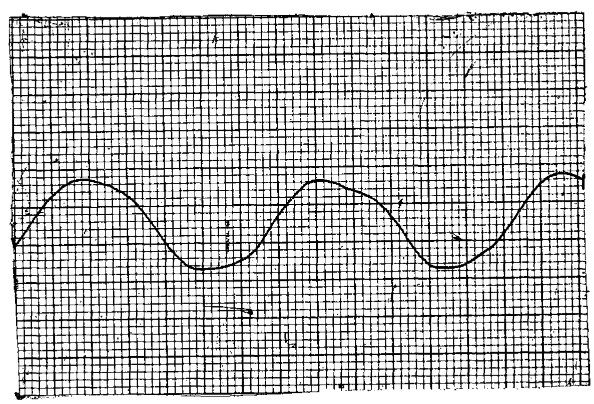
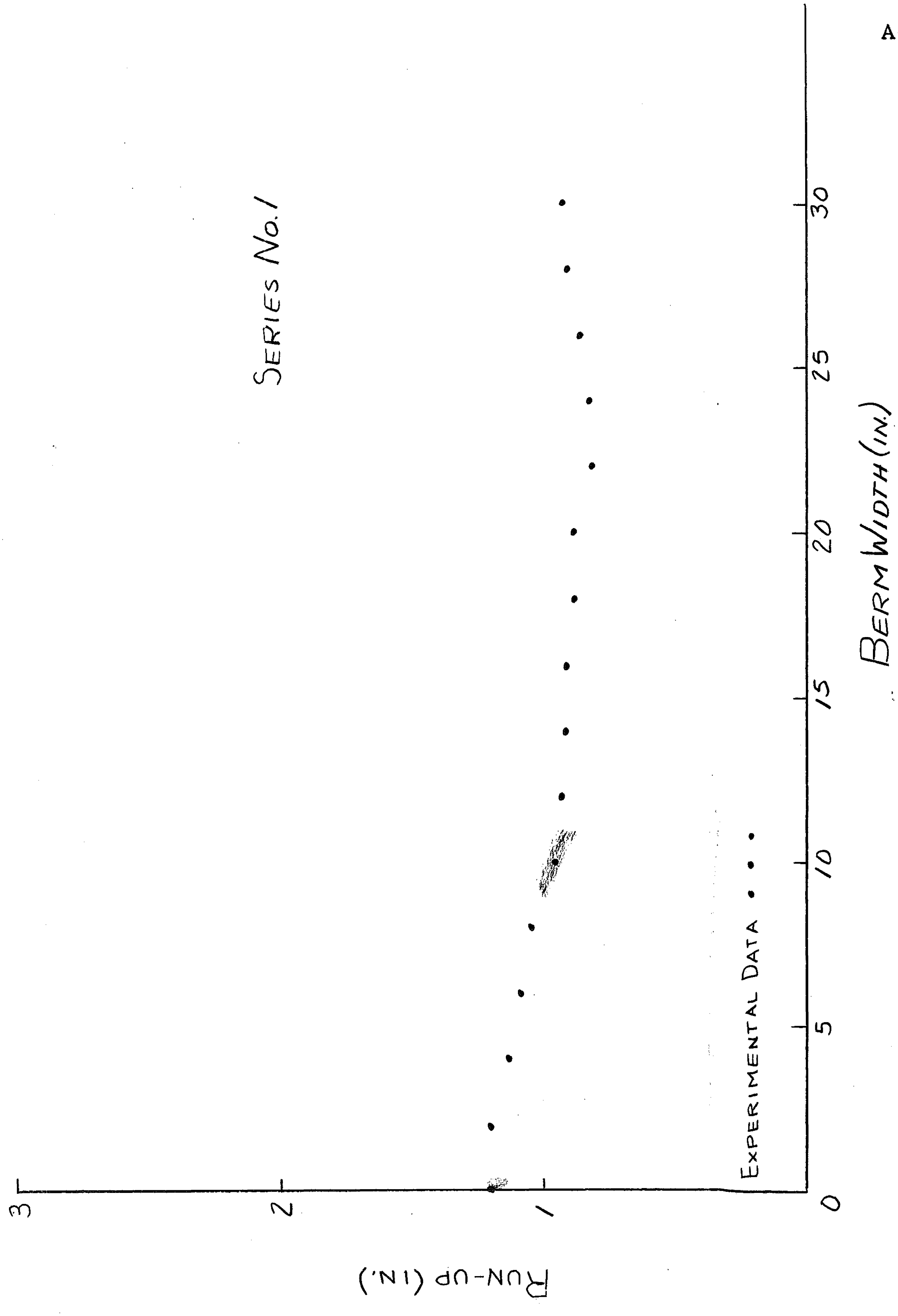


Series 12

Series Number 1

Calculation of Experimental Run-Up

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP LEFT	READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
0.67	3.0	1.40'	30"	9.875"	9.75"	9.813"	2.38"	0.94"
			28	9.75	9.625	9.688	2.35	0.91
			26	9.50	9.25	9.375	2.27	0.83
			22	9.50	9.125	9.313	2.26	0.82
			20	9.75	9.50	9.625	2.33	0.89
			18	9.75	9.50	9.625	2.33	0.89
			16	9.875	9.50	9.688	2.35	0.91
			14	9.875	9.50	9.688	2.35	0.91
			12	9.875	9.75	9.813	2.38	0.94
			10	10.375	9.50	9.938	2.41	0.97
			8	10.750	9.75	10.250	2.49	1.05
			6	10.875	10.00	10.438	2.53	1.09
			4	11.00	10.25	10.625	2.58	1.14
			2	11.375	10.50	10.938	2.65	1.21
			0	11.50	10.25	10.875	2.64	1.20

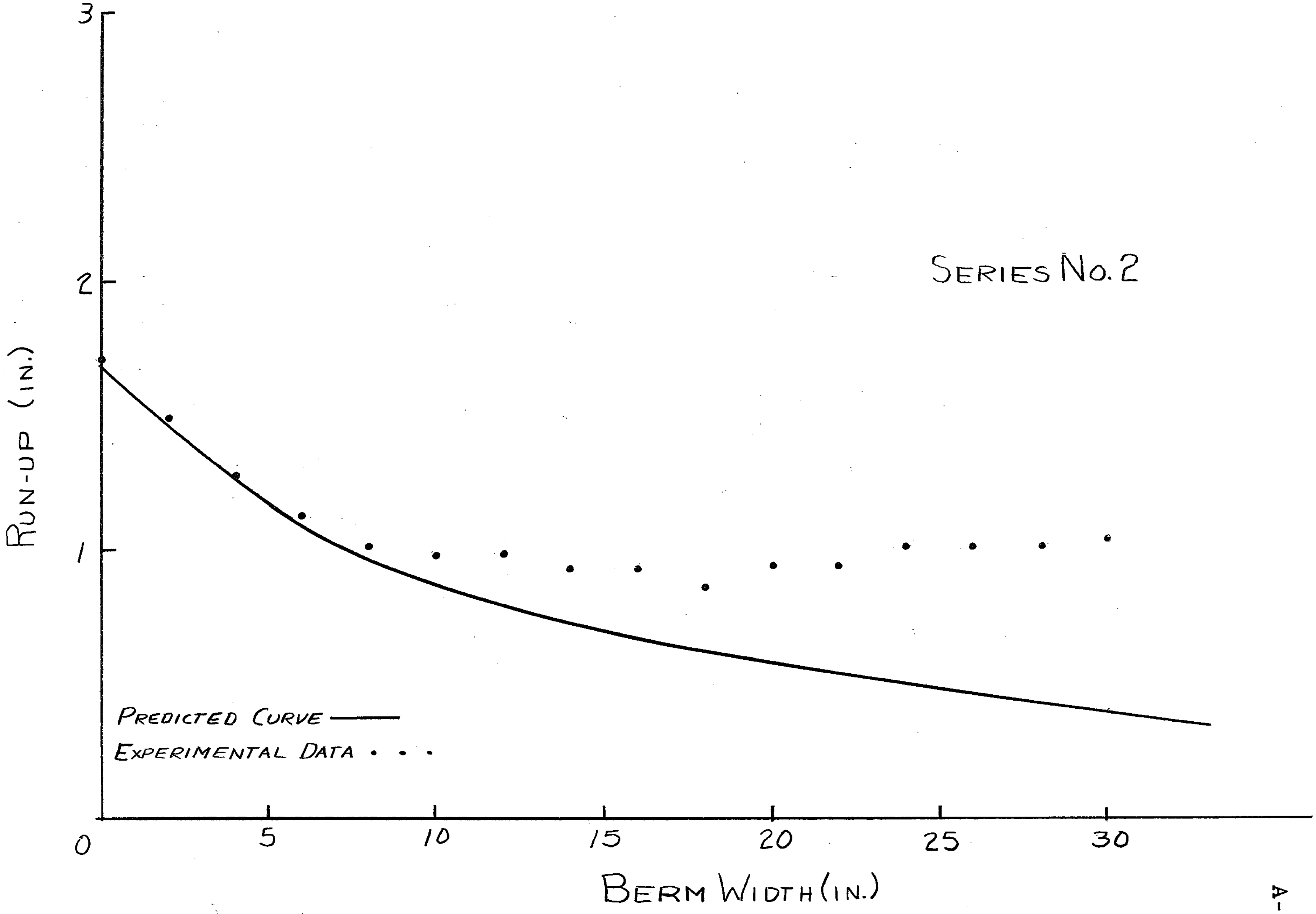

SERIES No. 1
EXPERIMENTAL DATA • • •
BERM WIDTH (IN.)
RUN-UP (IN.)
0
5
10
15
20
25
30
1
2
3

Series Number 2

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
0.67	2.8	1.4'	30"	10.75"	9.75"	10.250"	2.49"	1.05"
			28	10.5	9.75	10.125	2.46	1.02
			26	10.5	9.75	10.125	2.46	1.02
			24	10.75	9.5	10.125	2.46	1.02
			22	10.75	9	9.875	2.39	0.95
			20	10.5	9.25	9.875	2.39	0.95
			10	10	9	9.50	2.30	0.86
			16	10.5	9.125	9.813	2.38	0.94
			14	10.375	9.25	9.813	2.38	0.94
			12	10.5	9.5	10.00	2.43	0.99
			10	10.5	9.5	10.00	2.43	0.99
			8	10.5	9.75	10.125	2.46	1.02
			6	11	10.25	10.625	2.58	1.14
			4	11.5	11	11.250	2.73	1.29
			2	12.25	12	12.125	2.94	1.50
			0	13	13	13.00	3.15	1.71

Calculation of Predicted Run-Up

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0"	1.7"	4.07	.92	1.68"	1.68"
5	1.2	5.78	.65	1.19	1.19
10	0.9	7.93	.483	.88	.88
15	0.65	0.60	.40	.73	
	.75	9.84	.39	.71	.71
20	.60	12.65	.31	.57	.57
30	.45	17.75	.225	.41	.41

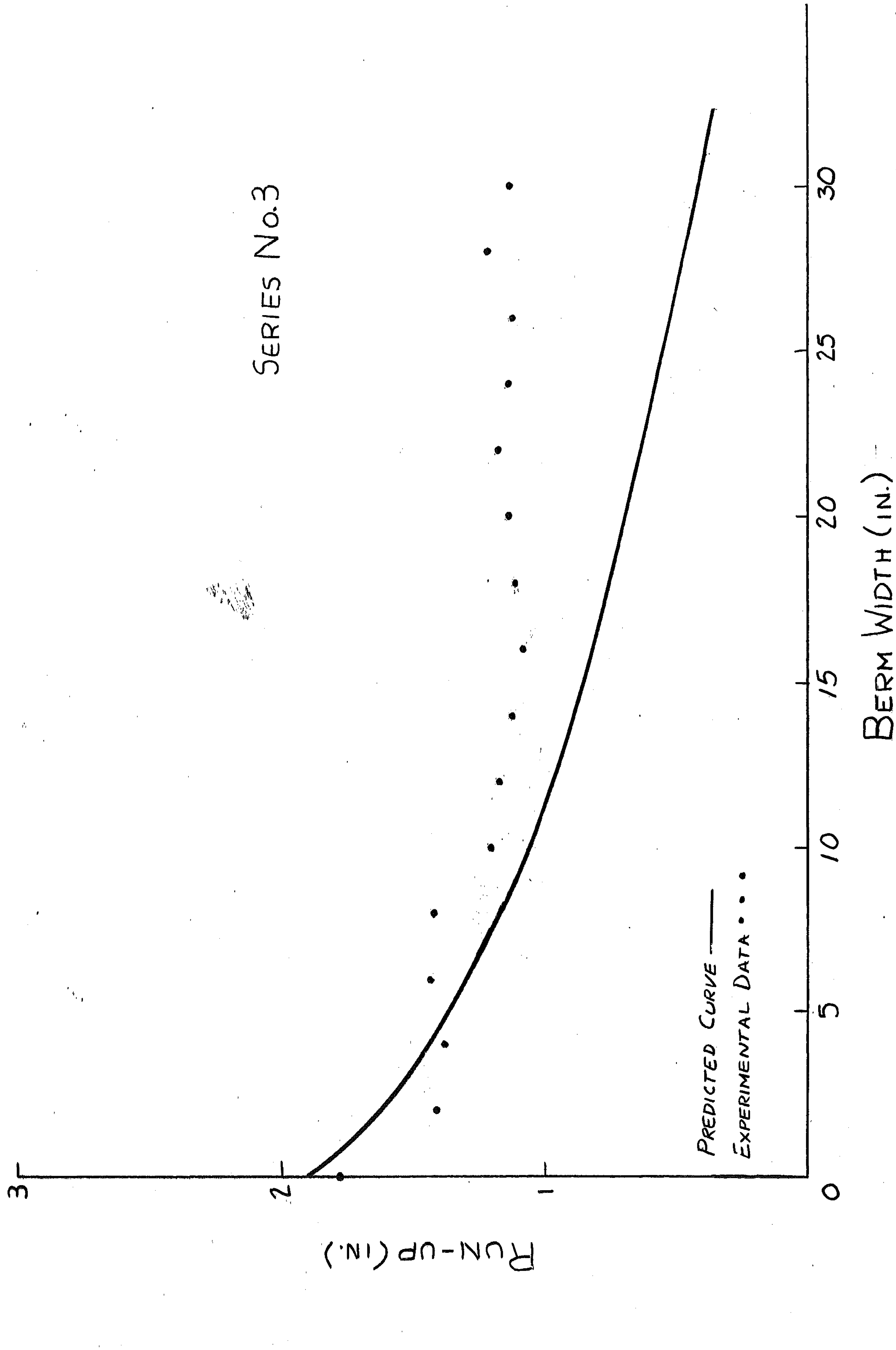


SERIES No. 2
RUN-UP (IN.)
3
2
1
0
5
10
15
20
25
30
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA

