CHAPTER 114

COMPUTER ALGORITHM OF WAVE RUNUP ON BEACHES

by

Flora Chu Wang[1] A. M. ASCE, James A. Purpura[2] M. ASCE

Tsao-Yi Chiu[3] and Yu-Hwa Wang[4] A. M. ASCE

ABSTRACT

An efficient computer program for predicting wave runup on beach profiles is presented. The solution is derived through the IBM 370/165 of the Computing Center, University of Florida.

The wave runup data utilized in this study is based on the laboratory-derived curve obtained from the experimental work of Saville, and expressed as linear regression; the historical storm frequency data is furnished by National Oceanic and Atmospheric Administration; and the surveyed beach profile is supplied by the field program of Coastal and Oceanographic Engineering Laboratory, University of Florida.

A broad spectrum of waves are selected to simulate hurricanes approaching the coast. The results thus obtained should provide useful guidelines in establishing the Coastal Construction Setback Line, and to the design criterion of Coastal Structures.

[1] Civil Engineer Consultant, 741 N. W. 36th Street, Gainesville, Florida.

[2] Professor of Civil & Coastal Engineering Department, University of Florida, Gainesville, Florida.

[3] Associate Engineer of Coastal & Oceanographic Engineering Laboratory, University of Florida, Gainesville, Florida.

[4] Assistant Professor of Civil & Coastal Engineering Department, University of Florida, Gainesville, Florida.

INTRODUCTION

In 1971, the Legislature of the State of Florida (8) enacted that the Department of Natural Resources shall establish a Coastal Construction Setback Line along the sand beaches of the State fronting on the Atlantic Ocean and the Gulf of Mexico.

The law provides that the establishing of such setback line shall be based on data determined from comprehensive engineering and topographic surveys which include dune elevations, foreshore slopes, offshore slopes, beach profiles, upland development and vegetation-bluff lines; and from historical storm and hurricane tides, the beach erosion trends, and the predicted wave runup.

The present study is attempted to develop an efficient computer algorithm for predicting wave uprush upon a complicated beach surface with changing slopes, and to facilitate the decision-making process in establishing of the construction of the setback line along the beaches.

BACKGROUND

Theory of Breaking Waves

No generally applicable wave runup theory exists for breaking waves. Breaking is known as a non-conservative process, and breaking point is a mathematical singularity.

LeMéhauté and Koh (2) concluded that the runup of breaking waves has been determined by theory only in the case of solitary waves, but the problem becomes increasingly difficult as the wave period decreases (or as the wave steepness increases) due to the influence of the backwash on the following waves.

The Bore runup theory elucidated by Shen and Meyer (9) which allows breaking is based on the first-order nonlinear long wave equations, the runup according to this theory depends very weakly on the slope of the beach, hence the analysis thus derived is of academic interest, and cannot be used for calculating the runup for the practical applications.

Experimental Investigations

Theory has not yet been able to give an accurate estimate of runup caused by waves on sloping beaches or structures, many experiments have been performed systematically to supplement the principle. An excellent qualitative description of the experimental findings has been summarized by the Beach Erosion Board Technical Report No. 4 (10).

Saville (6) performed a large number of experiments and found that wave runup R, the vertical height to which water from a breaking wave will rise on the structure face, increased with water depth d at the toe of the structure until a water depth-wave height ratio of between 1 and 3 was reached. His results were presented graphically showing the relative runup R/H_o' as a function of structure slope α, structure depth d and wave steepness H_o'/T^2, where H_o' referred to the equivalent deep water wave height and T the wave period.

Savage (5) furthered the experiments of Saville by including the effects of roughness and permeability. The recent experimental study of Machemehl and Herbich (3) on the effect of slope roughness on wave runup showed that the relative runup was reduced approximately 15% and 30% for regular and irregular wave tests respectively.

The work of Saville has been used for a number of years with reliability, hence his laboratory test data of relative runup is utilized in this study as a part of computer input.

Methods for Determining Wave Runup

Numerical analysis based on the method of characteristics has been developed by Freeman and LéMehauté (1) to calculate the runup of solitary waves and its effect due to bottom slopes. The predictions based on this method unfortunately depend on the chosen value of a constant which is somehow based on experience.

Wagges (12) proposed an empirical relationship between the breaker height-breaking depth ratio, wave steepness and the beach slopes. The proposed equations are approximations to what is usually scattered laboratory breaker data.

An approximate method for determining wave runup on composite slopes from laboratory-derived curves for single slopes was first presented by Saville (7). His method was one of successive approximations which involved the replacement of the actual composite slope with a hypothetical slope obtained from the breaking depth d_b, and an estimated wave runup R value. Saville found that the wave runup predicted by his method to be generally within 90% of experimental values except for the largest berms tested. The indications were that, after a horizontal berm had reached a certain width, further widening had no significant effect in reducing wave runup.

