DEPARTMENT OF THE ARMY | CORPS OF ENGINEERS

BEACH EROSION BOARD
OFFICE OF THE CHIEF OF ENGINEERS

LABORATORY STUDY OF EFFECT OF TIDAL ACTION ON WAVE-FORMED BEACH PROFILES

TECHNICAL MEMORANDUM NO. 52

LABORATORY STUDY OF EFFECT OF TIDAL ACTION ON WAVE-FORMED BEACH PROFILES

TECHNICAL MEMORANDUM NO. 52

BEACH EROSION BOARD

CORPS OF ENGINEERS

DECEMBER 1954

FOREWORD

Laboratory tests involving wave action on sand beaches have frequently been observed to result in beach profiles which are somewhat distorted as compared to the usually observed natural (field) beach profiles. This distortion appears to be mostly in the offshore area and consists of accentuated, yet systematic, offshore bars and troughs. It has been supposed that the formation and position of offshore bars and troughs in laboratory tests may well be greatly influenced by reflected waves set up in the wave tank when a constant period wave is utilized. The constant period type of tests appears to create nodal points, in terms of the propagated and reflected wave energies, thereby producing systematic peaks and troughs along the offshore profile. With the introduction of a tidal system, the zone of wave action is under continued motion up and down the shore; this should cause a resultant continuous movement of the nodal point locations and the influence of these on offshore bar and trough formation should therefore be lessened. This report presents the results of a limited study of the effects on laboratory equilibrium beach profiles of introducing a tidal system.

At the time the tests were performed, the project engineer, George M. Watts, was a hydraulic engineer in the Research Division of the Beach Erosion Board under the supervision of Joseph M. Caldwell, Chief of the Division. The technical staff of the Board was under the general supervision of Colonel J. U. Allen, Resident Member and R. O. Eaton, Chief Technical Assistant. At the time of completion of the report, the staff was under the general supervision of Colonel E. A. Hansen, Resident Member.

The authors of the report, George M. Watts and Robert F. Dearduff, were aided in the testing and laboratory work by Morrison G. Essick, and Herman P. VanEckhardt. The report was edited for publication by Albert C. Rayner, Chief, Project Development Division. Views and conclusions stated in the report are not necessarily those of the Beach Erosion Board.

This report is published under authority of Public Law 166, 79th Congress, approved July 31, 1945.

TABLE OF CONTENTS

LABORATORY STUDY OF EFFECT OF TIDAL ACTION ON WAVE-FORMED BEACH PROFILES

by

George M. Watts and Robert F. Dearduff
Hydraulic Engineers, Beach Erosion Board

INTRODUCTION

General .- Many variables influence the shape of beach profiles subjected to wave action, primary among them being the sand, wave, and tidal characteristics. The laboratory study presented herein is one of a series wherein these variables have been isolated in an attempt to determine their independent effects on the profile of laboratory sand beaches. In the first of these studies, Rector(1) determined the resultant equilibrium profiles for various sands for waves of constant height and constant period. In another study, Watts(2) investigated the effect of varying the wave period.

Purpose. - In the present study the same sands were used as in the previous studies, and waves of approximately constant height and constant period were used throughout each test. The study was undertaken to investigate the effect on the beach profiles of introducing tidal action. In particular, it was desired to determine the possible effect in reducing the accentuated offshore bar formation obtained in laboratory tests with constant wave conditions and no change in still water level.

APPARATUS

Wave Tank and Generator. - The wave tank used in this study, was 85 feet long, 14 feet wide and 4 feet deep. Longitudinal bulkheads spaced 3.5 feet apart in the tank, as shown in Figure 1, provided four compartments which permitted sands of four different sizes to be tested simultaneously. The wave generator, shown in Figure 2, consists of a quarter-circle metal scoop powered by an electric motor through a system of gears. The scoop was given a rotary motion through adjustable eccentrics located at the upper ends of the scoop arms. An adjustable vari-drive speed control unit attached to the electric motor provided a means of controlling the wave period.

(1) Rector, R. L. - Laboratory Study of Equilibrium Profiles of Beaches, Beach Erosion Board, Technical Memo. #41, Aug. 1954.

(2) Watts, George M. - Laboratory Study of Effect of Varying Wave Periods on Beach Profiles, Beach Erosion Board, Technical Memo. #53, Sept. 1954.

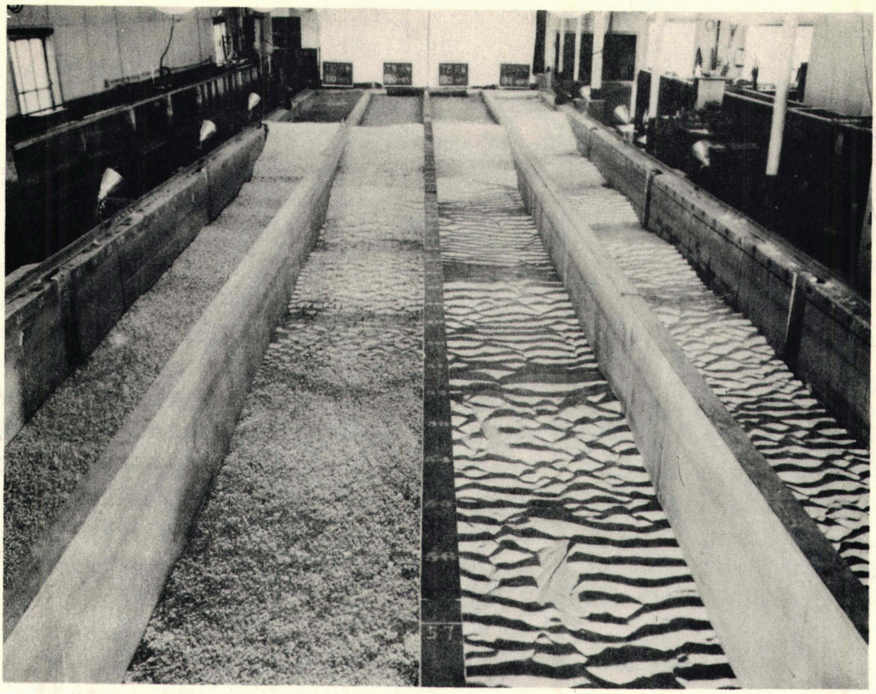

FIGURE 1 WAVE TANK AND PARTITIONS

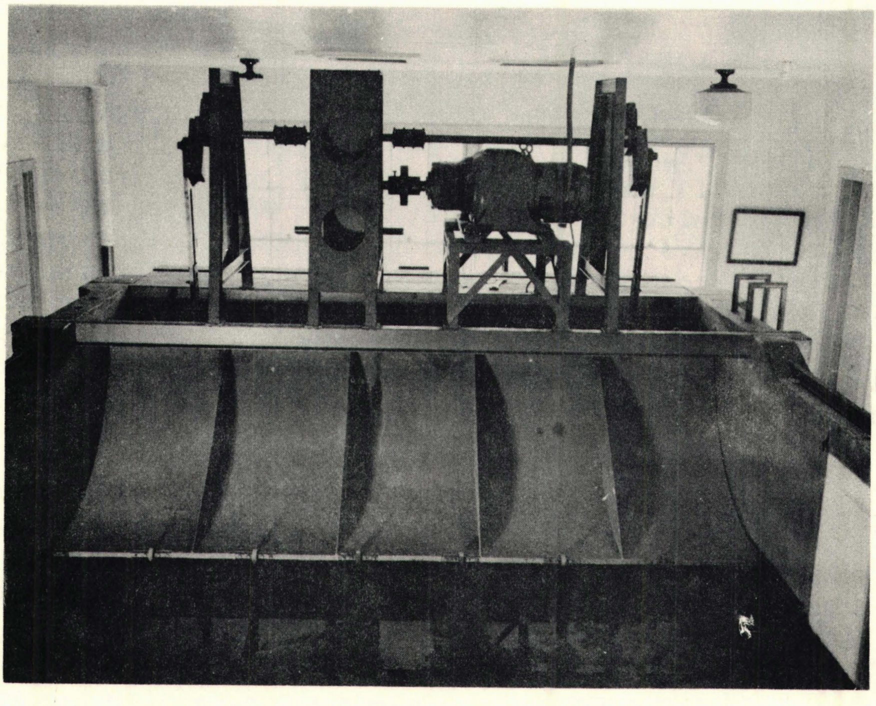

FIGURE 2 WAVE GENERATOR

Tide Control System. - Figure 3 is a schematic diagram of the tide control system. The system consists basically of a sump, a constant head tank, input or flood tide controls, discharge or ebb tide controls, and a tide recorder connected to a stilling well. During flood tide, the water was pumped from the sump into the constant head tank and then fed by means of the flood tide controls through a piping system with two discharge ports located on opposite sides of the wave tank about 22 feet in front of the wave generator. During ebb tide, the controls, allowed the water in the wave tank to be drained back through the discharge ports into the sump. A stilling well located about 20 feet in front of the wave generator alongside one wall of the tank actuated the tide gage which recorded the varying water level.