Series Number 3

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP LEFT	READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
0.67	2.6	1.4'	30"	11"	10.25"	10.625"	2.58"	1.14"
			28	11.375	10.5	10.938	2.65	1.21
			26	10.875	10.25	10.563	2.56	1.12
			24	11	10.25	10.625	2.58	1.14
			22	11	10.5	10.75	2.61	1.17
			20	11	10.25	10.625	2.58	1.14
			18	11	10	10.50	2.55	1.11
			16	10.875	10	10.438	2.53	1.09
			14	10.875	10.563	10.563	2.56	1.12
			12	11	10.5	10.750	2.61	1.17
			10	11.25	10.5	10.875	2.64	1.20
			8	12	11.5	11.750	2.85	1.41
			6	12.25	11.5	11.875	2.88	1.44
			4	12.25	11.125	11.687	2.83	1.39
			2	12.5	11	11.750	2.85	1.41
			0	13.5	13	13.250	3.21	1.77

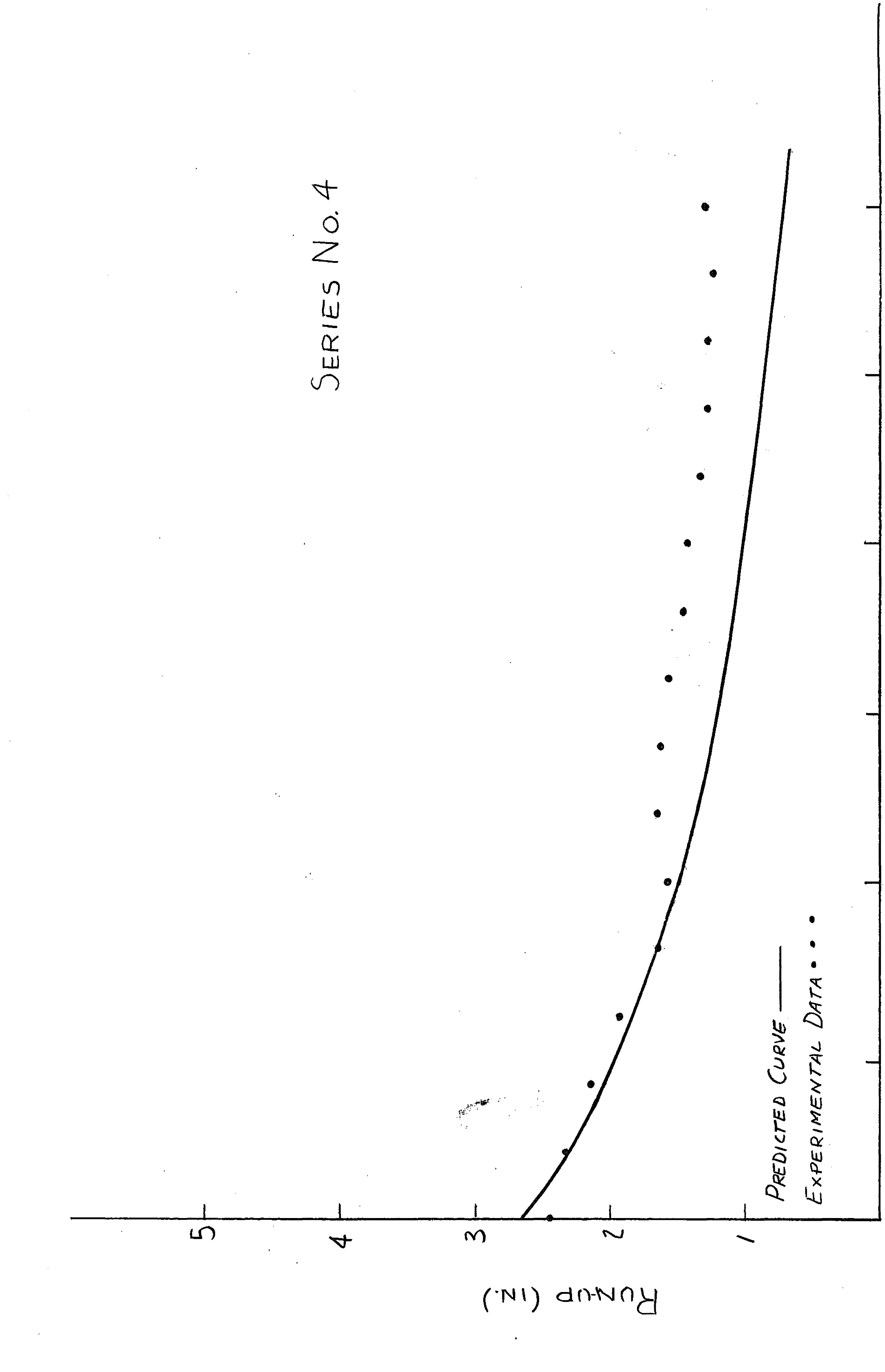
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	1.70"	4.12	.725	1.87"	
	1.90	4.17	.725	1.87	1.9"
5	1.65	5.44	.55	1.42	
	1.40	5.57	.53	1.37	1.35
10	1.00	7.32	.415	1.07	
	1.10	7.23	.42	1.09	1.1
15	.95	9.02	.34	.88	
	.85	9.18	.335	.865	.87
20	.70	12.45	.25	.645	.64
30	.35	15.96	.2	.40	.41


SERIES No.3
RUN-UP (IN.)
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
0
1
2
3
5
10
15
20
25
30

Series Number 4

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.00	2.8	1.4'	30"	11"	11.5"	11.25"	2.73"	1.29"
			28	10.5	11.5	11.00	2.67	1.23
			26	10.75	11.75	11.25	2.73	1.29
			24	11	11.5	11.25	2.73	1.29
			22	11	11.75	11.375	2.76	1.32
			20	11.75	11.75	11.75	2.85	1.41
			18	12	12	12.00	2.91	1.47
			16	12.5	12	12.25	2.97	1.53
			14	13	12.25	12.625	3.06	1.62
			12	13	12.5	12.750	3.09	1.65
			10	12.75	12.25	12.50	3.03	1.59
			8	13	12.5	12.75	3.09	1.65
			6	14	13.75	13.875	3.36	1.92
			4	14.5	15.25	14.875	3.61	2.17
			2	14.5	16.5	15.50	3.76	2.32
			0	15.5	16.5	16.00	3.88	2.44

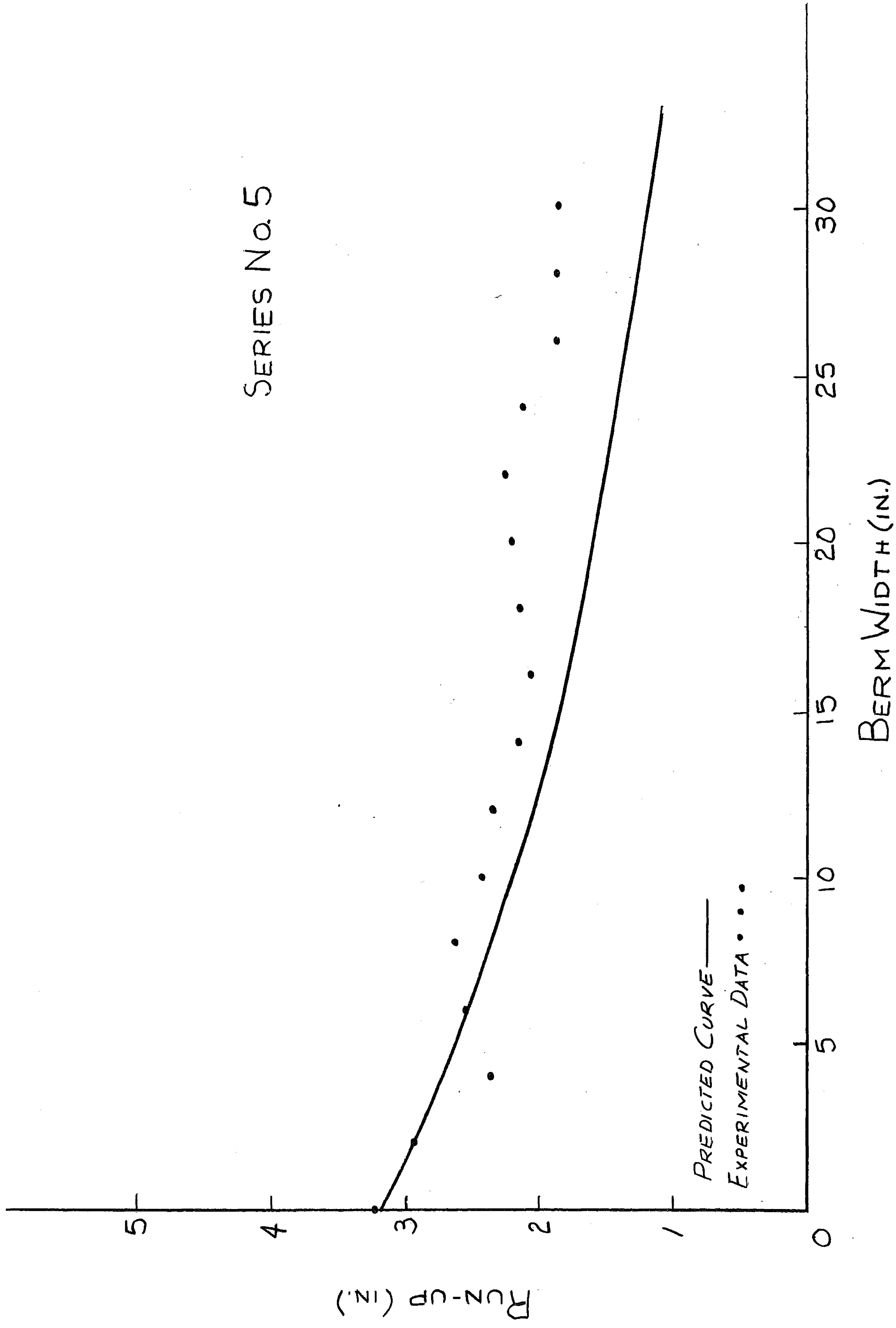
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	2.50"	4.13"	1.5	2.62	2.63"
5	2.00	5.38	1.14	2.0	2.0
10	1.60	6.81	.9	1.58	1.58
15	1.20	8.62	.69	1.21	1.21
20	1.10	10.15	.58	1.02	1.01
30	.85	13.92	.425	.75	
	.73	14.35	.41	.72	.72


Series No. 4
Run-up (in.)
Berm Width (in.)
Predicted Curve
Experimental Data
0
1
2
3
4
5
5
10
15
20
25
30

Series Number 5

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.00	2.4	1.4'	30"	13.5"	13.75"	13.625"	3.30"	1.86"
			28	13	14.5	13.75	3.33	1.89
			26	13.5	14	13.750	3.33	1.89
			24	14	15.25	14.625	3.55	2.11
			22	15	15.25	15.125	3.67	2.23
			20	14.5	15.5	15.00	3.64	2.20
			18	13.75	15.75	14.75	3.58	2.14
			16	13.5	15.5	14.50	3.52	2.08
			14	14.5	15.25	14.875	3.61	2.17
			12	15	16.25	15.625	3.79	2.35
			10	15.25	16.75	16.00	3.88	2.44
			8	15.75	17.75	16.75	4.06	2.62
			6	15.5	17.25	16.375	3.97	2.53
			4	14.5	17	15.750	3.82	2.38
			2	17	19	18.00	4.37	2.93
			0	17.5	21	19.250	4.67	3.23

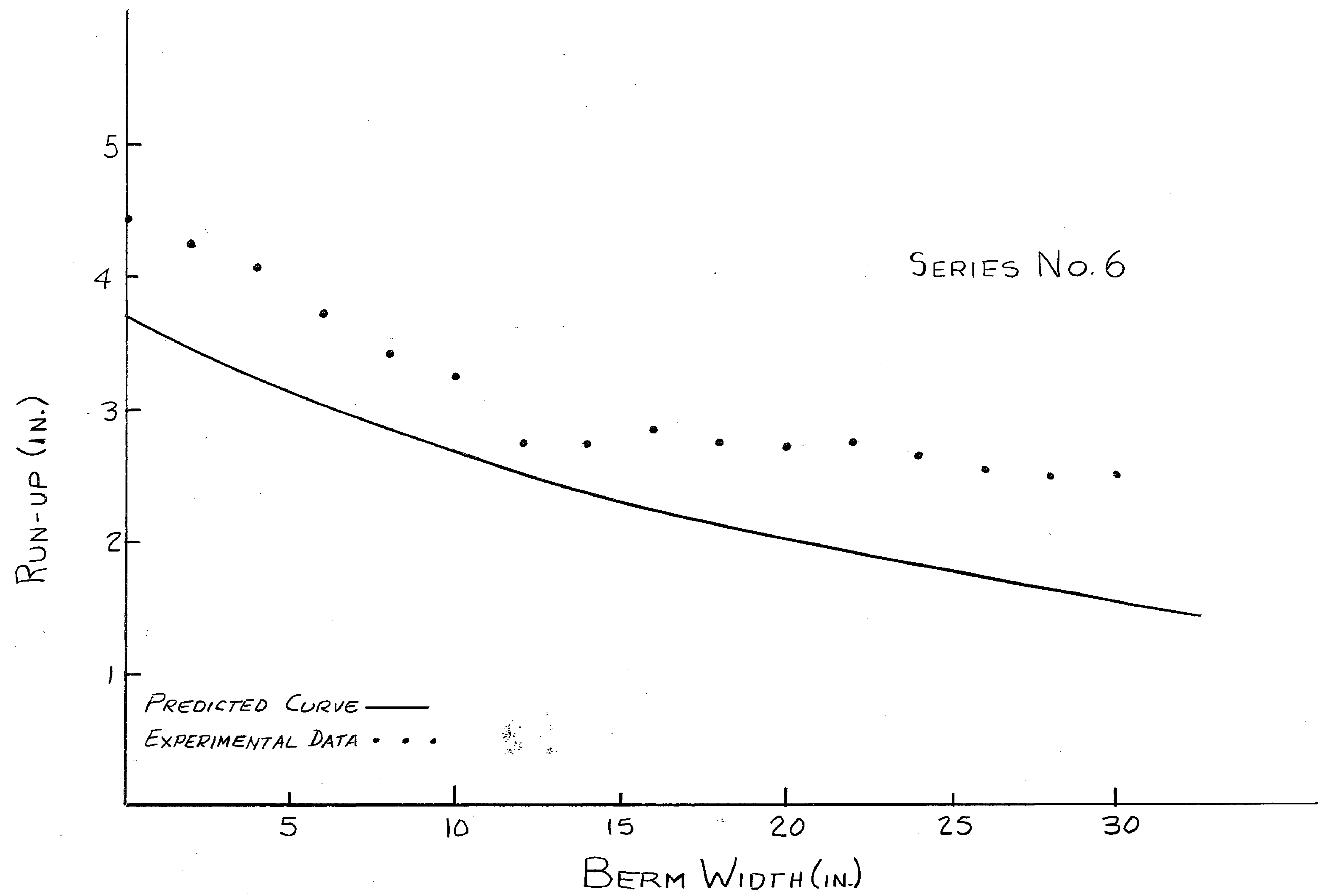
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	3.20"	4.12	1.14	3.24"	3.24"
5	2.60	5.08	.92	2.61	2.61
10	2.20	6.06	.78	2.21	2.21
15	1.90	7.26	.66	1.84	1.84
20	1.70	8.63	.55	1.56	
	1.550	8.56	.558	1.58	1.58
30	1.20	11.25	.42	1.19	1.19


SERIES NO. 5
RUN-UP (IN.)
BERM WIDTH (IN.)
0
5
10
15
20
25
30
1
2
3
4
5
PREDICTED CURVE
EXPERIMENTAL DATA

Series Number 6.