There is at present no proven technique to adequately describe a breaking wave in mathematical form, the approximate method of Saville's uprush prediction is adapted in the current analysis as a part of computer algorithm.

DESCRIPTION OF INPUT DATA

Laboratory-Derived Runup Curve

A typical laboratory-derived runup curve by Saville (7) is shown in Fig. 1. It delineates the model-determined relation between relative runup R/H_o' and structure slope $\cot\alpha$ as a function of wave steepness H_o'/T^2.

Data are read from the curve and are presented in Table 1, and have been used as an input for linear regression analysis. Their functional relationships have thus been obtained for different values of wave steepness. Many examples have demonstrated the frequency dealing with waves of H_o'/T^2 between 0.04 and 0.15 and practically never with values less than 0.005 or greater than 0.4; they have also exhibited that the computed hypothetical slopes are always in the range of 1 on 4 and 1 on 10 or flatter. Therefore, their lower and upper bounds, and linear logarithmic functional relationships displayed in Table 1 are justified under the practical considerations, and have been incorporated in the computer algorithm for ease of handling input data.

Topographic Surveyed Beach Profile

Fig. 2 shows the location map of a part of the study area and range lines for St. Lucie County, Florida.

The surveyed beach and offshore profiles range number 36 are displayed in Fig. 3 which are supplied by the field program of the University of Florida (4). The profile lines are begun behind the dune where existing and are extended seaward to wading depth. The profile input data are read in an increasing order of horizontal distance X associated with the elevation Y from the mean sea level. Due to the core storage requirement, the maximum of 50 stations are designed for each profile; and a maximum of 30 beach profiles can be included in the program as a single computer run.

Historical Storm Frequency Data

No reliable storm surge records are available of water levels on the open coast of Florida during major hurricanes which have occurred in the past few decades.

In a study of storm tide in Florida (11), the Department of Coastal and Oceanographic Engineering, University of Florida has analyzed the normal yearly high tides and high water levels caused by hurricanes and expressed the results as frequency of occurrence for a certain water level to be equaled or exceeded. Due to the lack of available data for the study area, the surge frequency curve thus derived indicates a much higher trend than the information newly furnished by National Oceanic and Atmospheric Administration (NOAA). Both surge elevation frequency curves are shown in Fig. 4.