Bed Material. - The size frequency distributions of the four sands used in the tests are shown in Figure 4. Materials with median diameters of 0.22, 0.46, and 3.44 millimeters were basic sands. The 1.20-millimeter sand was a mixture of the 0.46 and the 3.44-millimeter sands. These are the same sands used in the studies previously mentioned.

TEST PROCEDURE AND PRESENTATION OF RESULTS

General Testing Procedure. - The initial equilibrium profile study showed that profile changes occurring on a beach subjected to wave action are partly a function of the wave steepness (ratio of deep water wave height to wave length, H_o/L_o) and the relative sizes of the sand grains and the waves. It was also shown that beach profiles may be grouped in two classes; those shaped by waves where $H_o/L_o > 0.025$, and those shaped by waves where $H_o/L_o < 0.016$. Formation of the former class of profile is usually associated with general offshore movement of bed material (provided the relative coarseness of the sand and wave size, Md_o/L_o, is less than about 3×10^{-4}), and formation of the latter class of profile entails general onshore movement of the bed material. Since the wave steepness is a function of the wave period, it is possible to create dominant onshore or offshore movement of material for limiting sizes of that material, by selecting a certain wave height and period combination. Two wave height-period combinations were selected from the equilibrium profile study for this investigation. The first combined a wave height of 0.5 foot with a wave period of 2.68 seconds which resulted in a wave steepness ratio of 0.0136, considered equivalent to a normal wave; the second combined a wave height of 0.5 foot with a wave period of 2.0 seconds. This combination produced a wave steepness ratio of 0.0244, and was considered to approximate storm wave conditions.

The introduction of tidal action with its cyclic changes of still water level causes corresponding changes of depth at the wave generator. This change of depth affects the wave height, even though the period is constant, and consequently the wave steepness values at high, mean and low water levels would be slightly different. For the 2.00 and 2.68-second wave periods the wave steepness values varied about 4 and 10 percent, respectively, between high and low water levels.