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.00	2.0	1.4'	30"	16.5"	16"	16.25"	3.94"	2.50"
			28	16	16.5	16.25	3.94	2.50
			26	16	17.0	16.50	4.00	2.56
			24	16.5	17.5	17.00	4.12	2.68
			22	17	17.75	17.375	4.21	2.77
			20	17	17.25	17.125	4.15	2.71
			18	17	17.50	17.250	4.18	2.74
			16	17.5	17.75	17.625	4.27	2.83
			14	17.0	17.50	17.25	4.18	2.74
			12	17.0	17.50	17.25	4.18	2.74
			10	18.5	20.00	19.25	4.67	3.23
			8	19.0	21.0	20.00	4.85	3.41
			6	20.5	22.0	21.25	5.15	3.71
			4	22.0	23.5	22.75	5.52	4.08
			2	23.0	24.0	23.50	5.70	4.26
			0	25.0	23.5	24.25	5.88	4.44

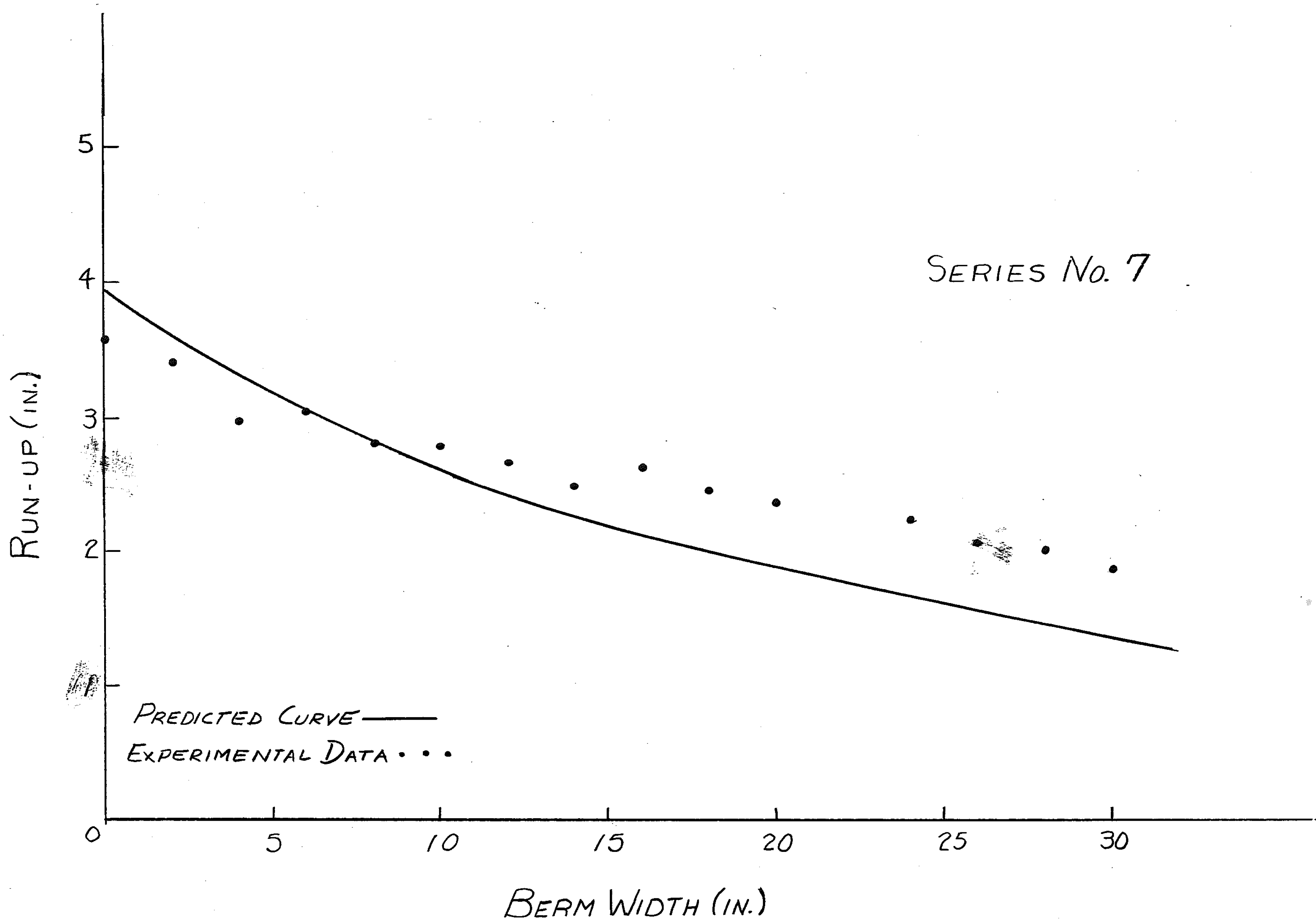
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	4.50"	4.16	.9	3.68	
	3.60	4.17	.9	3.68	3.68
5	3.20	4.88	.77	3.14	3.15
10	2.80	5.71	.66	2.00	
	2.68	5.72	.66	2.69	2.69
15	2.30	6.65	.57	2.32	2.32
20	2.10	7.51	.51	2.08	2.08
30	1.85	10.62	.37	1.51	
	1.50	10.3	.375	1.53	1.53


SERIES NO. 6
RUN-UP (IN.)
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
5
4
3
2
1
5
10
15
20
25
30

Series Number 7

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.31	2.4	1.4	30	14.25	13.25	13.75	3.33	1.89
			28	15	13.5	14.25	3.46	2.02
			26	15.5	13.5	14.5	3.52	2.08
			24	16	14.5	15.25	3.70	2.26
			22	16	15.5	15.75	3.82	2.38
			20	17	15.25	16.125	3.91	2.47
			18	17.5	16	16.75	4.06	2.62
			16	17.5	15	16.25	3.94	2.50
			14	18.5	15.25	16.875	4.09	2.65
			12	19	16	17.5	4.24	2.80
			10	17.5	17.5	17.5	4.24	2.80
			8	18.5	18.5	18.5	4.48	3.04
			6	18	18.5	18.25	4.42	2.98
			4	17.5	18	17.75	4.30	2.86
			2	19	21	20	4.85	3.41
			0	20	21.5	20.75	5.03	3.59

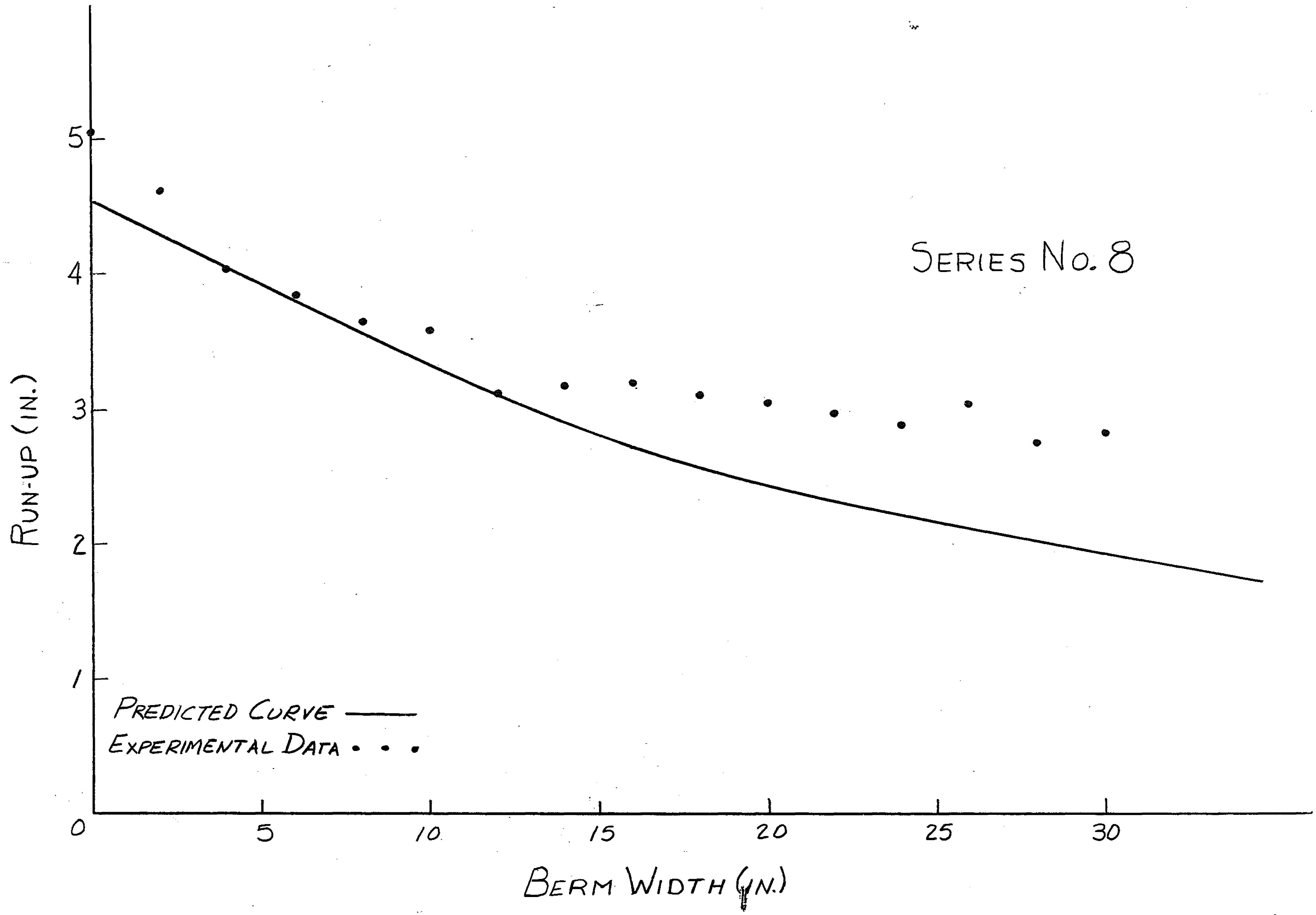
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	3.80	4.11	1.96	3.93	
	3.95	4.12	1.96+	3.95	3.95
5	3.40	4.94	1.6	3.21	
	3.15	4.92	1.6-	3.19	3.20
10	2.70	5.95	1.31	2.65	2.65
20	2.00	8.30	.93	1.88	
	1.85	8.42	.91	1.84	1.85
30	1.40	11.28	.67	1.35	1.35



Series No. 7
Run-up (in.)
5
4
3
2
1
0
5
10
15
20
25
30
Berm Width (in.)
Predicted Curve
Experimental Data

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.31	2.0	1.4	30	19.5	15.5	17.5	4.24	2.80
			28	18.5	16	17.25	4.18	2.74
			26	19.5	17.5	18.5	4.48	3.04
			24	19	17.75	17.875	4.33	2.89
			22	18.5	17.75	18.125	4.39	2.95
			20	19	18	18.5	4.48	3.04
			18	19.5	18.75	19.125	4.64	3.20
			16	19.5	18.5	19	4.61	3.17
			14	18.5	19	18.75	4.55	3.11
			12	21	20.5	20.75	5.03	3.59
			10	21.5	20.5	21	5.09	3.65
			8	22	21.5	21.75	5.27	3.83
			6	22	22	22	5.33	3.89
			4	22.5	22.5	22.5	5.46	4.02
			2	24	26	25	6.06	4.62
			0	26	27.5	26.75	6.48	5.04

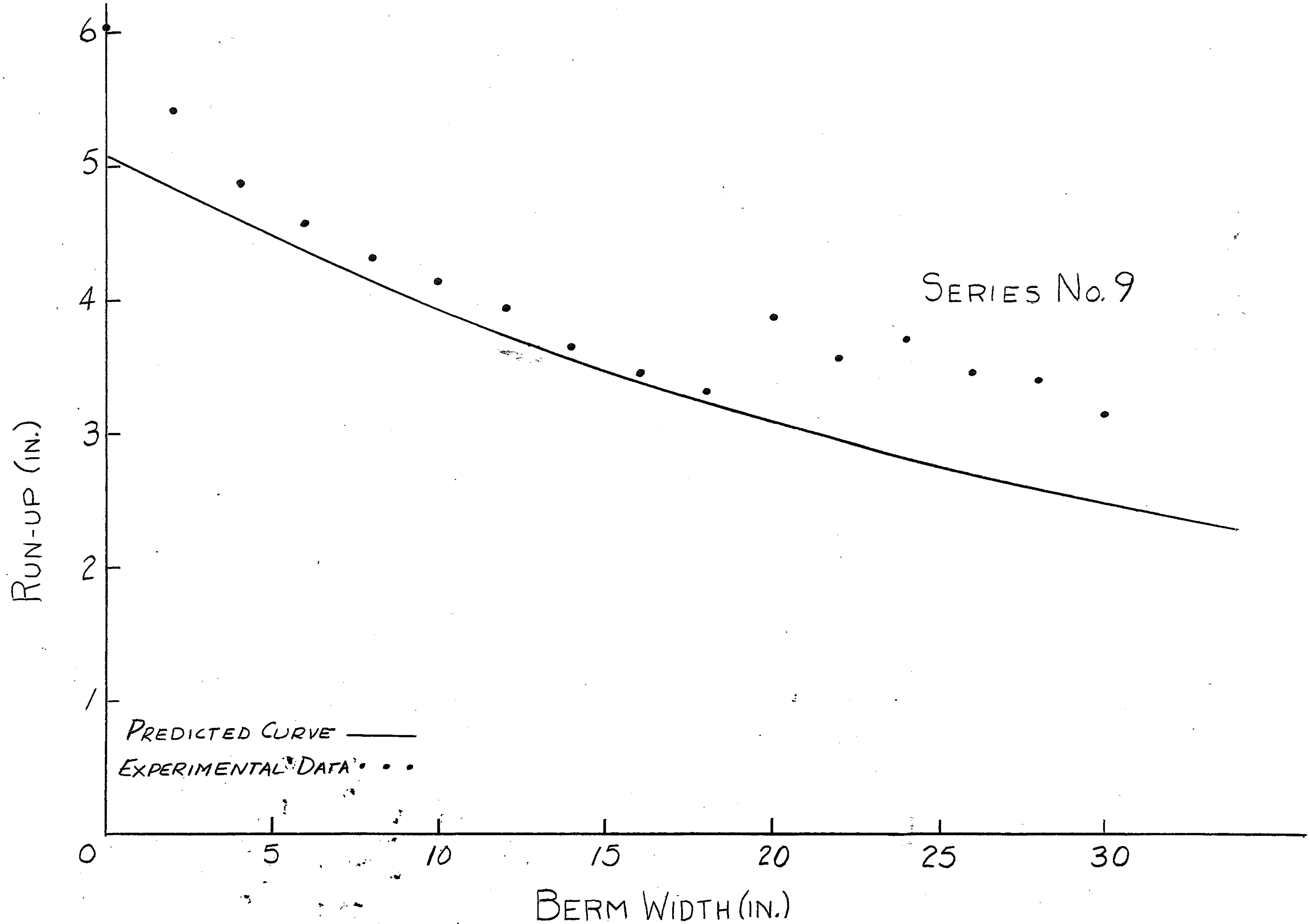
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	5.00	4.13	1.5	4.5	
	4.40	4.13	1.5	4.5	4.5
5	3.80	4.81	1.3	3.90	3.9
10	3.40	5.56	1.12	3.36	3.35
20	2.40	7.37	0.82	2.46	2.45
30	2.10	9.25	0.65	1.95	
	1.90	9.44	0.63	1.89	1.9