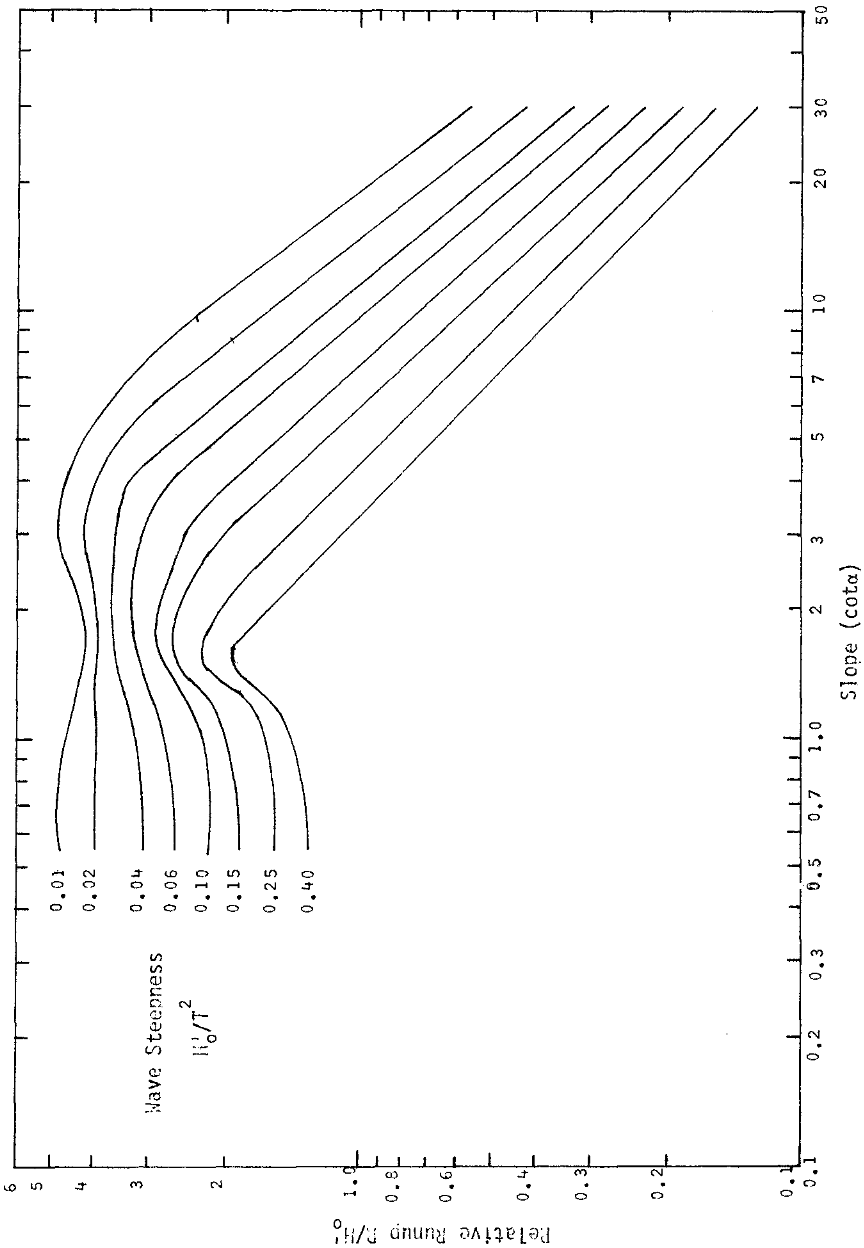

FIG. 1. - Relative Runup for Specific Values of Wave Steepness (After Saville, 1958)

TABLE 1. - Experimental Data of Relative Runup Read from Fig.1

Wave Stepness H_o'/T^2 / Slope cotα	Relatvie Runup R/H_o'							
	(1) 0.40	(2) 0.25	(3) 0.15	(4) 0.10	(5) 0.06	(6) 0.04	(7) 0.02	(8) 0.01
1.9	1.70 (a)							
2.5	1.27	1.64 (a)						
3.3	0.98	1.25	1.85 (a)	2.40 (a)				
4.0	0.83	1.05	1.51	1.95	2.80 (a)	3.40 (a)		
6.0	0.56	0.72	0.99	1.27	1.74	2.10	3.00 (a)	
8.0	0.43	0.54	0.73	0.93	1.25	1.50	2.10	3.00 (a)
10.0	0.35	0.44	0.58	0.74	0.97	1.16	1.60	2.27
15.0	0.24	0.30	0.38	0.48	0.61	0.73	0.90	1.35
20.0	0.18	0.23	0.28	0.35	0.44	0.52	0.68	0.92
25.0	0.15	0.19	0.22	0.28	0.34	0.40	0.52	0.69
30.0	0.13	0.16	0.18	0.23	0.28	0.32	0.41	0.55
38.5	0.10 (b)	0.12	0.14	0.18	0.21	0.24	0.31	0.40
48.5		0.10 (b)	0.11	0.14	0.16	0.19	0.23	0.29
53.0			0.10 (b)	0.13	0.15	0.17	0.21	0.26
66.0				0.10 (b)	0.11	0.13	0.16	0.20
73.0					0.10 (b)	0.12	0.14	0.17
83.0						0.10 (b)	0.13	0.15
95.0							0.10 (b)	0.12

Note:
(a) Preset upper bound of relative runup for linear logarithmic interpolation
(b) Preset lower bound of relative runup for linear logarithmic interpolation