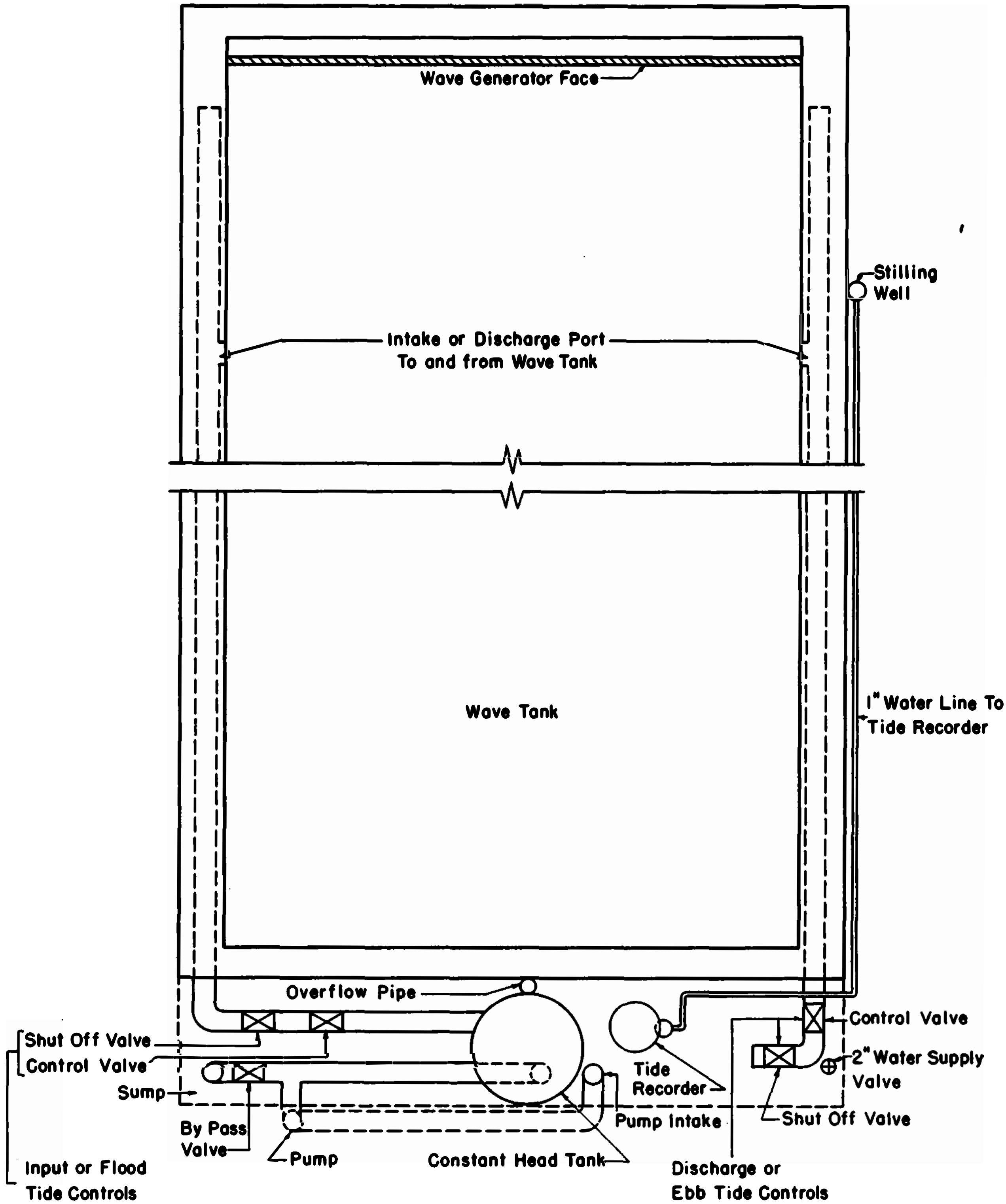

FIGURE 3-SCHEMATIC DIAGRAM OF TIDE CONTROL SYSTEM

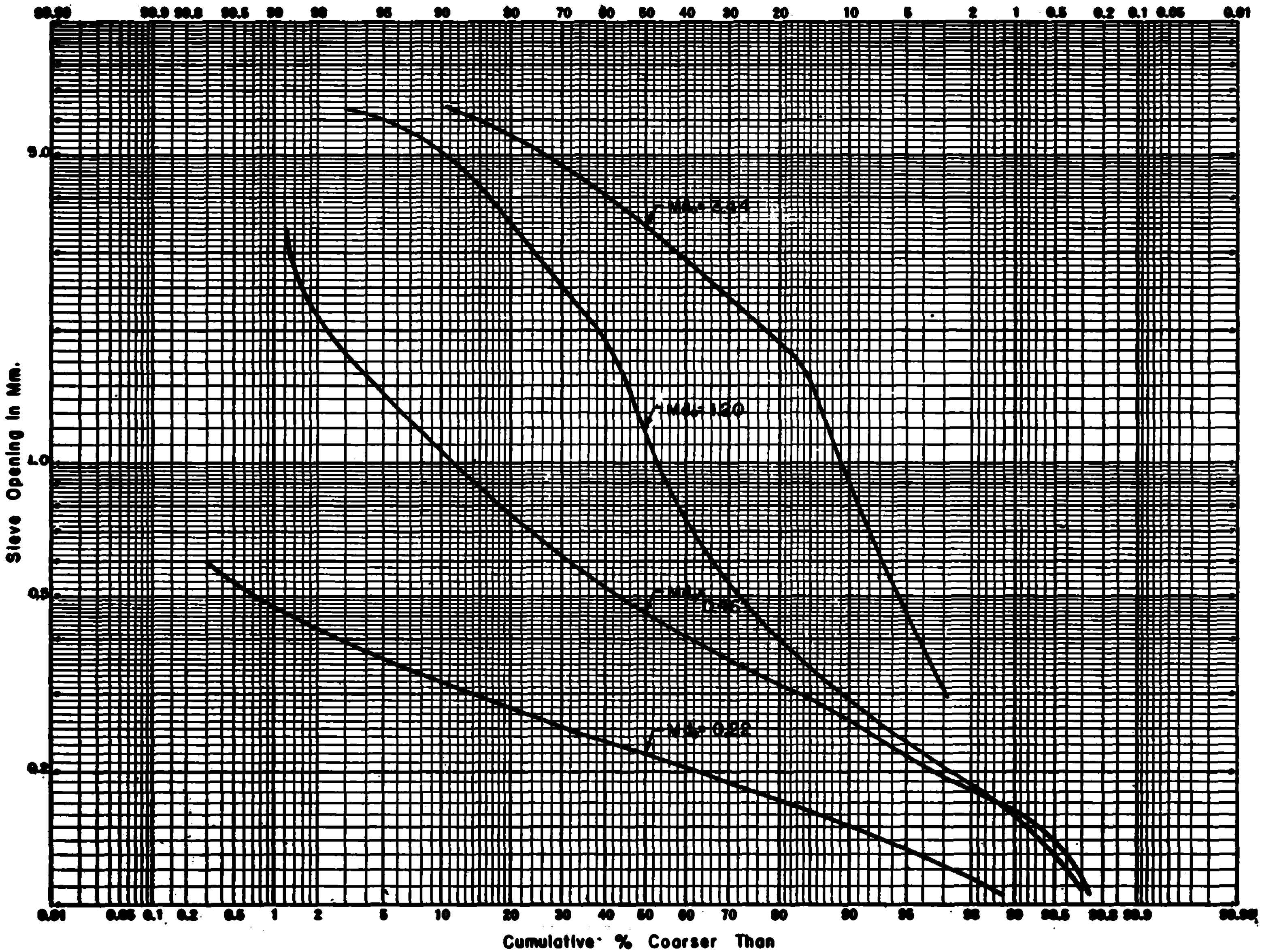

FIG. 4 SIZE FREQUENCY DISTRIBUTION OF FOUR SANDS

Laboratory studies of wave action involving the utilization of the same sand in a sequence of tests, have shown that the intermediate or final results may be influenced by the techniques employed to redistribute the sand before each separate test. To study this difficulty in laboratory practice further and to observe any relationship between sand size distribution and tidal magnitude and duration, sand samples were taken from the beach before wave action (original slope) and after a test duration of 40 hours for three tests (A, B, and C). The samples were taken at stations 10, 20, 30, 40, 50 and 60 (the station numbers correspond to feet from the beach end of the tank). The beach samples consisted of rectangular sections about 6 inches in length along the profile, 2 inches in width and 3/8 of an inch in depth.

Presentation of Results. - The profiles resulting from the tests are plotted on Figures 5 to 8, incl. The four sets of profiles on each figure represent the profiles for the four sizes of sand. All plotted profiles are those taken after operation of the tests for 40 hours. The equilibrium profile for the test without tidal action is also included with each set of profiles.

Figures 5 and 6 are plots of profiles showing the effect of tidal range, Figure 5 being those for a wave period of 2.00 seconds and Figure 6 for a period of 2.68 seconds. The A portions of these figures are for a tidal cycle of 4 hours, the B portions for a cycle of 1 hour.

In Figures 7 and 8, the profiles are replotted for the 2.00 and 2.68-second periods respectively to show the effect of tidal cycle duration, the A portions being for a tidal range of 0.50 foot and the B portions for 0.24 foot.

The data on sand size variations obtained for Tests A, B, and C are given in Table 2. The effect of tidal range upon the sand grain size distribution after the final shape of the beach had been established, involved a comparison of tests A and B. The procedures for these tests were the same except for a difference in tidal range, test A having a tidal range of 0.5 foot and test B a range of 0.24 foot. The effect of tidal cycle duration upon the sand grain size distribution involved a comparison of the analyses after the final shape of the beach had been established for tests A and C. The procedures for these tests were the same except for the tidal duration, test A having a cycle of 4 hours and test C having a cycle of 1 hour. The effects of tidal range and duration were studied by computing the ratio of the median diameter of the sand after 40 hours of test duration, to the median diameter of the sand in the original slope at selected stations along the profile. These ratios are also presented in Table 2.