SERIES NO. 8
RUN-UP (IN.)
5
4
3
2
1
0
5
10
15
20
25
30
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA

Series Number 9

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.31	1.6	1.4	30	20	18	19	4.61	3.17
			28	21	19	20	4.85	3.41
			26	21	19.5	20.25	4.91	3.47
			24	23	19.5	21.25	5.15	3.71
			22	22	19.5	20.75	5.03	3.59
			20	23	21.0	22	5.33	3.89
			18	18	21.5	19.75	4.78	3.34
			16	19.5	21.0	20.25	4.91	3.47
			14	21	21	21	5.09	3.65
			12	21	23.5	22.25	5.40	3.96
			10	22	24.0	23	5.58	4.14
			8	22.5	24.0	23.75	5.76	4.32
			6	24	25.5	24.75	6.00	4.56
			4	25	27.0	26	6.31	4.87
			2	27	29.5	28.25	6.85	5.41
			0	30	31.5	30.75	7.47	6.03

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	6.00	4.16	1.32	5.08	
	5.00	4.14	1.31	5.03	5.05
5	4.50	4.72	1.18	4.53	4.5
10	3.60	5.39	1.02	3.92	
	3.95	5.36	1.03	3.95	3.95
15	3.40	6.08	.90	3.45	3.45
20	3.00	6.87	.80	3.07	3.1
30	2.70	8.34	.66	2.54	
	2.50	8.46	.65	2.49	2.50

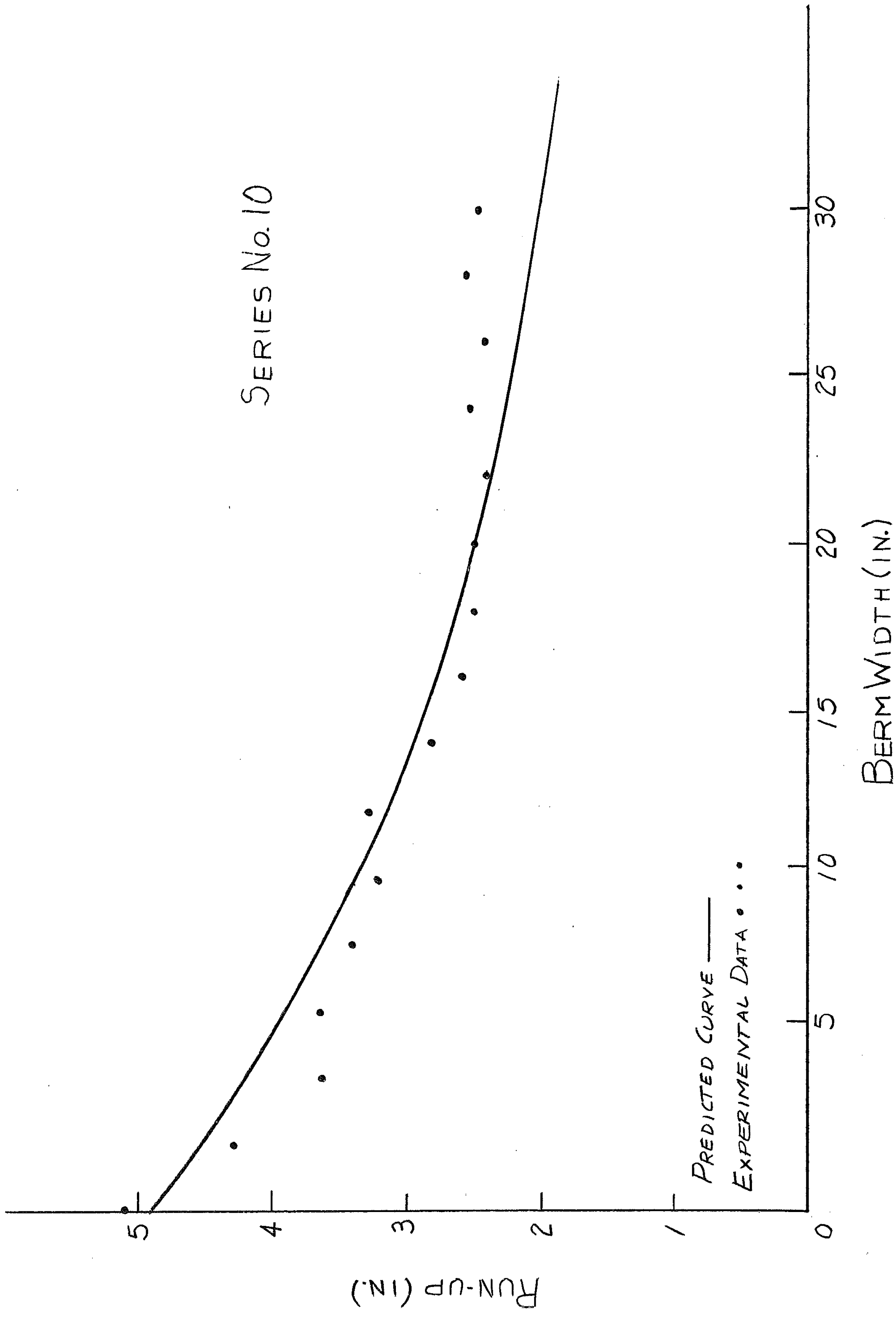


Series No. 9
Run-up (in.)
6
5
4
3
2
1
0
5
10
15
20
25
30
Berm Width (in.)
Predicted Curve
Experimental Data

Series Number 10

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP LEFT	READING RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.67	2.2	1.4	30	17	15.25	16.125	3.91	2.47
			28	16.50	16.50	16.5	4.01	2.57
			26	15.50	16.25	15.875	3.85	2.51
			24	16.0	16.75	16.375	3.97	2.53
			22	15.0	16.75	15.875	3.85	2.41
			20	15.25	17.25	16.25	3.94	2.50
			18	15.50	17.0	16.25	3.94	2.50
			16	16	17.25	16.625	4.03	2.59
			14	17.0	18.25	17.625	4.28	2.84
			12	19	20.0	19.5	4.73	3.29
			10	19.75	18.75	19.25	4.67	3.23
			8	20.50	19.50	20	4.85	3.41
			6	21.50	20.50	21	5.09	3.65
			4	21.0	21.0	21	5.09	3.65
			2	23	24.25	23.625	5.73	4.29
			0	27.0	27.0	27	6.55	5.11

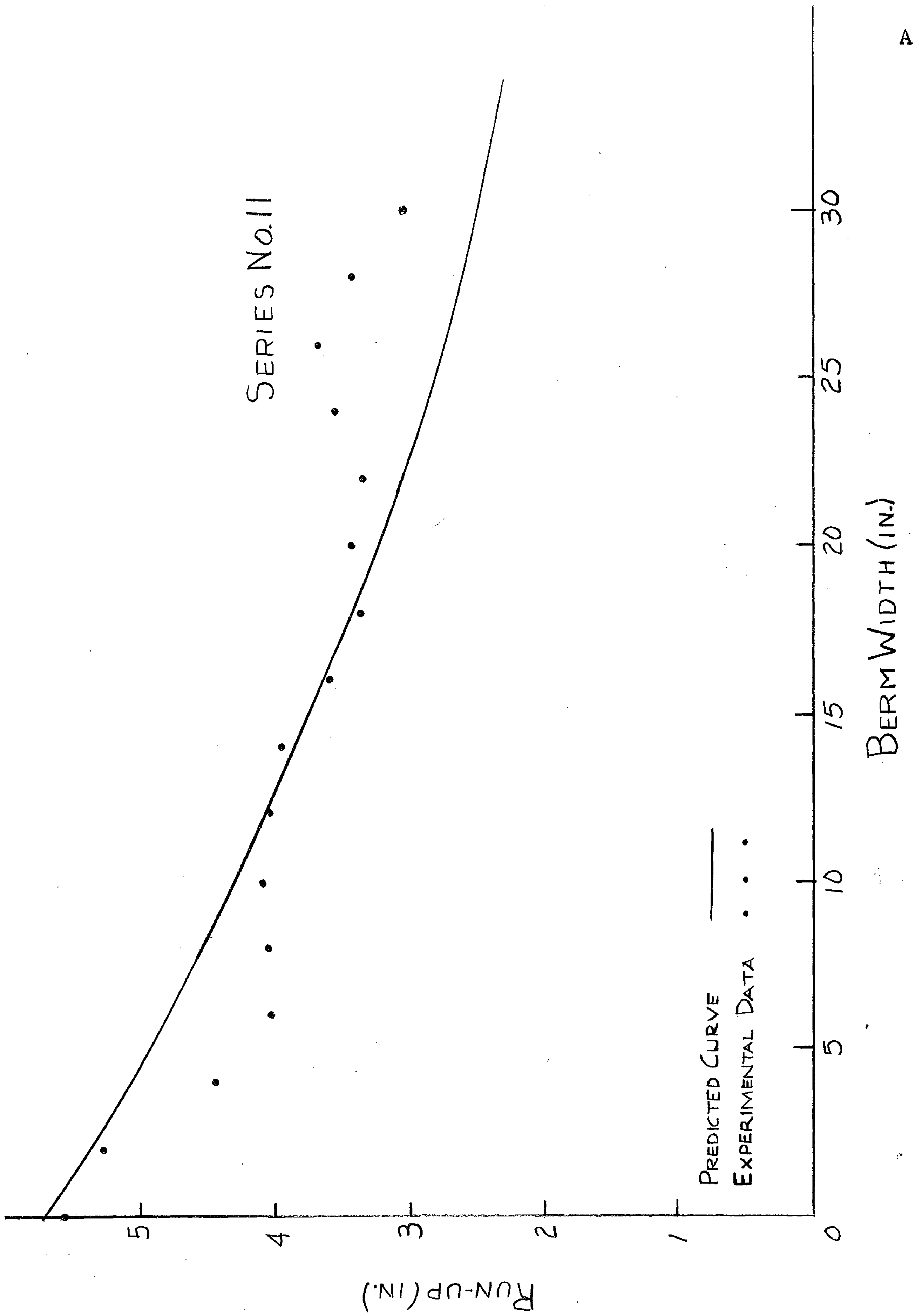
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	4.70	4.14	2.68	4.9	
	4.95	4.17	2.65	4.88	4.9
5	3.80	4.87	2.2	4.05	
	4.10	4.86	2.2+	4.05+	4.05
10	3.20	5.64	1.88	3.46	
	3.50	5.64	1.88	3.46	3.45
15	2.90	6.62	1.57	2.89	2.9
20	2.50	7.65	1.36	2.5	2.5
30	2.00	9.08	1.1	2.02	2.0


SERIES No. 10
RUN-UP (IN.)
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
0
1
2
3
4
5
10
15
20
25
30

Series Number 11

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.67	1.8	1.4	30	18.5	18.25	18.375	4.46	3.02
			28	20	20	20	4.85	3.41
			26	20.5	21.5	21	5.09	3.65
			24	20	21	20.5	4.97	3.53
			22	19	21.5	19.75	4.79	3.35
			20	19	21	20	4.85	3.41
			18	19.5	21	19.75	4.79	3.35
			16	21	20.5	20.75	5.03	3.59
			14	22	22.5	22.25	5.40	3.96
			12	23	22	22.5	5.46	4.02
			10	23	22.5	22.75	5.52	4.08
			8	23.5	21.75	22.625	5.49	4.05
			6	22	23	22.5	5.46	4.02
			4	24	24.5	24.25	5.88	4.44
			2	28	27.5	27.75	6.73	5.29
			0	29	29	29	7.03	5.59