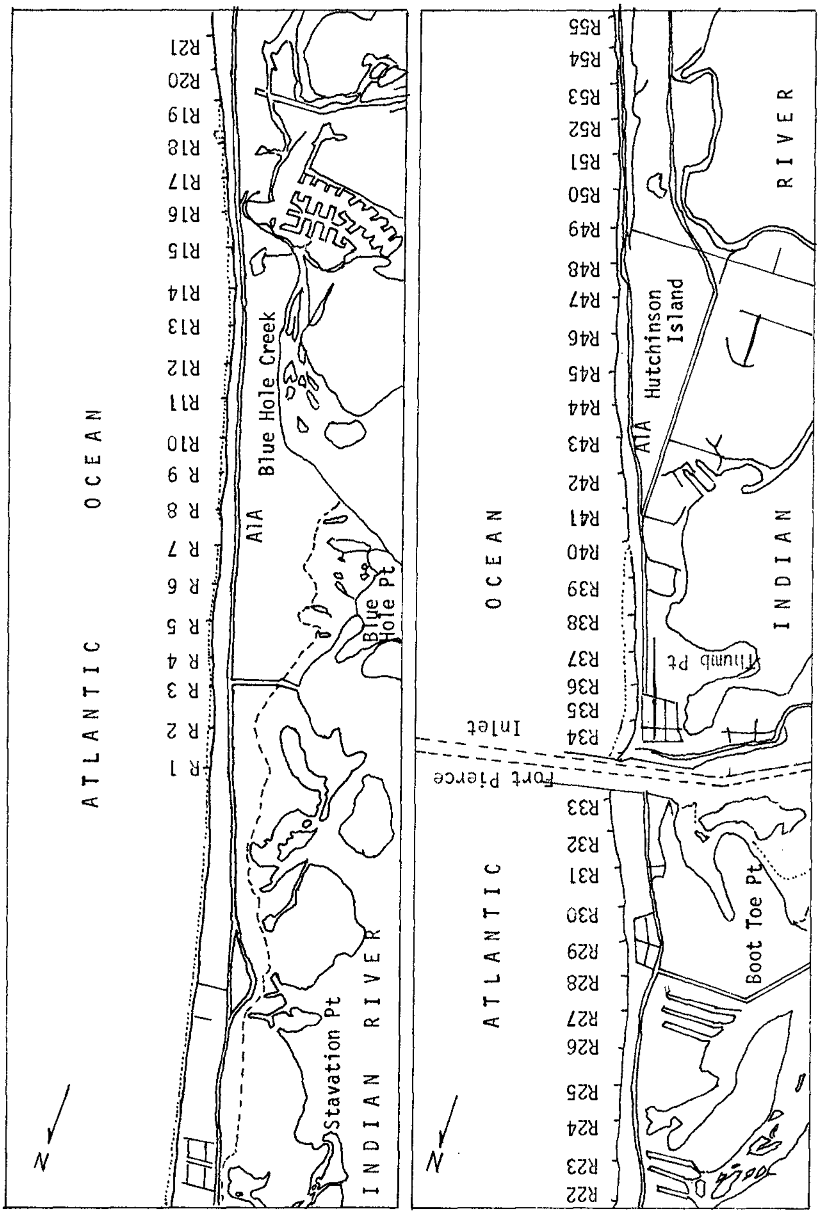

FIG. 2. - Location Map of Study Area and Range Lines, St. Lucie County, Florida (After University of Florida,1972)

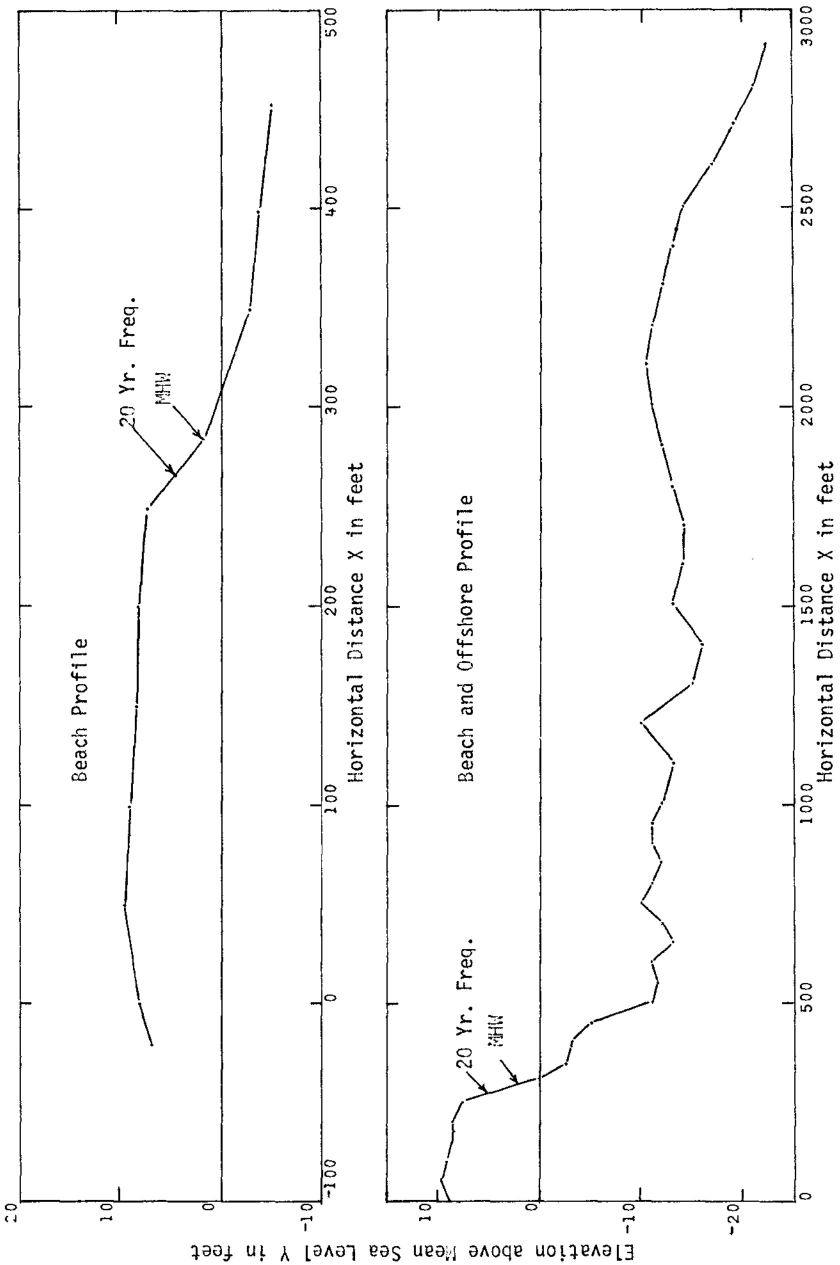

FIG. 3. - Surveyed Beach and Offshore Profiles Range Number 36, St. Lucie County, Florida (After University of Florida, 1972)