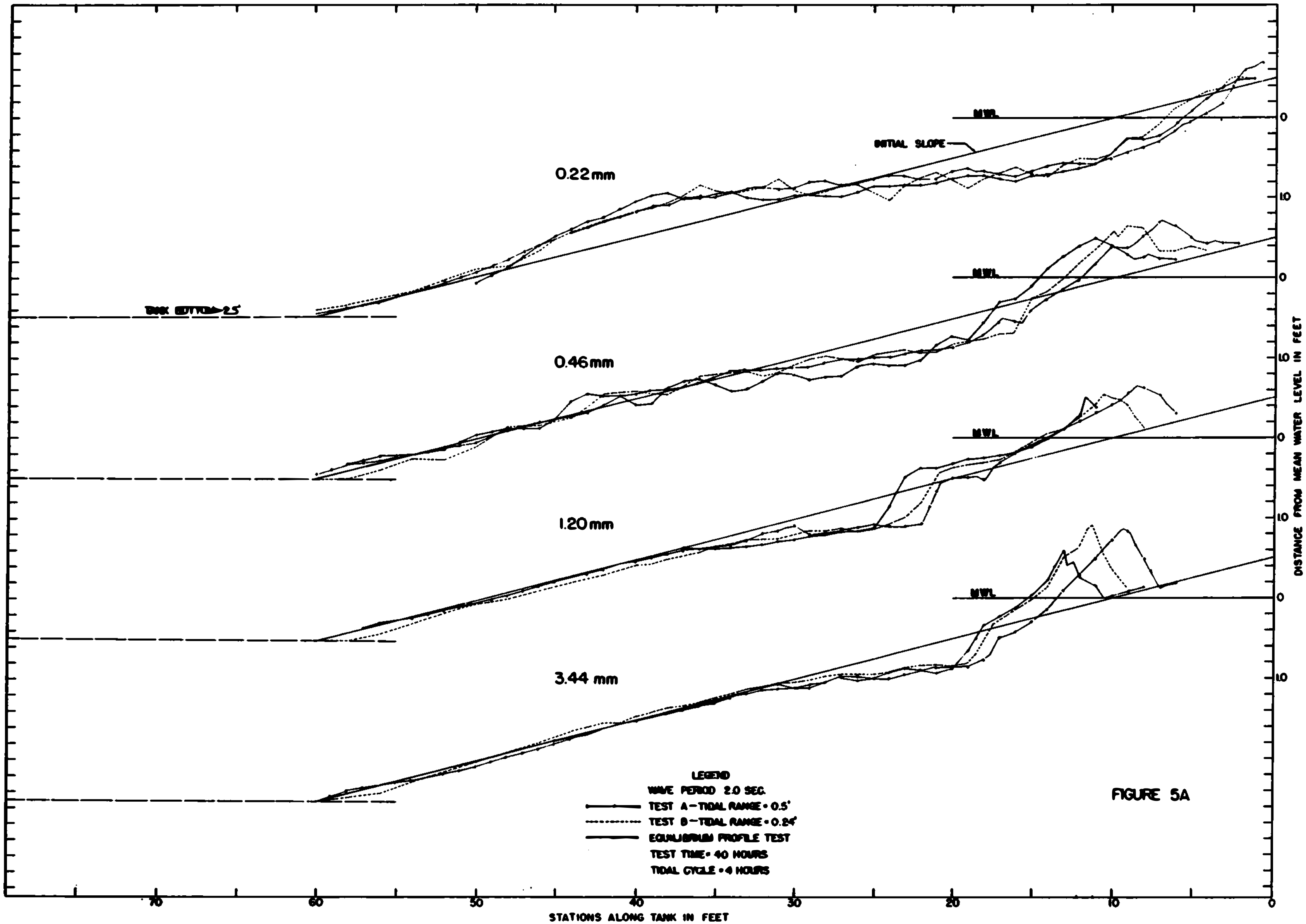

FIGURE 5 — EFFECT OF TIDAL RANGE

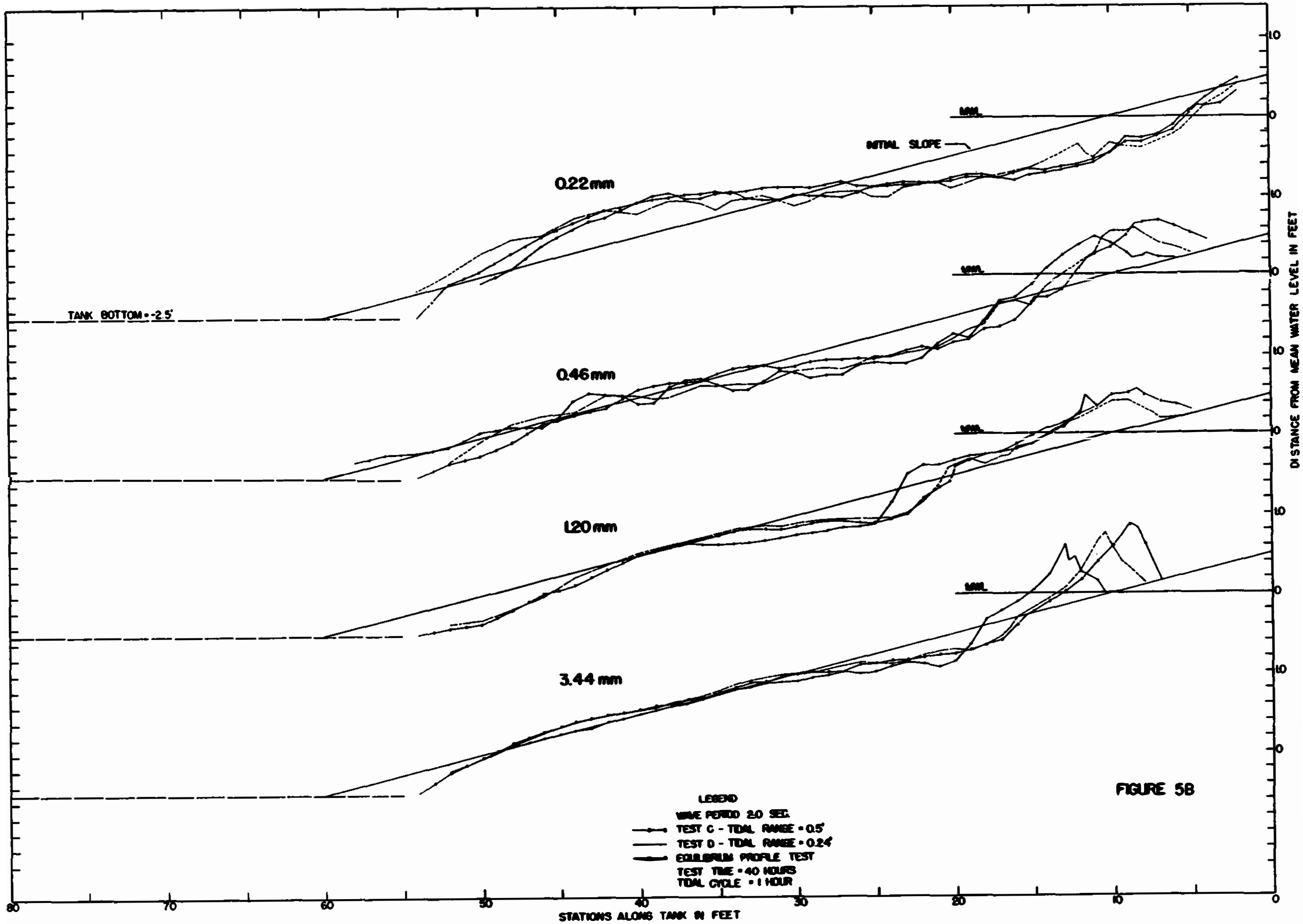

FIGURE 5 — EFFECT OF TIDAL RANGE

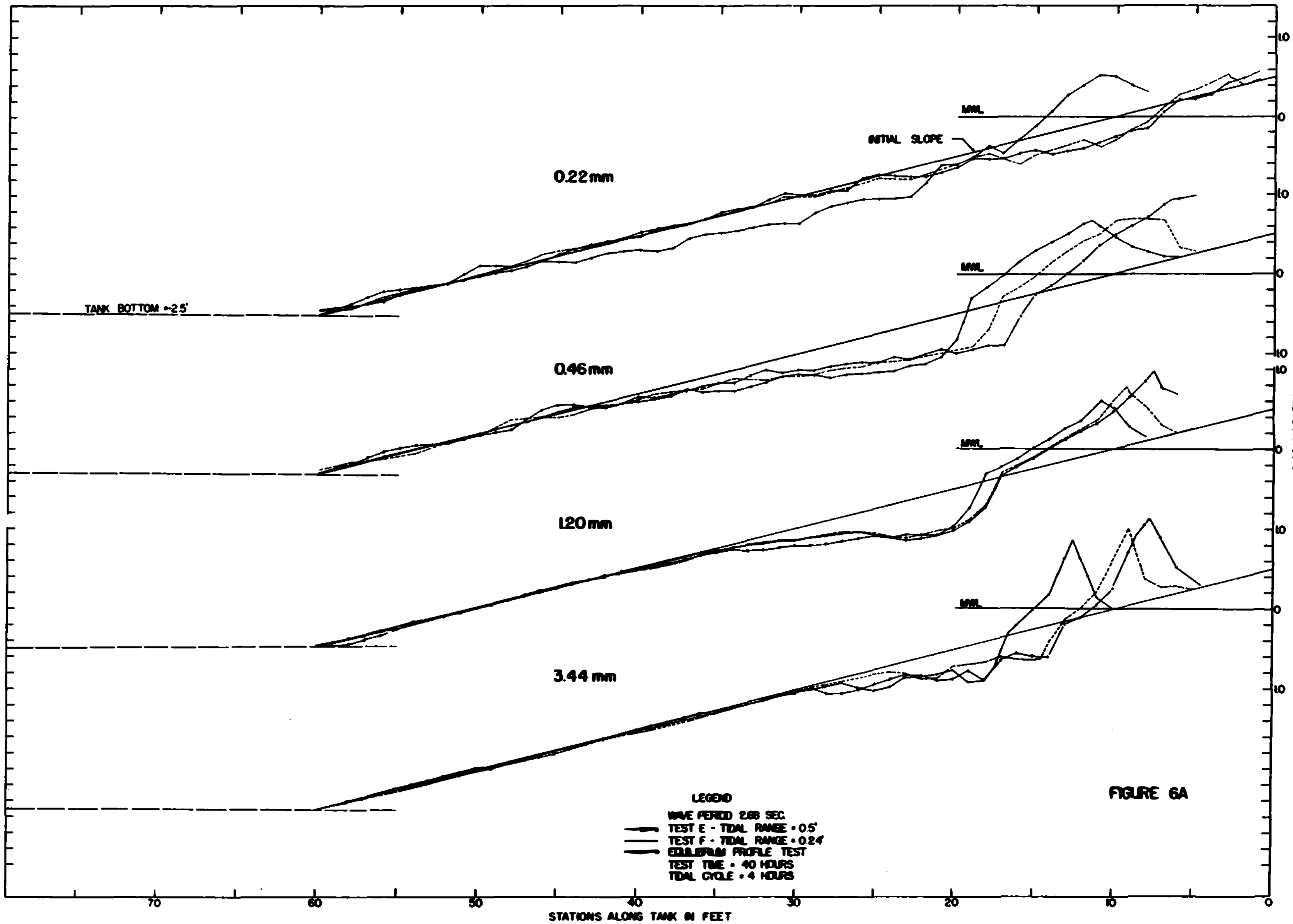

FIGURE 6 — EFFECT OF TIDAL RANGE

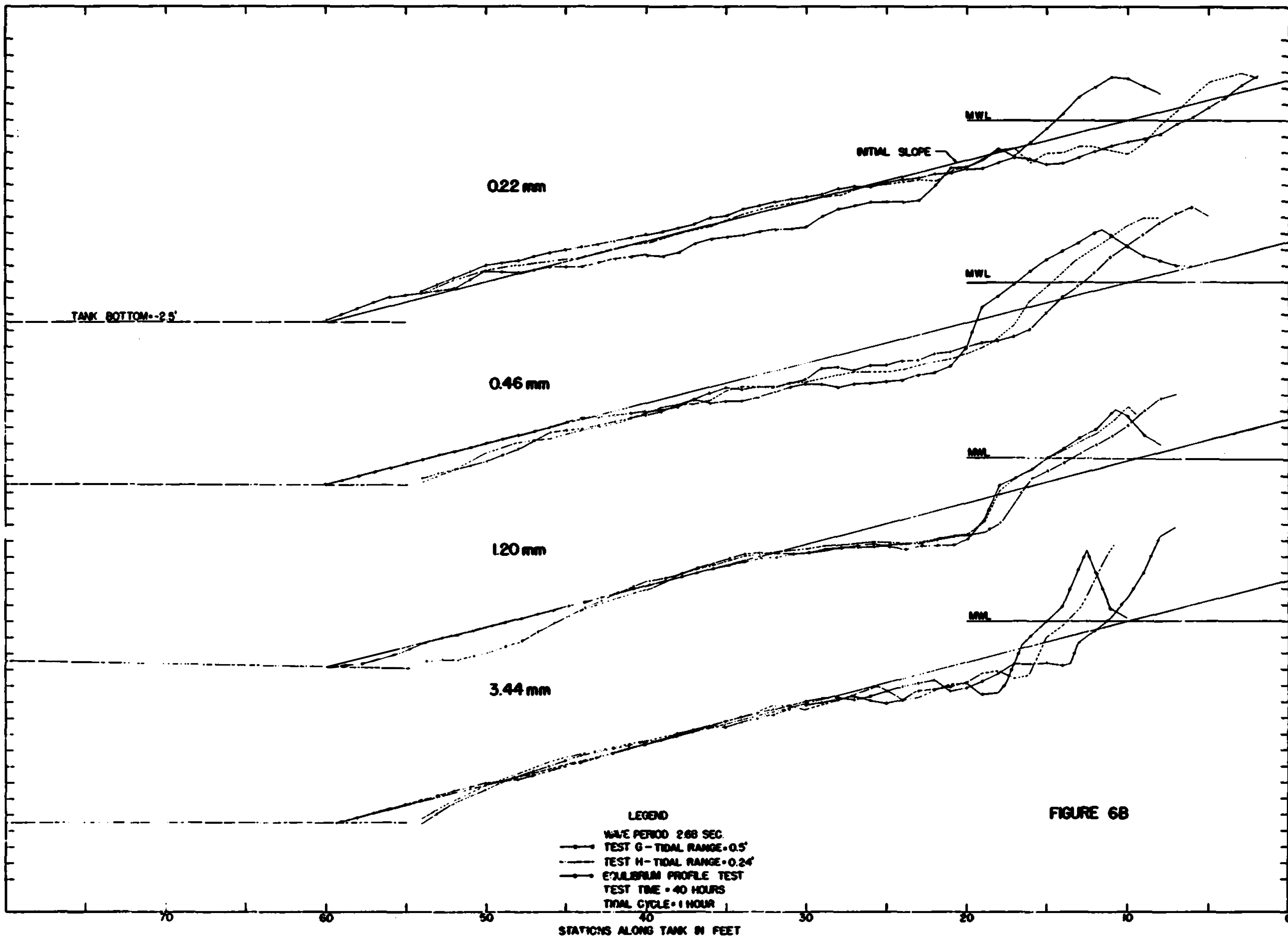

FIGURE 6 — EFFECT OF TIDAL RANGE

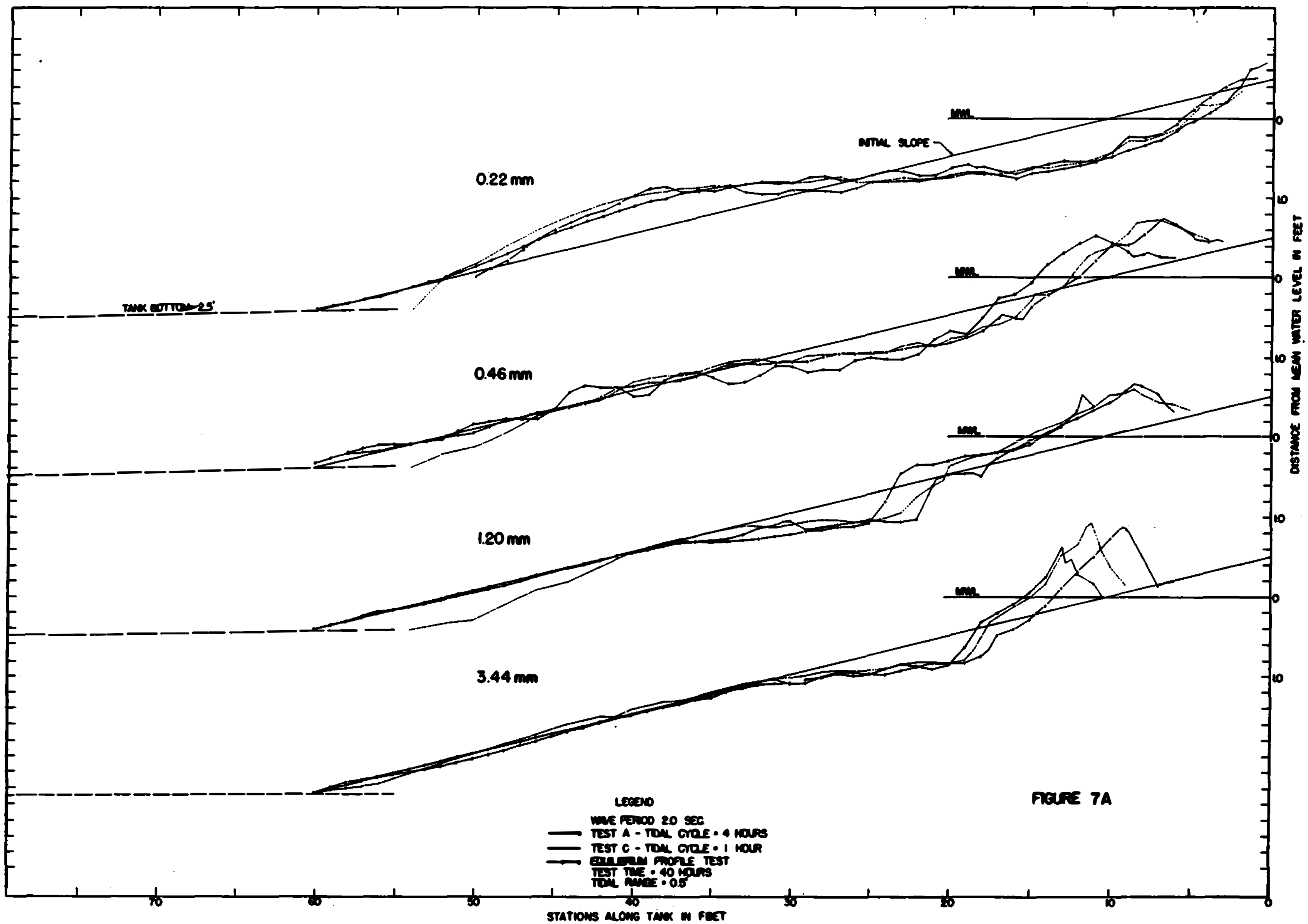

FIGURE 7 — EFFECT OF DURATION OF TIDAL CYCLE

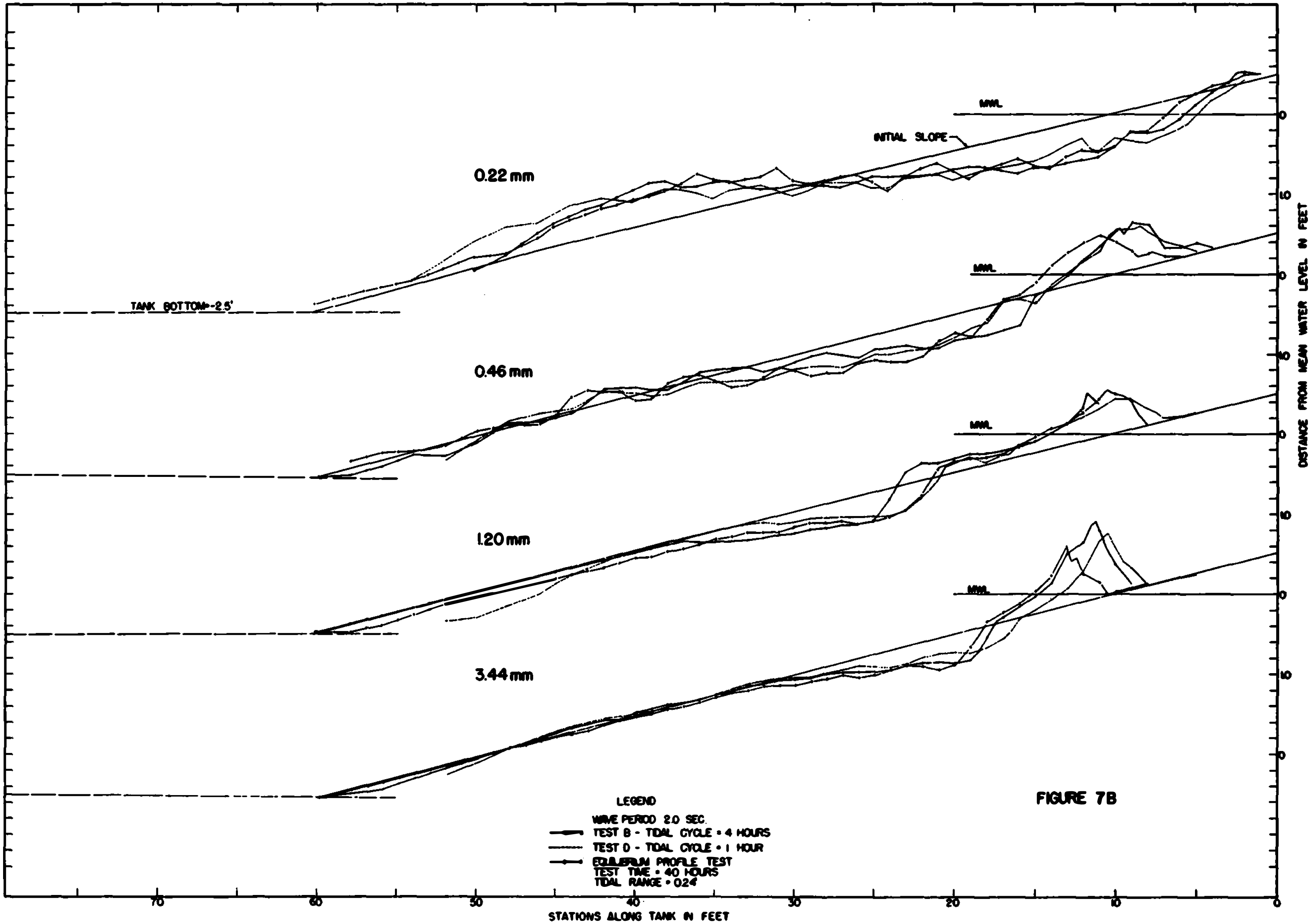

FIGURE 7 — EFFECT OF DURATION OF TIDAL CYCLE

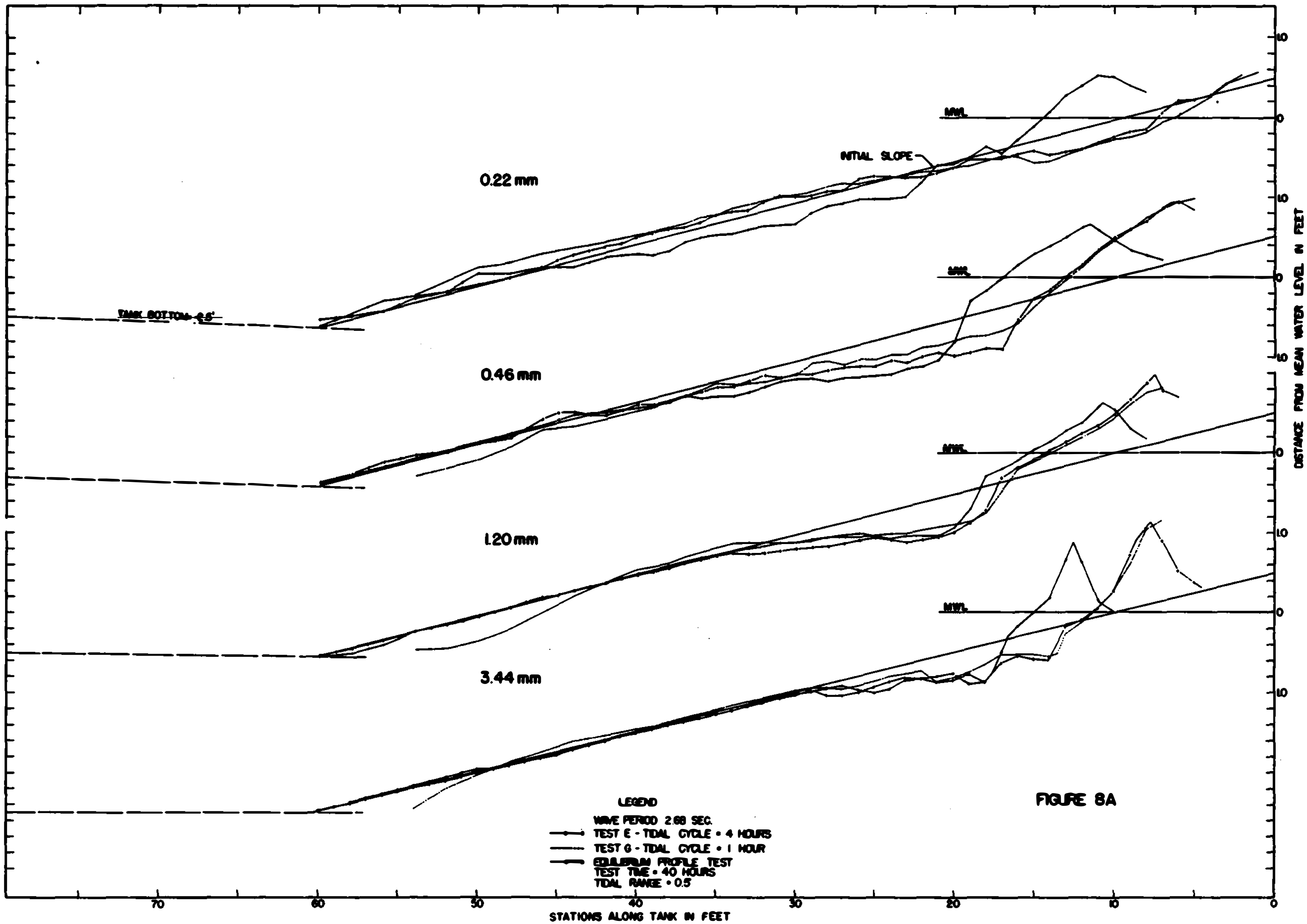

FIGURE 8 — EFFECT OF DURATION OF TIDAL CYCLE

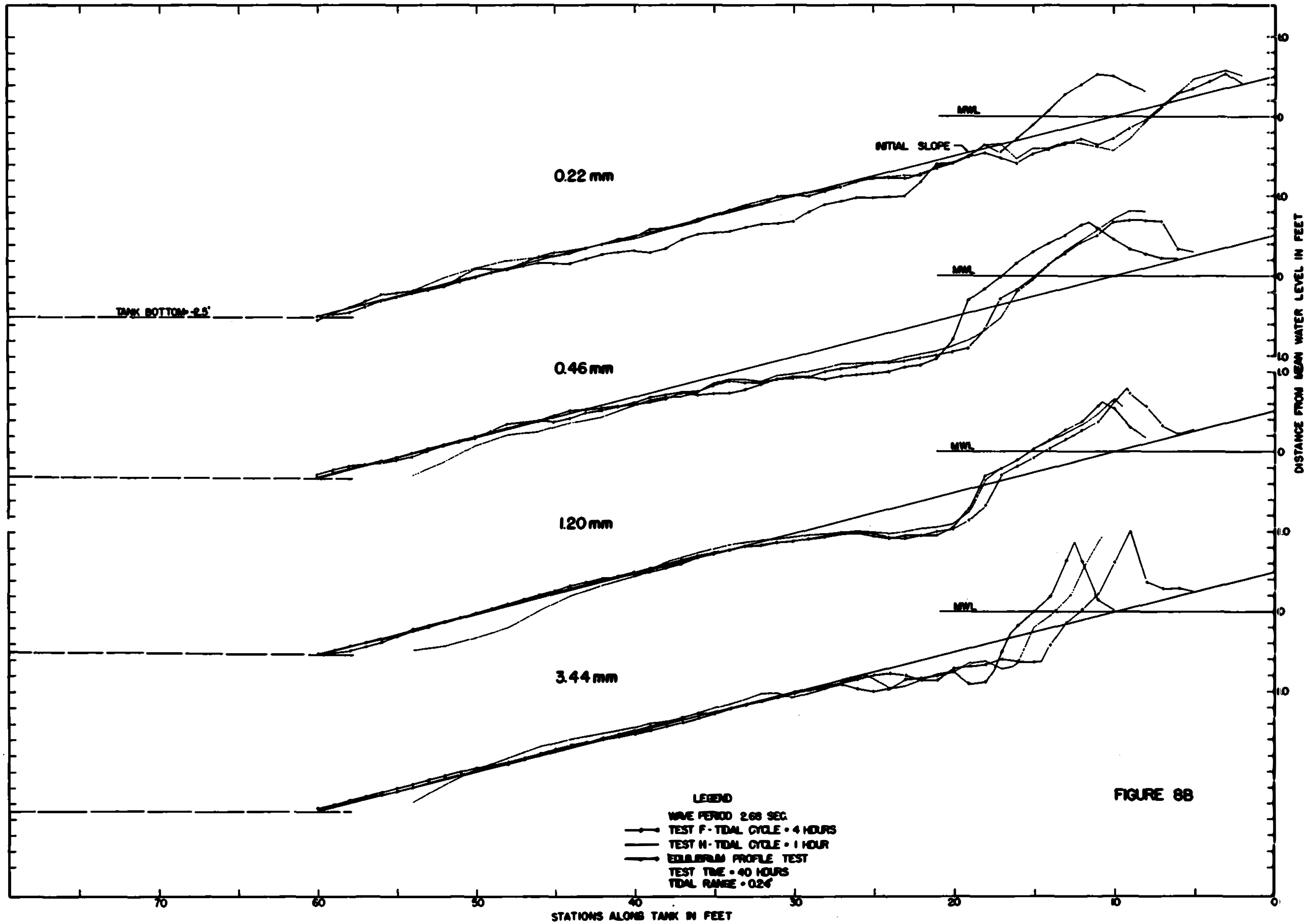

FIGURE 8 — EFFECT OF DURATION OF TIDAL CYCLE

TABLE 2

SAND SORTING DATA

	Test	Station 10	Station 20	Station 30	Station 40	Station 50	Max. Range about mean of Extreme Values ± %
Sand Class - 0.22 mm.							
Md_0 in mm.	A	0.20	0.19	0.18	0.18	---	5.3
	B	.21	.21	.21	.21	.21	0.0
	C	.22	.18	.21	.20	.15	19.0
Md_{40} in mm.	A	.27	.23	.24	.22	.21	
	B	.32	.22	.24	.21	.20	
	C	.23	.21	.21	.22	--	
Md_{40}/Md_0	A	1.35	1.21	1.36	1.22	--	
	B	1.54	1.08	1.15	1.01	0.98	
	C	1.05	1.11	1.03	1.15	--	
Sand Class - 0.46 mm.							
Md_0 in mm.	A	.62	.58	.54	.53	--	7.8
	B	.56	.42	.29	.42	.47	31.8
	C	.61	.34	.36	.36	.36	28.4
Md_{40} in mm.	A	1.30	.58	.37	.37	.40	
	B	.81	.40	.35	.27	.32	
	C	.74	.43	.35	.30	.27	
Md_{40}/Md_0	A	2.09	1.00	.63	.70	--	
	B	1.44	.96	1.21	.67	.68	
	C	1.21	1.29	.81	.64	.75	
Sand Class - 1.20 mm.							