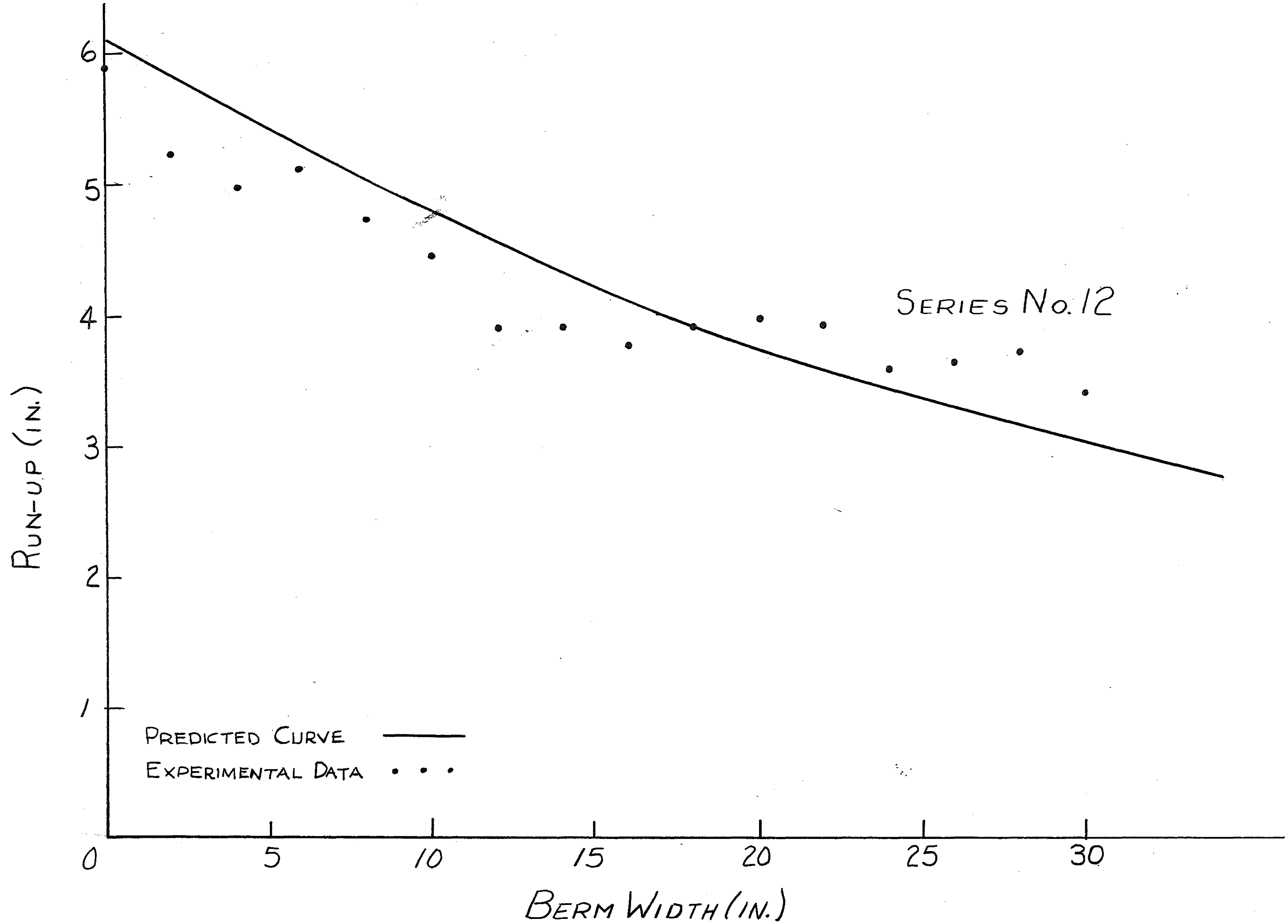
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	5.50	4.18	2.3	5.75	
	5.80	4.18	2.3	5.75	5.75
5	4.80	4.76	2.0	5.0	
	5.05	4.77	2.0	5.0	5.0
10	4.40	5.38	1.73	4.32	4.3
15	3.70	6.16	1.5	3.75	3.75
20	3.30	6.92	1.32	3.3	3.3
30	2.80	8.59	1.04	2.55	
	2.50	8.79	1.01	2.51	2.5


Series No. 11
Berm Width (in.)
Run-up (in.)
Predicted Curve
Experimental Data
0
5
10
15
20
25
30
1
2
3
4
5

Series Number 12

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.67	1.5	1.4	30	20	19.75	19.875	4.82	3.38
			28	22	20.5	21.25	5.15	3.71
			26	21	21	21	5.09	3.65
			24	20	21.5	20.75	5.03	3.59
			22	22	22	22	5.34	3.90
			20	21.5	23	22.25	5.40	3.96
			18	21.5	23	22.25	5.34	3.90
			16	21	22	21.5	5.21	3.77
			14	22	22	22	5.34	3.90
			12	23	23	22	5.34	3.90
			10	24.5	24	24.25	5.88	4.44
			8	25.5	25.5	25.5	6.18	4.74
			6	27.5	26.5	27	6.55	5.11
			4	26.5	26.5	26.5	6.43	4.99
			2	27	28	27.5	6.67	5.23
			0	31	29.5	30.25	7.34	5.90

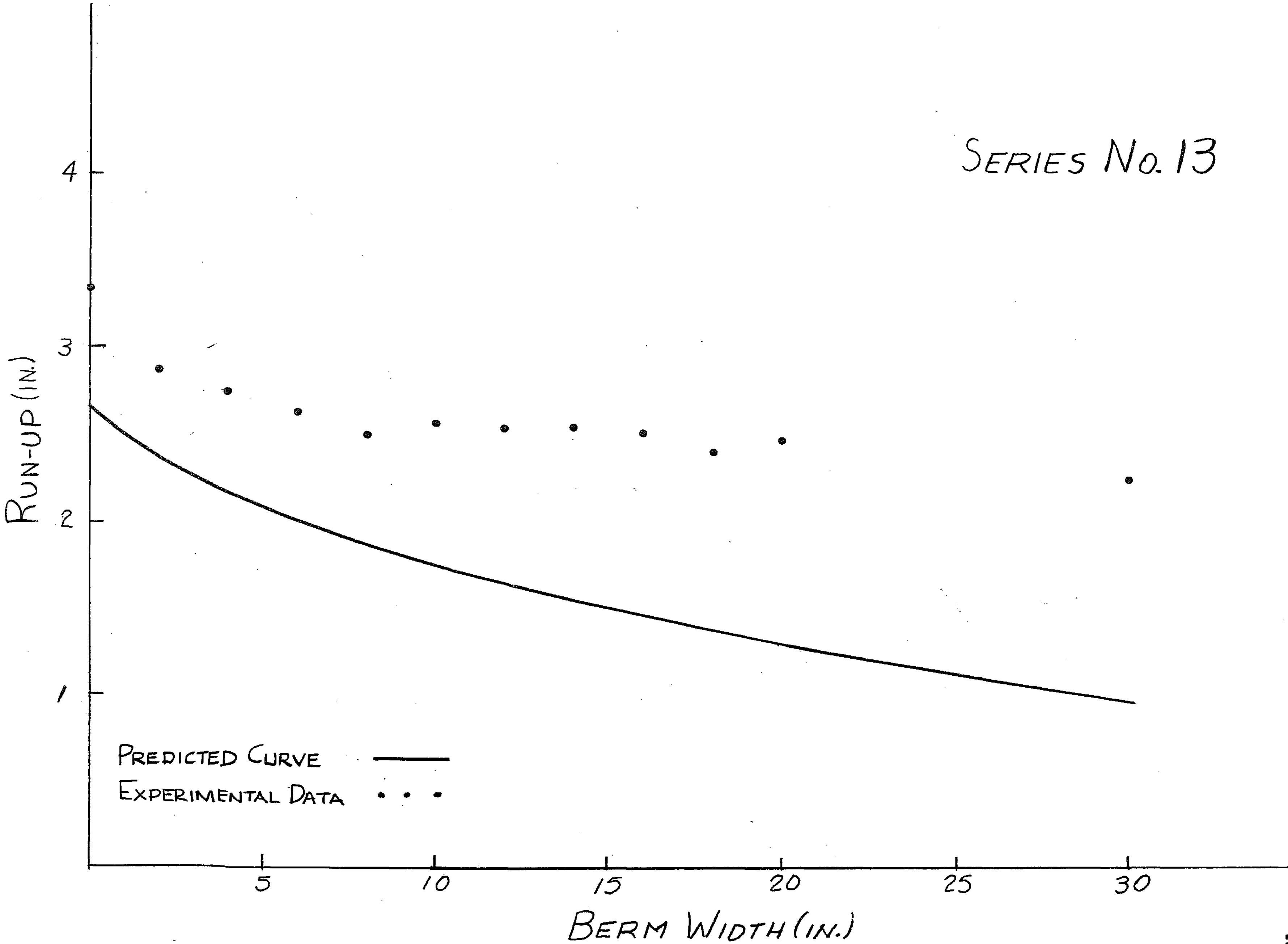
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	5.70	4.23	1.9	6.02	
	6.05	4.18	1.93	6.11	6.1
5	5.30	4.68	1.7	5.38	5.4
10	4.70	5.28	1.5	4.75	4.75
15	4.2	5.89	1.33	4.24	4.2
20	3.80	6.56	1.19	3.77	3.75
30	3.50	7.85	.99	3.14	
	3.10	8.02	.96	3.04	3.05


Series No. 12
Run-up (in.)
Berm Width (in.)
Predicted Curve
Experimental Data
0
1
2
3
4
5
6
10
15
20
25
30

Series Number 13

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
0.81	2.4	1.2	0	10	9.5	9.75	2.37	3.33
			2	8	7.75	7.875	1.91	2.87
			4	7.5	7.25	7.375	1.79	2.75
			6	7	6.75	6.875	1.67	2.63
			8	6.5	6.25	6.375	1.55	2.51
			10	7	6.25	6.625	1.61	2.57
			12	7	6.0	6.5	1.58	2.54
			14	6.5	6.5	6.5	1.58	2.54
			16	6.0	6.5	6.25	1.52	2.48
			18	5.5	6.25	5.875	1.43	2.39
			20	6.0	6.25	6.125	1.48	2.44
			30	5.0	5.5	5.25	1.27	2.23

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	3.2	4.2	.88	2.65	
	2.6	4.21	.88	2.65	2.65
5	2.4	5.22	.73	2.2	
	2.15	5.48	.70	2.1	2.1
10	1.8	6.48	.59	1.78	1.8
15	1.6	7.77	.50	1.5	1.5
20	1.3	9.28	.415	1.25	1.25
30	1.1	12.05	.32	.97	.95