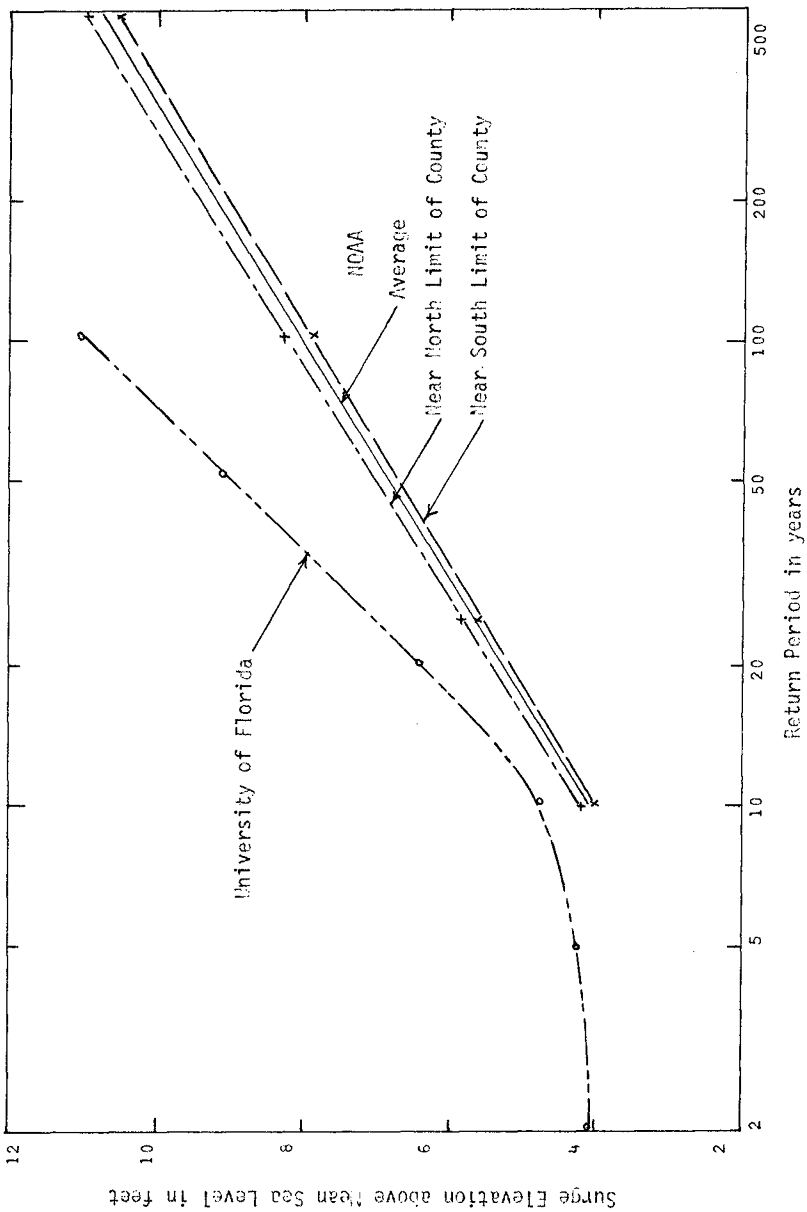

FIG. 4. - Storm Surge Elevation Frequency Curves, St. Luice County, Florida
(After NOAA, 1972 and University of Florida, 1962)

The NOAA's data are utilized in the present study. For example, with a return period of 20 years, a 5.3 ft. of storm surge is read directly from the curve, superimposed with an estimated 2.0 ft. of wave setup and a predicted mean high tide level of 1.9 ft., the total of 9.2 ft. still water level can be used in the study to simulate a hurricane approaching the coast. Similarly, a 4.5 ft. still water level could also be used to represent a condition under normal weather but with heavy action caused by remote storms.

Wave Heights and Wave Periods

The wave forecasting procedures may be used to translate the comprehensive offshore wind speed and direction data into wave data. With the advent of high-speed computers, a broad spectrum of waves can be examined for the responses of each beach profile. Wave heights range from 2 ft. to 26 ft. and wave periods from 4 to 16 seconds have been tested to estimate the wave uprush upon the surveyed beach profiles. Six combinations of wave height and wave period for each value of still water level are designed as one set of input data on wave condition.