Md_0 in mm.	A	1.65	.92	1.10	1.42	--	28.3
	B	1.10	1.07	1.20	1.23	.88	16.6
	C	1.00	1.95	1.05	1.09	.95	34.4
Md_{40} in mm.	A	1.70	.55	.80	1.15	1.02	
	B	2.35	1.12	.63	1.18	1.00	
	C	1.30	1.65	2.20	1.42	--	
Md_{40}/Md_0	A	1.03	.60	.73	.81	--	
	B	2.14	1.05	.53	.96	1.14	
	C	1.30	.85	2.10	1.30	--	
Sand Class - 3.44 mm.							
Md_0 in mm.	A	3.90	3.85	3.55	3.55	3.85	4.7
	B	4.00	3.90	3.40	3.80	4.55	14.5
	C	3.90	3.35	4.05	4.20	4.90	18.8
Md_{40} in mm.	A	5.20	5.10	3.20	3.55	3.90	
	B	5.20	4.60	3.50	3.70	4.50	
	C	5.30	3.90	3.70	3.70	3.80	
Md_{40}/Md_0	A	1.33	1.32	.90	1.00	1.02	
	B	1.30	1.18	1.03	.98	.99	
	C	1.36	1.16	.92	.88	.78	

* * * * * * * *

Md_0 indicates median diameter in original beach slope before testing
Md_{40} indicates median diameter after 40-hour test operation

Test Data

	Range (ft.)	Cycle (hrs.)
A	0.5	4
B	0.24	4
C	0.5	1

ANALYSIS OF RESULTS

Effect of the Tidal Range on Beach Profile. - The effect of the variation in tidal range was obtained by comparison of the tests presented in Figures 5 and 6. Figure 5 presents the results for the 2.00-second wave period and Figure 6 presents the results for the 2.68-second wave period, otherwise the only difference in the data results from the variation in tidal range.