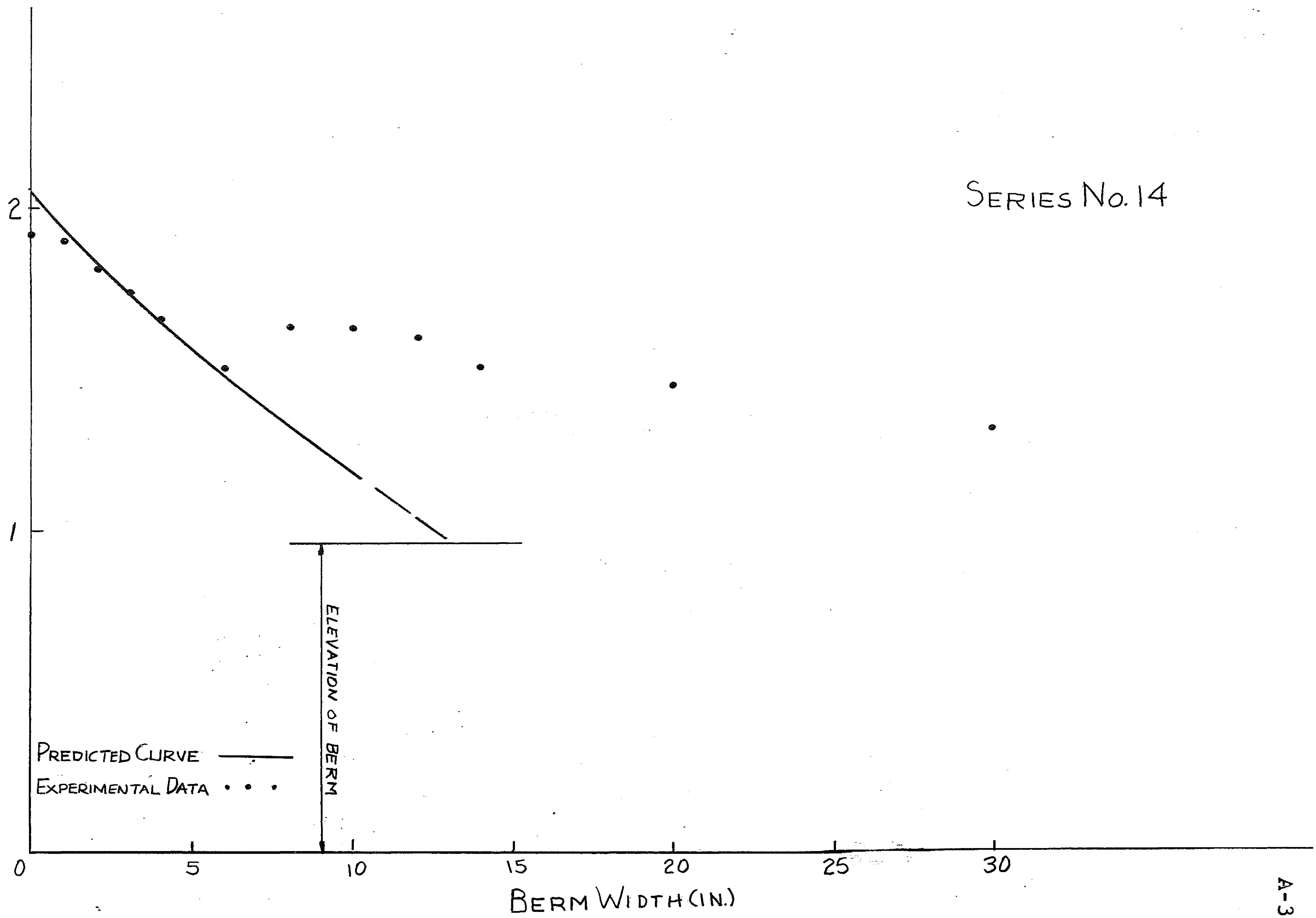


SERIES No. 13
RUN-UP (IN.)
4
3
2
1
BERM WIDTH (IN.)
5
10
15
20
25
30
PREDICTED CURVE
EXPERIMENTAL DATA

Series Number 14

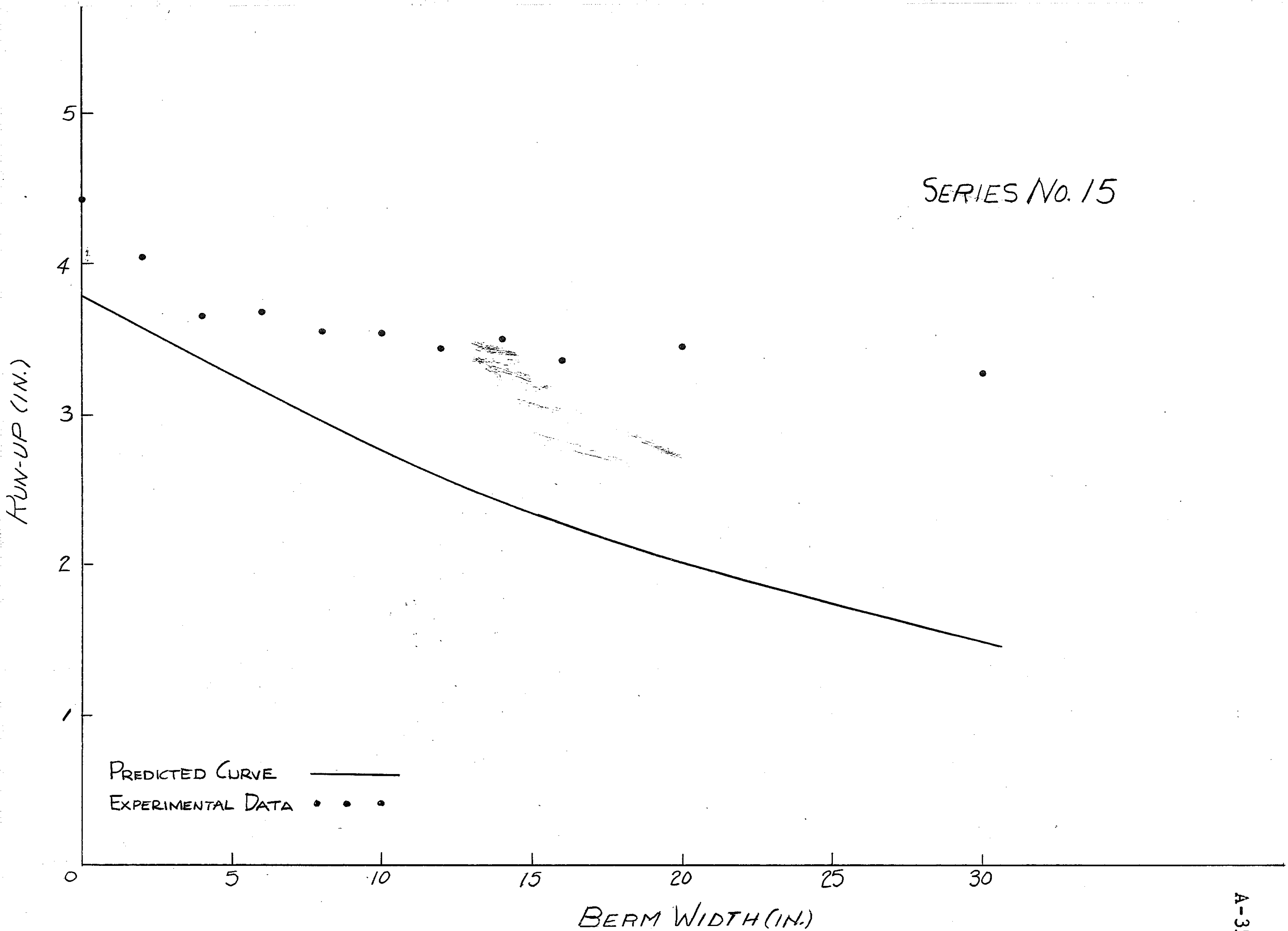
PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
0.81	2.8	1.2	0	3.5	4.5	4.0	0.97	1.93
			1	3.5	4.25	3.875	0.94	1.90
			2	3.25	3.75	3.5	0.85	1.81
			3	3.25	3.25	3.25	0.74	1.75
			4	2.75	3.0	2.875	0.70	1.66
			6	2.0	2.5	2.25	0.55	1.51
			8	3.0	2.5	2.75	0.67	1.63
			10	3.0	2.5	2.75	0.67	1.63
			12	3.0	2.25	2.625	0.64	1.60
			14	2.0	2.5	2.25	0.55	1.51
			20	2.0	2.0	2.0	0.49	1.45
			30	1.5	1.5	1.5	0.36	1.32

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	1.9	4.27	1.25	2.05	
	2.1	4.26	1.25	2.05	2.05
5	1.65	5.72	.96	1.57	1.55
10	1.2	7.6	.72	1.18	1.18


SERIES No. 14
2
1
0
5
10
15
20
25
30
BERM WIDTH (IN.)
ELEVATION OF BERM
PREDICTED CURVE
EXPERIMENTAL DATA

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.07	2.0	1.2	0	14.5	14	14.25	3.46	4.42
			2	13	12.5	12.75	3.09	4.05
			4	11	11.25	11.125	2.70	3.66
			6	11	11.5	11.25	2.73	3.69
			8	10.5	10.75	10.625	2.58	3.54
			10	11	10.25	10.625	2.58	3.54
			12	10	10.5	10.25	2.49	3.45
			14	10.5	10.5	10.5	2.55	3.51
			16	9	10.75	9.875	2.39	3.35
			20	10	10.5	10.25	2.49	3.45
			30	8.5	10.5	9.5	2.31	3.27

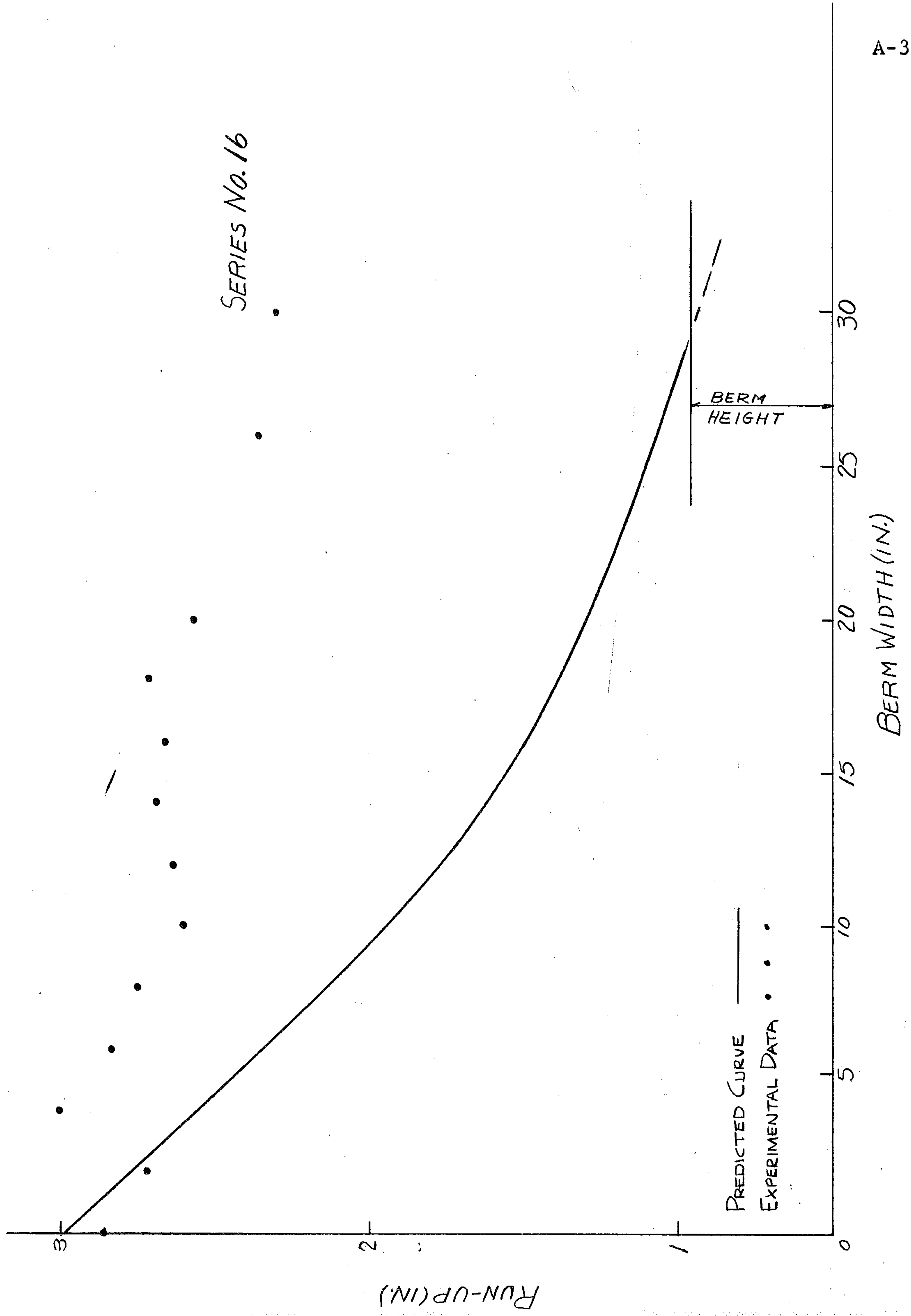
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	4.2	4.18	1.15	3.78	
	3.7	4.21	1.15	3.78	3.8
5	3.5	4.96	.97	3.19	
	3.15	4.97	.97	3.19	3.2
10	2.8	5.84	.85	2.8	2.8
15	2.4	6.78	.71	2.35	2.35
20	2.0	7.86	.62	2.04	2.05
30	1.3	10.5	.47	1.55	1.6


SERIES NO. 15
RUN-UP (IN.)
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
0
5
10
15
20
25
30
1
2
3
4
5

Series Number 16

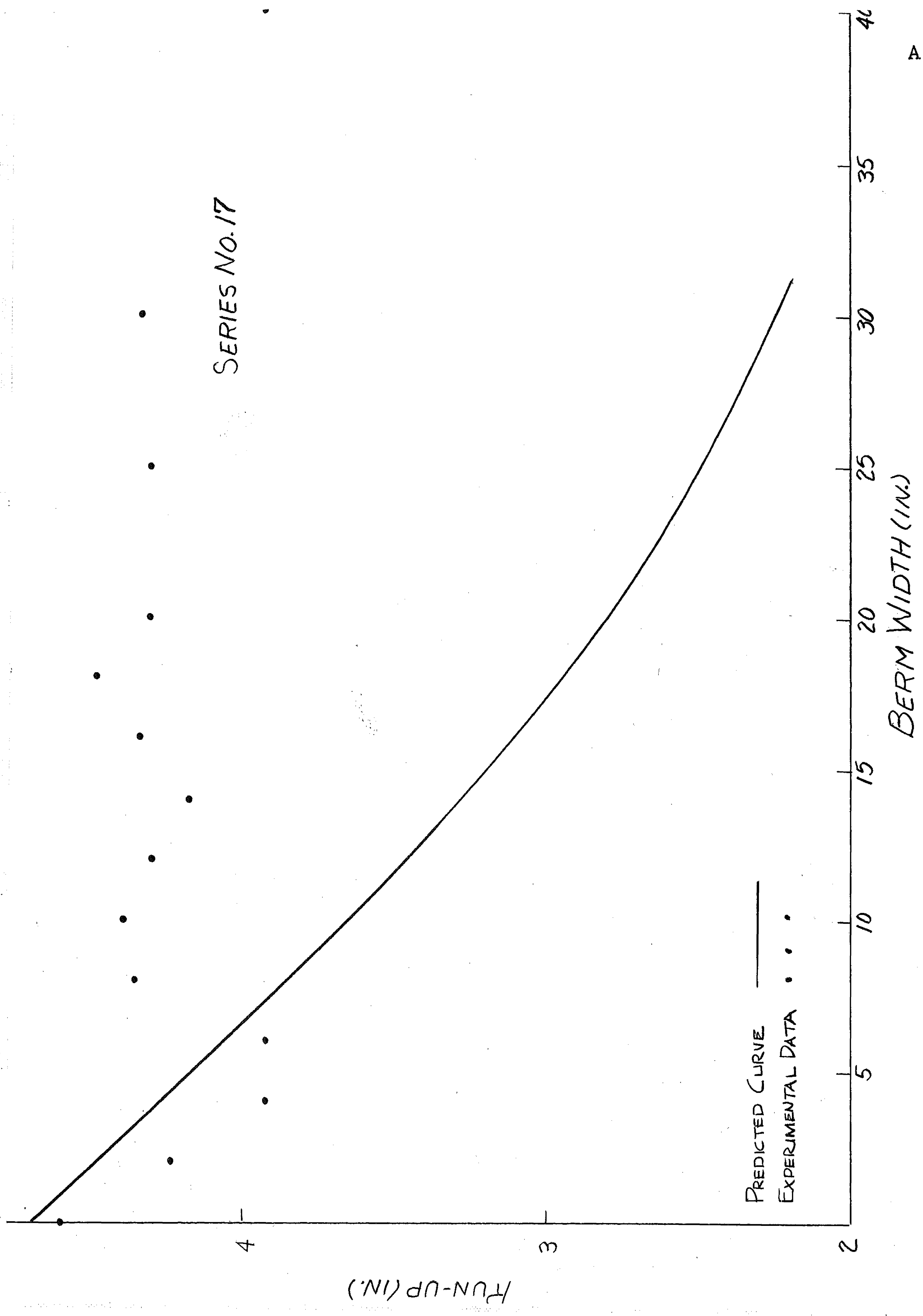
PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.07	2.5	1.2	0	8.0	7.75	7.875	1.91	2.87
			2	7.5	7.0	7.25	1.76	2.72
			4	9.5	7.5	8.5	2.06	3.02
			6	8.5	7.0	7.75	1.88	2.84
			8	8.0	6.75	7.375	1.79	2.75
			10	7.0	6.5	6.75	1.64	2.60
			12	7.0	6.75	6.875	1.67	2.69
			14	7.5	6.75	7.125	1.73	2.69
			16	7.0	7.0	7.0	1.70	2.66
			18	7.5	7.0	7.25	1.76	2.72
			20	6.5	6.75	6.625	1.61	2.57
			26	5.5	6.0	5.75	1.40	2.36
			30	5.0	6.0	5.5	1.34	2.30

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	3.0	4.18	1.55	3.0	3.0
5	2.6	5.18	1.25	2.43	
	2.4	5.24	1.22	2.41	2.4
10	2.0	6.45	1.0	1.94	1.95
15	1.6	7.94	.8	1.55	1.55
20	1.3	9.64	.66	1.28	1.28
30	1.0	12.8	.49	.94	-


SERIES No. 16
BERM HEIGHT
BERM WIDTH (IN.)
RUN-UP (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
0
5
10
15
20
25
30
1
2
3

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.35	1.6	1.20	0	14.5	15.5	15.0	3.64	4.60
			2	12	15	13.5	3.28	4.24
			4	10	14.5	12.25	2.97	3.93
			6	11	13.5	12.25	2.97	3.93
			8	13	15.0	14.0	3.40	4.36
			10	13.5	14.75	14.13	3.43	4.39
			12	12.5	15.0	13.75	3.34	4.30
			14	12.0	14.5	13.25	3.22	4.18
			16	13.0	14.5	13.75	3.38	4.34
			18	14.0	15.0	14.50	3.52	4.48
			20	13	14.5	13.75	3.34	4.30
			25	13	14.5	13.75	3.34	4.30
			30	13	14.75	13.87	3.37	4.33
			40	11	13.50	12.25	2.97	3.93
			50	10				

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	4.6	4.21	1.45	4.7	4.7
5	4.0	4.72	1.3	4.2	
	4.25	4.71	1.3	4.2	4.2
10	3.9	5.50	1.13	3.68	
	3.65	5.52	1.12	3.65	3.65
15	3.3	6.28	.98	3.18	
	3.15	6.32	.98	3.18	3.2
20	2.8	7.17	.86	2.79	2.8
30	2.1	8.93	.69	2.23	2.25