DEVELOPMENT OF COMPUTER ALGORITHM

Initial Estimation of Wave Runup Profile

The initial wave runup at each beach station is estimated by assuming a hypothetical slope extending from the breaking point to the point of the station. The relationships between the estimated slope $\cot\alpha_i$ at the station i and breaking depth d_b are

$$\cot\alpha_i = \frac{X_{db} - X_i}{Y_i - Y_{db}} \qquad \text{.........................(1)}$$

wherein (X_i, Y_i) are the coordinates at beach station i and (X_{db}, Y_{db}) are the coordinates of breaking depth d_b intercepted with beach profile and computed by the solitary wave equation for a given set of wave height H_o' and wave period T,

$$d_b = \frac{H_o'}{1.5(H_o'/T^2)^{1/3}} \qquad \text{.........................(2)}$$

Using this computed hypothetical slope and a known wave steepness, a value of initial runup R_i at station i can be determined from the linear regression of laboratory-derived runup curve. Thereby, for a chosen still water level WTL, the vertical coordinate of runup Y_i' can be expressed as

$$Y_i' = R_i + WTL \qquad \text{.........................(3)}$$

The runup of other stations are also routed, the initial wave runup profile can thus be predicted.

Search for Feasible Wave Runup

The previous step provides a logical estimation of initial wave runup profile. From then on, three possible cases can be identified:

(a) All runup are above their beach stations, no feasible runup;
(b) all runup are below their beach stations, no solution either;
(c) some runup are above their beach stations and some are below, a feasible solution exists.

Based upon the theory of linearity, the refined algorithm is initiated, it says: For any two successive beach stations, if runup of first point is above its beach station while the second one is below, or vice versa, then there exists a feasible solution. Such solution can be found by the iterative procedure presented as follows:

(a) Find the linear equation of two successive beach stations (X_i, Y_i) and (X_{i+1}, Y_{i+1}) exhibiting alternative runup;
(b) find the linear equation of these two alternative runups (X_i, Y'_i) and (X_{i+1}, Y'_{i+1});
(c) find the intersection (X_r, Y_r) of the above two linear equations, which can be easily varified as:

$$X_r = \frac{X_i(Y_{i+1} - Y'_{i+1}) + X_{i+1}(Y'_i - Y_i)}{(Y'_i - Y_1) + (Y_{i+1} - Y'_{i+1})} \quad \text{....................(4)}$$

$$Y_r = \frac{Y_i(Y_{i+1} - Y'_{i+1}) + Y_{i+1}(Y'_i - Y_i)}{(Y'_1 - Y_i) + (Y_{i+1} - Y'_{i+1})} \quad \text{....................(5)}$$

(d) compute the hypothetical slope extending from the breaking point (X_{db}, Y_{db}) to the point of intersection (X_r, Y_r);
(e) determine the new runup R_n by known regression function;
(f) if the difference of new runup with initial estemated one is less than a tolerance limit TL, say 0.05 feet, then the feasible runup has been obtained;
(g) otherwise, repeat the process by substituting

$$\begin{aligned} X_{i+1} &= X_r \\ Y_{i+1} &= Y_r \\ Y'_{i+1} &= R_n + WTL \end{aligned} \quad \text{....................(6)}$$

and find the new intersection point which in turn determines a new runup.

Final Recommendation of Wave Runup

The above algorithm further provides a multiple choice of feasible runup for a beach surface with changing slopes. This information is extremely valuable to the designer from a coastal engineering point of view. In the present computer model, the final recommended runup R_f for a given wave condition is taken as that feasible runup with maximum X distance, that is, the one which is closest to the offshore.

FORMULATION OF COMPUTER PROGRAM

The preceeding algorithms have been translated into a FORTRAN IV program for use with the University of Florida IBM 370/165 computer, and consists of a main routine and 9 subroutines. The main program MAI is designed to read in all input data, to initiate calling a series of subroutines, and to print out the detailed results and summary tables.

The input are designed with up to 30 beach profiles and up to 50 stations for each profile. Each wave condition, designed as 6 combinations of wave height and wave period associated with one still water level, is treated as a new sub-problem, therefore, no limitation on number of wave conditions has been imposed.

The functions of each subroutine are described briefly as follows:

(a) Subroutine STA is designed to find the lowest station of the beach profile;
(b) subroutine BXY is developed to compute the wave steepness, the breaking depth and its coordinates intercepting with the beach profile;
(c) subroutine STL is used to find the still water level which intercepts the beach profile;
(d) subroutine INT is designed to interpolate the known regression equation of relative runup;
(e) subroutine RNI is developed to estimate the initial wave runup profile;
(f) subroutine RNF is used to search for the feasible runup;
(g) subroutine RNR is designed to recommend the final computed runup;
(h) subroutine OPD is developed to pring out the detailed results for each beach profile, and reprint the input data to facilitate checking; and
(i) subroutine OPS is used to print out the summary results for a group of 12 beach profiles under one wave condition.

The program logic and the sequence in which individual steps performed are displayed in Fig. 5. The program requires 21,584 bytes of storage; 1,218 bytes for the main program, and 20,366 bytes for 9 subroutines.