In Figures 5A and 5B, for all size of sands, the resulting foreshore and offshore slopes appear to be about the same whether a 0.50 or 0.24-foot tidal range is introduced. The 0.50-foot tidal range tests indicate that more material is actually moved throughout the beach profile; that is, where the material is such that foreshore accretion or erosion dominates , the greater tidal range appears to make these actions more pronounced. In the finer sand classes (0.46 and 0.22 mm.), a system of offshore bars and troughs was formed when the tidal range was 0.24 foot; the system appears to exist also when a 0.50-foot tidal range is introduced; however, it is substantially reduced throughout the offshore zone.

In Figure 6A and 6B, where the test procedure was the same as that in Figures 5A and 5B except the wave period was 2.68 seconds, the results indicate that the foreshore and offshore slopes are essentially the same whether a 0.50 or 0.24-foot tidal differential is introduced. Again, the 0.50-foot tidal range appears to actually move more material throughout the beach profile. In these tests there was not the prevalent system of offshore bars and troughs (as compared to the 2.00-second period test) when the smaller tidal range was introduced. The bars and troughs that did exist in the offshore zone seem to be about the same whether a 0.50 or 0.24-foot tidal range was introduced.

Effect of the Tidal Cycle Duration on Beach Profile. - The effect of variation in tidal duration was obtained by comparison of Figures 7 and 8. Figure 7 presents the results for the 2.00-second wave and Figure 8 presents the results for the 2.68-second wave, otherwise the only difference in the data results from the variation in duration of the tidal cycle.

In Figures 7A and 7B, for all sizes of sands, the resulting foreshore and offshore slopes are essentially the same whether the tidal cycle was 4 hours or 1 hour. There is some evidence that the 4-hour cycle creates more actual material movement throughout the beach profile; however this tendency is not consistent for all tests in Figure 7. There were systematic bar and trough formations in the offshore zone when either tidal cycle frequency was used. The duration of tidal cycle seems to have had little influence on the bar and trough formation, although introduction of a tidal system considerably lessened the prominence of this formation.

In Figures 8A and 8B, where the test procedure was the same as in Figures 7A and 7B except that the wave period was 2.68-seconds, the results also indicate that the offshore and foreshore general slopes are virtually the same whether a 4-hour or 1-hour tidal cycle was introduced. There is no consistent evidence to indicate that either of the tidal durations will tend to move more material throughout the beach profile. The sytematic offshore bar and trough formation existed for either tidal duration used; however the formation was not very prevalent and there was no consistent evidence to indicate that either cycle duration tends to reduce this feature.