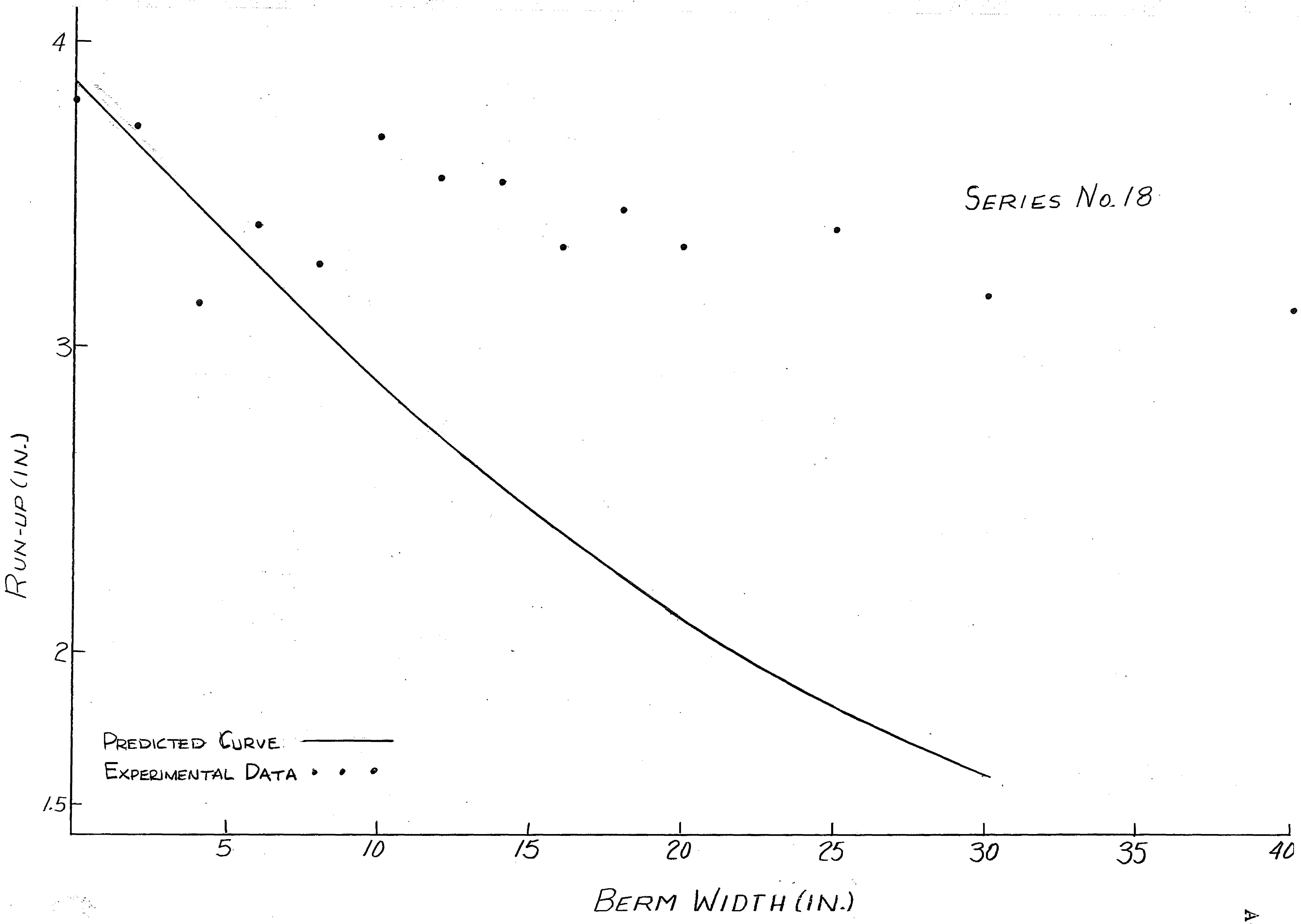


SERIES NO. 17
PREDICTED CURVE
EXPERIMENTAL DATA
BERM WIDTH (IN.)
RUN-UP (IN.)
5
10
15
20
25
30
35
40
2
3
4

Series Number 18

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RUN-UP READINGS RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.35	2.1	1.2	0	11	12.5	11.75	2.85	3.81
			2	11	11.75	11.37	2.76	3.72
			4	7	11.0	9.00	2.18	3.14
			6	9	11.0	10.00	2.43	3.39
			8	8.5	10.5	9.50	2.31	3.27
			10	11	11.5	11.25	2.73	3.69
			12	10	11.5	10.75	2.61	3.57
			14	10	11.25	10.63	2.58	3.54
			16	9	10.50	9.75	2.37	3.33
			18	9.5	11.00	9.75	2.49	3.45
			20	9.0	10.5	9.75	2.37	3.33
			25	9.0	11.0	10.0	2.43	3.39
			30	8	10.25	9.12	2.21	3.17
			40	8	9.75	8.88	2.16	3.12
			50	6				

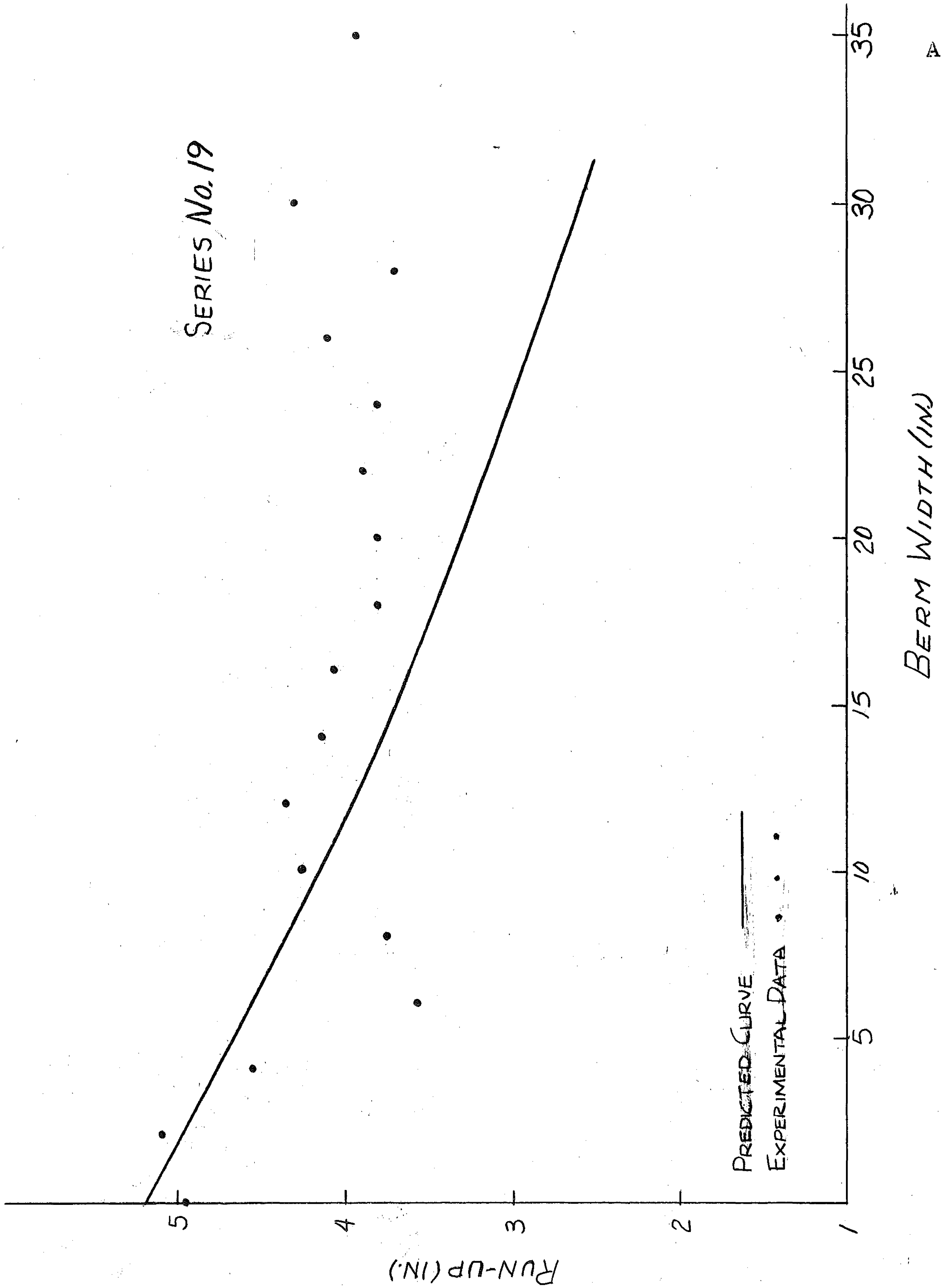
BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	3.8	4.18	1.7	3.86	3.85
5	3.4	4.17	1.5	3.4	3.4
10	3.1	5.80	1.3	2.95	
	2.9	5.87	1.28	2.9	2.9
15	2.5	6.86	1.08	2.45	2.45
20	2.1	8.01	.92	2.09	2.1
30	1.7	10.36	.70	1.59	1.6


SERIES No. 18
RUN-UP (IN.)
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
4
3
2
1.5
5
10
15
20
25
30
35
40

Series Number 19.

PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.67	1.6	1.20	0	16.5	16.5	16.5	4.00	4.96
			2	16.0	18	17.0	4.13	5.09
			4	14	15.5	14.75	3.58	4.54
			6	9	12.5	10.75	2.61	3.57
			8	10	13.0	11.50	2.79	3.75
			10	12	15.0	13.50	3.28	4.24
			12	12.5	15.5	14.0	3.40	4.36
			14	12	14	13.0	3.16	4.12
			16	11.5	14	12.75	3.09	4.05
			18	10.5	13.0	11.75	2.85	3.81
			20	10.5	13.0	11.75	2.85	3.81
			22	11.5	12.75	12.13	2.94	3.90
			24	10	13.5	11.75	2.85	3.81
			26	13	13	13.0	3.16	4.12
			28	11	11.5	11.25	2.73	3.69
			30	14.0	13.5	13.75	3.34	4.30
			35	12.5	12.0	12.25	2.97	3.93
			40	10	10.5	10.25	2.49	3.45
			50	8				

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	5.0	4.19	1.85	5.18	
	5.2	4.19	1.85	5.18	5.2
5	4.0	4.82	1.65	4.62	
	4.7	4.77	1.66	4.65	4.65
10	4.3	5.41	1.5	4.20	4.2
15	3.7	6.12	1.33	3.72	3.7
20	3.3	6.87	1.18	3.31	3.3
30	2.8	8.52	.95	2.66	
	2.6	8.62	.92	2.58	2.6

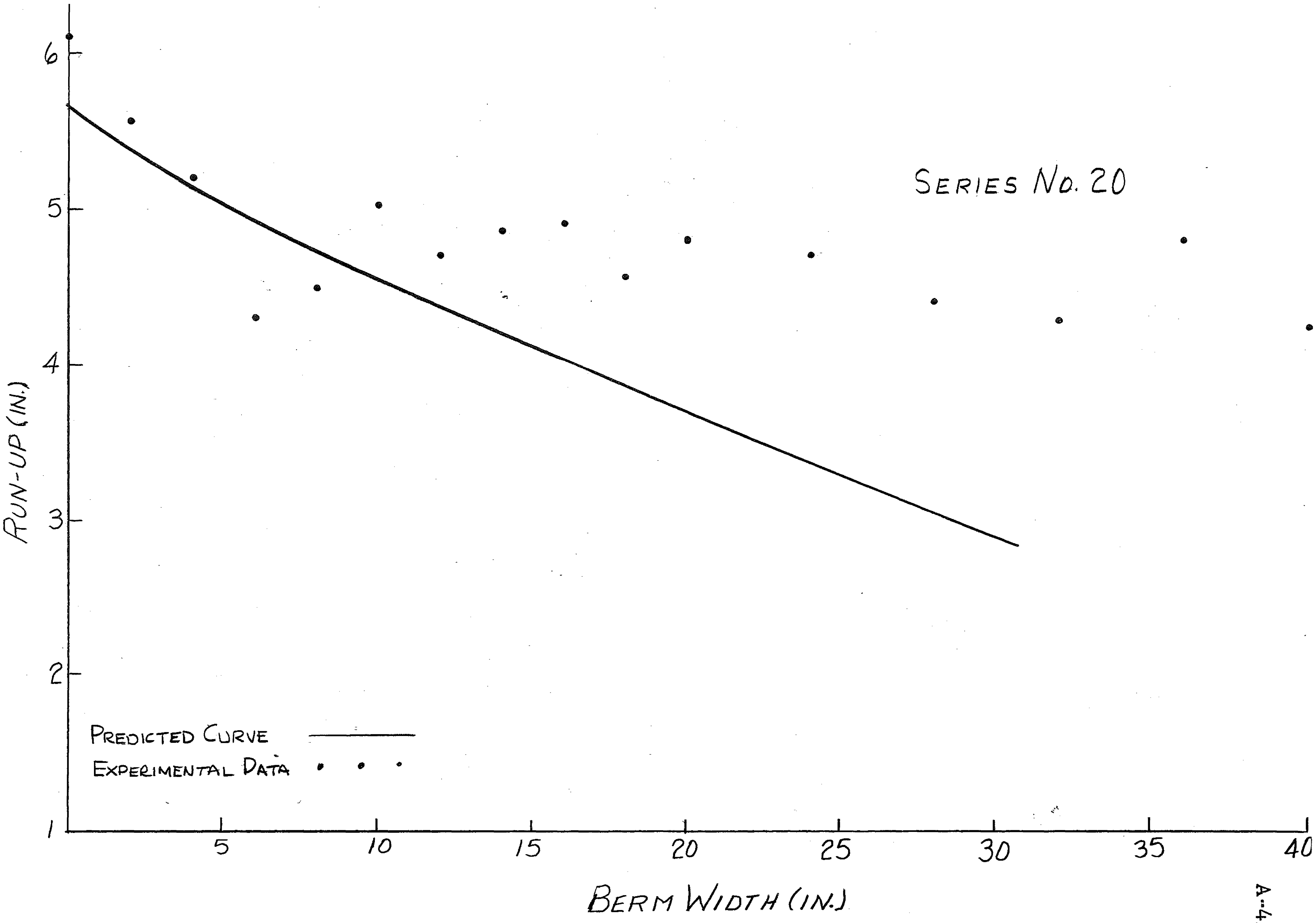


SERIES No. 19
BERM WIDTH (IN.)
RUN-UP (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA
5
10
15
20
25
30
35
1
2
3
4
5