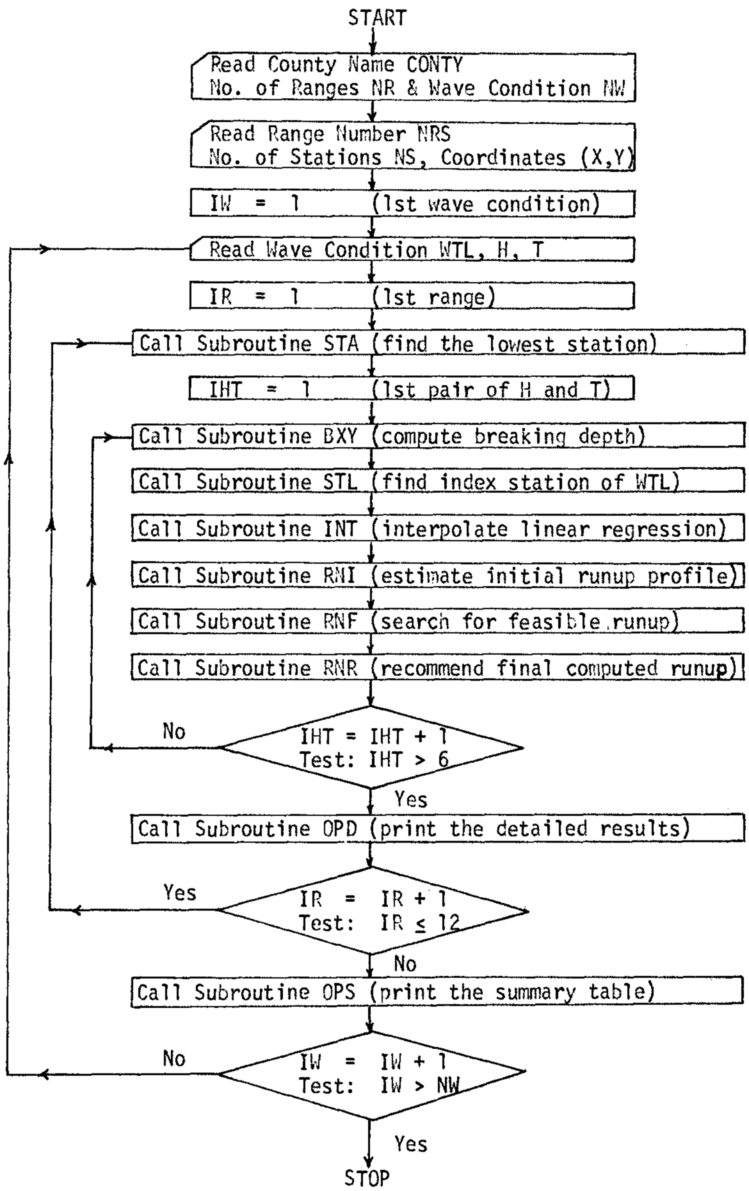

FIG. 5. - Flow Chart for the Wave Runup FORTRAN Computer Program

SAMPLE PROBLEM AND COMPUTER RESULTS

The beach profile range number 7 of St. Lucie County, Florida is used for an example problem. The profile consists of 12 beach stations. Still water level of 9.2 feet is used in conjunction with waves of 4, 6, 8 and 10 feet in height and 6, 8 and 10 seconds in period. A sample input data is illustrated in Fig. 6.

Detailed computer results from a series of calculations of wave runup on beach profiles are shown in Table 2. All essential input data are also printed in Table 2.

The summary results for a group of 12 beach profiles are printed in a tabular form which makes it a relatively easy task for analyzing by the design engineer. Table 3 is a typical computer summary output.

Fig. 7 shows the engineering significance of all message output in a graphical form. The computer plotting is currently being developed at the Department of Civil and Coastal Engineering, University of Florida.

CONCLUSIONS AND RECOMMENDATIONS

For examining the response of the 24 beach profiles to a variety of waves, eighteen combinations of still water level, wave height, and wave period are used to compute the wave runup. For these 432 study cases, the total computer execution time is 13.79 seconds CPU on IBM 370/165. The results of these studies show that:

(a) The extreme high waves do not cause high runup due to the fact that they break far from the shorelines;
(b) lower waves (or reformed waves) with longer periods produce much higher runup;
(c) because of the low dune elevation in the study area of St. Lucie County, over 90% of the beach profiles are overtopped with the 9.2 ft. still water level and wave of 6 ft. in height and 8 seconds in period. Even with the 4.5 ft. still water level, some low profiles are overtopped by the low and long waves.

The computer program developed herein is mainly for the computations of wave uprush on beach profiles. The results thus obtained are essential to the design criterion in setting up coastal construction setback lines. At the certain time interval, with new surveyed data which in turn makes the new computer results available, the establishment of such setback line could be subject to review by the Department of Natural Resources.