Comparison of Equilibrium and Tidal Profiles. - In comparing the resulting profiles for the constant period non-tidal tests and the tests presented herein, only Figures 5 and 6 are considered, since as previously pointed out, the data presented in Figures 7 and 8 are a rearrangment of the data from Figures 5 and 6. The results in Figures 5A and 5B which are for the 2.00-second wave period show that whether the tidal range is 0.50 or 0.24 foot the agreement between the constant period tests and the tidal tests remains essentially the same whether the tidal cycle duration is 1 hour or 4 hours. There was a tendency in the tidal tests toward greater actual material movement throughout the beach profile than in the constant period tests. The most significant difference was that the tendency toward formation of a series of offshore bars was greatest in the constant period test and by introducing the tidal cycle, these formations were considerably inhibited; the 0.50-foot tidal range being more effective in reducing the bar and trough system. The duration of the tidal cycle appeared to have little effect in inhibiting the formation of the bars or ridges.

The results in Figure 6 where the wave period was 2.68 seconds indicate introduction of a tidal cycle in the laboratory tests did not materially affect the general shape, or average foreshore and offshore slopes, of the resulting beach profiles. The general agreement between profiles resulting from the constant period tests and those of the tidal tests remains about the same whether the tidal range is 0.50 or 0.24 foot, or the tidal cycle duration is 4 hours or 1 hour. The one exception to this general agreement is for the 0.22-millimeter sand. The results in 6A and 6B show that the constant period wave action created a definite foreshore accretion with offshore erosion, whereas the introduction of a tidal cycle created a slight foreshore accretion, a slight offshore accretion, and erosion between these zones. The other three sand classes show similar profiles when the constant period and tidal tests are compared; the significant difference with tides being lengthened zones of offshore erosion and foreshore accretion. The crest positions of the foreshore accretion for the tidal tests are located shoreward of those for the constant period tests. Excluding the 0.22-millimeter sand, the resulting profiles for the tidal and constant period tests appear to have about the same foreshore and offshore slopes. The offshore bar and trough formations, inherent in the constant period tests for the finer sands, appear to be reduced by the tidal tests; the 0.50-foot tidal range being the most effective. The duration of the tidal cycle appeared to have little effect on the offshore formations.

Sand Sorting. - Table 2 presents the median diameters for sand samples taken along the initial slopes for three tests. These data reveal that for the 0.22-millimeter sand, the sand was fairly uniformly mixed for tests A and B, but apparently poorly mixed for test C since the magnitude of variation in median diameters for samples throughout the initial beach slope amounted to 19 percent. For the 0.46-millimeter sand, only test A indicates reasonably good consistency in mixing throughout the initial beach slope. The coarser materials, 1.20 and 3.44-millimeters, illustrate a greater spread in median diameters for samples taken along the initial profile. There was a general tendency for the material to be slightly "pre-sorted"; that is, the median diameters of samples were smaller in the seaward direction.

Table 2 also presents ratios of the median diameters for samples taken at various stations before and after 40 hours test time. For nearly all tests, these data show a coarser gradation of material in the nearshore zone (approximately station 10 to 30) and a finer gradation in the offshore zone, at the end of 40 hours of test time. For the data herein, there seems to be no apparent correlation between the size distribution and the range or duration of the tidal cycle. The sorting of the material from coarse to fine in a seaward direction along the beach profile seems to have been at about the same rate whether the tidal range was 0.50 or 0.24 foot, and about the same whether the tidal cycle required 4 hours or 1 hour.

DISCUSSION

Effect of Tidal Range. - As an increase in tidal range enables waves to reach farther landward, it would be expected that the resulting accretion or erosion in the foreshore zone would be positioned farther landward. The data presented in Figures 5 and 6 seem to verify this expectation. For the 0.22-millimeter sand in Figures 5A and 6A there is a general tendency for the foreshore zone to be eroded, due to the dominant wave characteristics relative to the sand size, and in each case for the 0.50-foot tidal range the resulting profile is positioned farther landward. This most landward position for the larger tidal range is the case for the resulting profiles in the other three classes of sands also. The prevailing feature in comparing the resulting profiles for the 0.50 and 0.24-foot tidal range is that in each test the resulting foreshore and offshore slopes remain about the same. The resulting slopes are essentially unaffected when either of the tidal ranges is employed. The influence of tidal ranges of either 0.24 and 0.50-foot is noticeable in the reduction of the systematic offshore bar and trough formations which are prevalent in the finer sands. The greater reduction of these bars was found when the 0.50-foot tide differential was employed. In addition to the effect of greater movement of the zone of wave action, this might be attributed to the fact that the 0.50-foot tide creates a 10 percent variation in wave steepness values, while the 0.24-foot tide creates only a 4 percent range in those values, thereby influencing the forces which cause changes in the offshore bottom configurations.

Effect of Tidal Cycle Duration. - The data plotted in Figures 7 and 8 do not exhibit any consistent evidence as to whether the 4 or 1-hour tidal cycle tends to move more material throughout the beach profile. In general, it appears that as long as the tidal differential is constant, the duration of the tidal cycle in the tests presented herein, has little relationships to or significant effect on the quantity of material moved. This perhaps is the reason that, as long as the tidal range is constant, the duration of the tidal cycle has little influence on the systematic formation of offshore bars and troughs. Perhaps of more significance for the tidal cycle duration tests is the fact that the resulting foreshore and offshore slopes are essentially the same, for all types of sands, whether the cycle was 4 hours or 1 hour in length.

Comparison of Equilibrium Profile and Tidal Tests. - Except with the 0.22-millimeter sand, the foreshore and offshore slopes formed by the constant period non-tidal tests agree very closely with the slopes as formed when the water level was varied. The introduction of a 0.24 or 0.50-foot tidal differential and repeating the tidal cycle every 4 hours or every hour, seemed to introduce few appreciable changes in the final profile slopes for sands other than the 0.22-millimeter sand. The results of these tests do show that the dominant direction of movement of material can be influenced by introduction of tidal action. This is illustrated in Figure 6A for the 0.22-millimeter sand where the constant period wave attack produced a final beach profile of foreshore accretion and offshore erosion, whereas the tidal tests indicated no predominant direction of movement, the material movement resulting in slight offshore accretion and slight foreshore accretion with erosion between these zones. The cause of this difference in resulting profiles between tests where the test procedure was the same except that tidal action was introduced could be attributed to the fact that as the water level was varied, the effective wave steepness values were changed. The relationships between the 0.22-millimeter sand and the effective wave steepness values are undoubtedly near a critical point, with a result that there is no dominant onshore or offshore movement of material.

The constant period non-tidal tests tended to form patterns of offshore bars and troughs for the finer sands and by introducing a tidal action these bars and troughs were reduced. Variation of tidal magnitude appears to have more influence than that of tidal duration on these offshore formations. It was pointed out in the variable wave period study that these offshore formations are probably a result of nodal zones created by reflected energy from the foreshore zone and the energy propagated by the approaching waves. As the tidal action is introduced, the repetitive action of the system is somewhat interrupted (both by slight changes in wave height, and by movement of the zones of wave action, and presumably of these nodal points) and the magnitude of the offshore bar and trough formation is reduced.

Sand Sorting. - In this series of tests, care was exercised in mixing the sand after completion of each test; however the data as presented in Table 2 illustrate the almost unavoidable variations in material characteristics. The data show that it is difficult to obtain a distribution of sands of the same median diameter throughout the initial beach profile after previous testing has resulted in a selective sorting of the sand by grain size. The influence of this rather heterogeneous bed mixture on the resulting final beach profile cannot be evaluated from these tests; however it must be assumed that it is not too influential on the final form of the profile, since in general the test results, in terms of final slopes, appear to be compatible with those of the two other series of tests performed with the same sands. The variations of results that are probable in the actual sampling procedure have not been evaluated; therefore the percentage variations indicated in Table 2 could be influenced by this factor.

The data presented in Table 2 show also that for all tests studied there is a sorting of material along the final beach profile, coarser material being in the foreshore zone and the finer material being in the offshore zone. The data do not indicate any correlation for sand sorting as a result of introducing a tidal system.

CONCLUSIONS

As a result of this study, it is concluded that the introduction of tidal action, regardless of range or duration of cycle, does not cause appreciable changes in the foreshore or offshore slopes. However introduction of tidal action entails changes in wave steepness values with the result that for critical values of steepness relative to sand size distinct changes in the equilibrium profile may occur. Tidal action in proportion to its range causes a greater movement of material throughout the beach profile and is more effective in inhibiting offshore bar and trough formation inherent in the non-tidal tests. The greater movement of material associated with the tidal tests resulted in higher berms accompanied by shore line recession, as compared to previous non-tidal tests.