Series Number 20

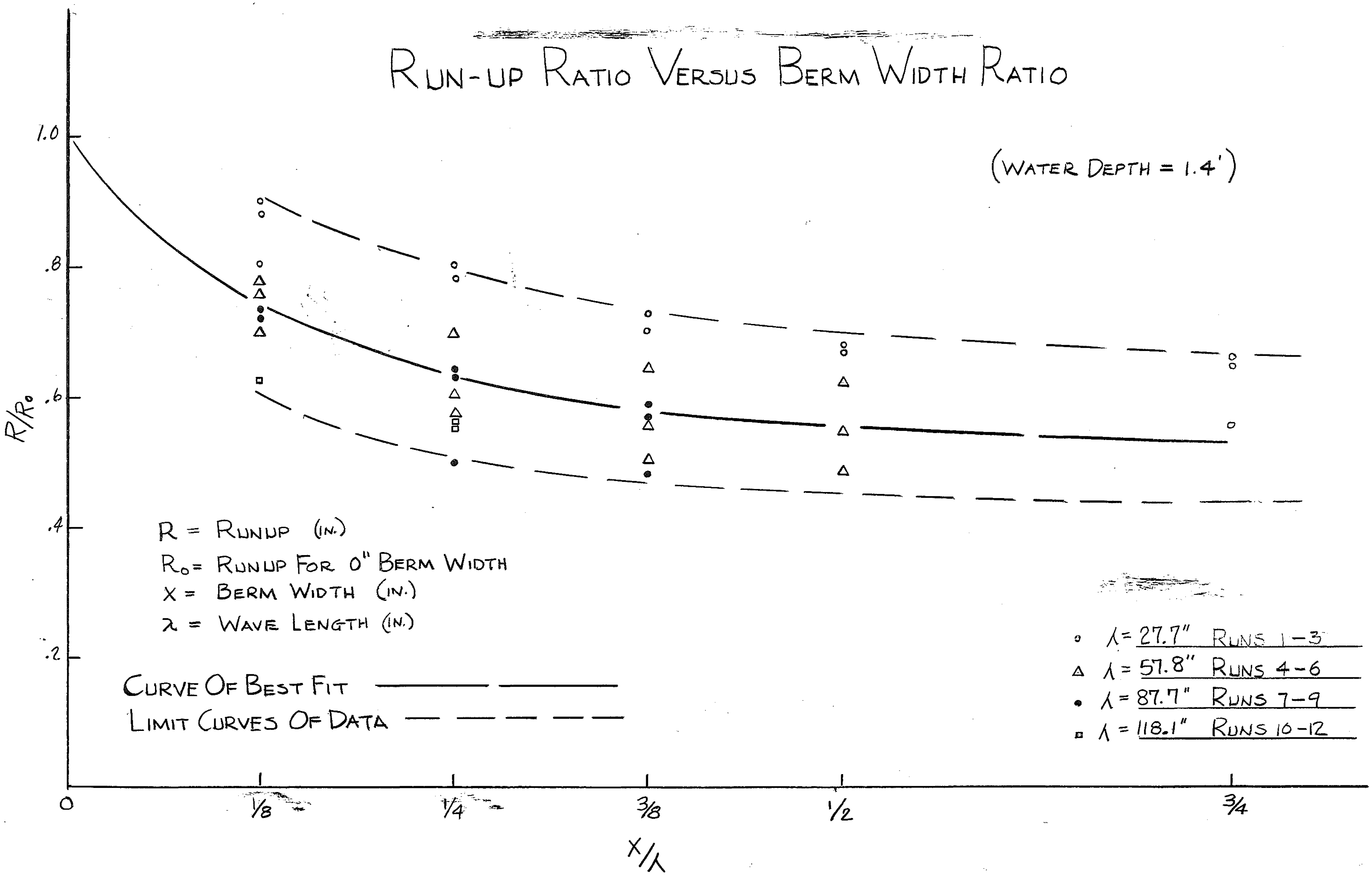
PERIOD	STROKE SETTING	DEPTH	BERM WIDTH	RUN-UP READINGS LEFT	RIGHT	AVERAGE READING	RUN-UP FROM BERM	RUN-UP FROM M.W.L.
1.67	1.2	1.20	0	21.0	21	21	5.10	6.06
			2	17.5	20.5	19.0	4.61	5.57
			4	17	18	17.5	4.25	5.21
			6	13.0	14.5	13.75	3.34	4.30
			8	13	16	14.50	3.52	4.48
			10	16	17.5	16.75	4.07	5.03
			12	15	16	15.50	3.76	4.72
			14	15	17	16.0	3.88	4.84
			16	16	16.5	16.25	3.94	4.90
			18	15.0	14.75	14.87	3.61	4.57
			20	16.0	15.50	15.75	3.82	4.78
			24	16.0	15.0	15.50	3.76	4.72
			28	14	14.5	14.25	3.46	4.42
			32	14	13.5	13.75	3.34	4.30
			36	15	13.5	15.75	3.82	4.78
			40	14	13	13.50	3.28	4.24

BERM WIDTH	TRIAL RUN-UP	COMPUTED SLOPE	R/H'o	COMPUTED RUN-UP	RUN-UP
0	6.0	4.21	1.75	5.66	
	5.6	4.19	1.75	5.66	5.65
5	5.4	4.72	1.56	5.05	
	5.0	4.83	1.54	4.98	5.0
10	4.4	5.37	1.41	4.55	
	4.6	5.32	1.41	4.55	4.55
15	4.2	5.93	1.27	4.11	4.1
20	3.7	6.62	1.14	3.69	3.7
30	3.3	7.98	.92	2.98	
	2.95	8.18	.90	2.92	2.9


SERIES NO. 20
RUN-UP (IN.)
6
5
4
3
2
1
5
10
15
20
25
30
35
40
BERM WIDTH (IN.)
PREDICTED CURVE
EXPERIMENTAL DATA

Computation of Run-up Ratio

Berm Width / Wave Length		0	1/8	1/4	3/8	1/2	3/4
Series 1	R	1.30	1.17	1.04	.95	.88	.85
	R/Ro	1.00	.90	.80	.73	.68	.65
Series 2	R	1.70	1.35	1.07	.97	.94	.95
	R/Ro	1.00	.80	.63	.57	.55	.56
Series 3	R	1.67	1.46	1.30	1.17	1.12	1.10
	R/Ro	1.00	.88	.78	.70	.67	.66
Series 4	R	2.6	1.82	1.50	1.32	1.28	
	R/Ro	1.00	.70	.58	.51	.49	
Series 5	R	3.10	2.46	2.18	2.02	1.95	
	R/Ro	1.00	.78	.70	.65	.63	
Series 6	R	4.6	3.48	2.8	2.6	2.55	
	R/Ro	1.00	.76	.61	.56	.55	
Series 7	R	3.6	2.5	2.0			
	R/Ro	1.00	.70	.56			
Series 8	R	5.0	3.1	2.8			
	R/Ro	1.00	.62	.56			
Series 9	R	6.0	3.7	3.3			
	R/Ro	1.00	.62	.55			
Series 10	R	5.0	3.1	2.5	2.4		
	R/Ro	1.00	.62	.50	.48		
Series 11	R	5.4	3.9	3.4	3.2		
	R/Ro	1.00	.72	.63	.59		
Series 12	R	5.4	4.3	3.8	3.4		
	R/Ro	1.00	.73	.64	.57		



RUN-UP RATIO VERSUS BERM WIDTH RATIO
(WATER DEPTH = 1.4')
1.0
.8
.6
.4
.2
R/Ro
R = RUNUP (IN.)
Ro = RUNUP FOR 0" BERM WIDTH
X = BERM WIDTH (IN.)
λ = WAVE LENGTH (IN.)
CURVE OF BEST FIT
LIMIT CURVES OF DATA
λ = 27.7" RUNS 1-3
λ = 57.8" RUNS 4-6
λ = 87.7" RUNS 7-9
λ = 118.1" RUNS 10-12
0
1/8
1/4
3/8
1/2
3/4
X/λ

R/Hȯ vs Hȯ/T^2 - FOR VARIOUS BERM WIDTHS (DEPTH OF WATER - 1.4')

RUN No.	BERM WIDTH	RUN-UP R	Hȯ	R/Ho'	T	T^2	Hȯ/T^2	db
1	0"	1.20"	1.08	1.111	.67	.448	.200	1.23"
2	0	1.71	1.83"	.934	.67	.448	.339	1.74"
3	0	1.77	2.58"	.686	.67	.448	.480	2.19"
4	0	2.44	1.75"	1.394	1.00	1.000	.146	2.22
5	0	3.23	2.84"	1.137	1.00	1.000	.236	3.06"
6	0	4.44	4.08	1.088	1.00	1.000	.340	3.90"
7	0	3.59	2.02	1.777	1.31	1.716	.097	2.82"
8	0	5.04	3.00	1.680	1.31	1.716	.146	3.78
9	0	6.03	3.84	1.570	1.31	1.716	.186	4.48"
10	0	5.11	1.84	2.777	1.67	2.788	.0548	3.24"
11	0	5.59	2.50	2.236	1.67	2.788	.0745	3.99"
12	0	5.90	3.17	1.861	1.67	2.788	.0945	4.65"
1	10"	.97"	1.08"	.898	.67	.448	.200	1.23
2	10	.99	1.83"	.541	.67	.448	.339	1.74
3	10	1.20	2.58"	.465	.67	.448	.480	2.19
4	10	1.59	1.75"	.908	1.00	1.000	.146	2.22
5	10	2.44	2.84"	.859	1.00	1.000	.236	3.06
6	10	3.23	4.08"	.792	1.00	1.000	.340	3.90
7	10	2.80	2.02"	1.386	1.31	1.716	.097	2.82
8	10	3.65	3.00"	1.217	1.31	1.716	.146	3.78
9	10	4.14	3.84"	1.078	1.31	1.716	.186	4.48
10	10	3.23	1.84"	1.755	1.67	2.788	.0548	3.24
11	10	4.08	2.50"	1.632	1.67	2.788	.0745	3.99
12	10	4.44	3.17"	1.400	1.67	2.788	.0945	4.65

RUN NO.	BERM WIDTH	RUN-UP R	Ho'	R/Ho'	T	T^2	Ho'/T^2
1	20"	0.89	1.08	0.824	.67	.200	.200
2	20	.95"	1.83"	.519	.67	.339	.339
3	20	1.14	2.58"	.442	.67	.480	.480
4	20	1.41	1.75"	.805	1.00	.146	.146
5	20	2.20"	2.84	.775	1.00	.236	.236
6	20	2.71"	4.08	.664	1.00	.340	.340
7	20	2.47	2.02	1.233	1.31	.097	.097
8	20	3.04	3.00	1.013	1.31	.146	.146
9	20	3.89	3.84	1.013	1.31	.186	.186
10	20	2.50	1.84	1.359	1.67	.0548	.0548
11	20	3.41	2.50	1.364	1.67	.0754	.0745
12	20	3.96	3.17	1.249	1.67	.0945	.0945
1	30"	.94	1.08	.870	.67	.200	.200
2	30	1.05	1.83	.574	.67	.399	.339
3	30	1.14	2.58	.442	.67	.480	.480
4	30	1.29	1.75	.737	1.00	.146	.146
5	30	1.86	2.84	.655	1.00	.236	.236
6	30	2.50	4.08	.613	1.00	.340	.340
7	30	1.89	2.02	.936	1.31	.097	.097
8	30	2.80	3.00	.933	1.31	.146	.146
9	30	3.17	3.84	.826	1.31	.186	.186
10	30	2.47	1.84	1.342	1.67	.0548	.0548
11	30	3.02	2.50	1.208	1.67	.0745	.0745
12	30	3.38	3.17	1.066	1.67	.0945	.0945

FIGURE A-1

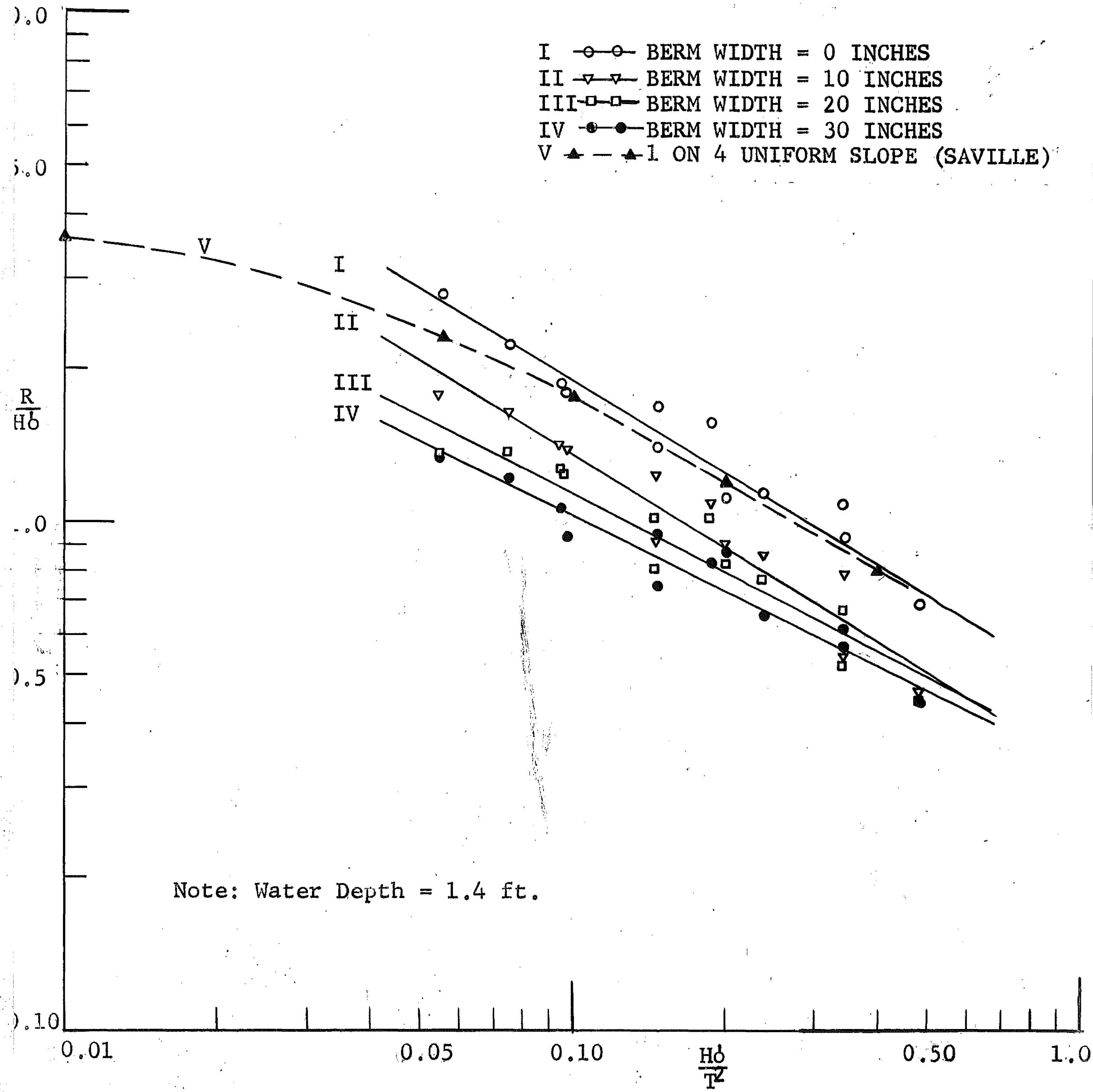


FIGURE A-1: $\frac{R}{H_o'}$ VERSUS $\frac{H_o'}{T^2}$ FOR VARIOUS BERM WIDTHS

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