The methodology of this computer program in the prediction of wave runup can be equally applied to the design crest elevation of protective structures subject to wave action such as breakwaters, seawalls, beach fills, and dams. It is hoped that the current computer approach could be served as a viable tool in the design and analysis processes.

Card A: County Name, Number of Beach Profile and Wave Condition (10A4,2I10)

CONTY				NR	NW		
ST. LUICE	COUNTY			1	1		

Card B: Beach Profile Range Number, and Number of Beach Stations (2I10)

NRS	NS						
7	12						

Card C: Beach Station Coordinates (11F7.0)

X	Y	X	Y	X	Y	X	Y	X	Y	X
-80.0	11.04	-50.0	10.73	0.0	12.19	50.0	12.24	75.0	9.09	100.0
11.37	130.0	10.69	133.0	8.73	150.0	6.28	200.0	1.48	250.0	-1.77
280.0	-4.07									

Card D: Wave Condition (F5.0,5x,12F5.0)

WTL	H	T	H	T	H	T	H	T	H	T	H	T	
9.20	4.0	6.0	6.0	6.0	4.0	8.0	6.0	8.0	8.0	10.0	10.0	10.0	

FIG. 6. - Input Data Form of Wave Runup Computer Program

TABLE 2. - Detailed Results of Wave Runup Computer Program

ST. LUICE COUNTY

WAVE RUNUP ON BEACHES

RANGE NUMBER 7 STILL WATER LEVEL = 9.20 FEET

STA NO.	DIST. X FT.	ELEV. Y FT.	H = 4.0 FT. T = 6.0 SEC.			H = 6.0 FT. T = 6.0 SEC.			H = 4.0 FT. T = 8.0 SEC.			H = 6.0 FT. T = 8.0 SEC.			H = 8.0 FT. T = 10.0 SEC.			H = 10.0 FT. T = 10.0 SEC.		
			DB 5.54	XDB 177.3	YDB 3.66	DB 7.26	XDB 195.3	YDB 1.94	DB 6.71	XDB 189.5	YDB 2.49	DB 8.80	XDB 216.6	YDB 0.40	DB 12.4	XDB 268.2	YDB -3.17	DB 14.4	XDB *	YD8 *
			R	XR	YR	R	XR	YR	R	XR	YR	R	XR	YR	R	XR	YR	R	XR	YR
1	-80.0	11.04	0.78	-	-	1.08	-	-	1.05	-	-	1.49	-	-	2.27	+	+	*	*	*
2	-50.0	10.73	0.85	-	-	1.18	-	-	1.15	-	-	1.59	-55.8	10.79	2.44	+	+	*	*	*
3	0.0	12.19	1.35	-	-	1.76	-	-	1.81	-	-	1.69	-44.4	10.89	3.26	+	+	*	*	*
4	50.0	12.24	1.94	-	-	2.41	-	-	2.58	-	-	3.04	50.0	12.24	4.07	+	+	*	*	*
5	75.0	9.09	1.76	60.1	10.96	2.32	55.7	11.52	2.49	54.3	11.69	2.63	+	+	3.63	+	+	*	*	*
6	100.0	11.07	2.82	+	+	3.31	+	+	3.71	+	+	4.02	+	+	4.94	+	+	*	*	*
7	130.0	10.69	4.49	+	+	4.71	+	+	5.62	+	+	5.31	+	+	5.91	+	+	*	*	*
8	133.3	8.73	3.40	+	+	3.80	+	+	4.37	+	+	4.42	+	+	5.16	+	+	*	*	*

NOTE: " - " = RUNUP IS BELOW THE STATION
" + " = RUNUP IS OVER TOPPING
" * " = BREAKING DEPTH IS LOWER THAN THE LOWEST STATION

TABLE 3. - Summary Results of Wave Runup Computer Program

ST. LUICE COUNTY STILL WATER LEVEL = 9.20 FEET WAVE RUNUP ON BEACHES						
RANGE NUMBER	H= 4.0 FT T= 6.0 SEC	H= 6.0 FT T= 6.0 SEC	H= 4.0 FT T= 8.0 SEC	H= 6.0 FT T= 8.0 SEC	H= 8.0 FT T=10.0 SEC	H=10.0 FT T=10.0 SEC
2	R= 2.24 FT X= 22.6 FT Y=11.44 FT	R= 1.75 FT X=-28.1 FT Y=10.95 FT	R= 1.71 FT X=-34.5 FT Y=10.91 FT	R= 5.47 FT + +	R= 6.03 FT + +	* * *
3	R= 1.05 FT X= 50.0 FT Y=10.25 FT	R= 1.09 FT X=-15.1 FT Y=10.29 FT	R= 1.07 FT X=-11.8 FT Y=10.27 FT	R= 1.14 FT X=-102.4FT Y=10.34 FT	R= 1.81 FT X=-122.4FT Y=11.01 FT	* * *
4	R= 0.59 FT X=-83.3 FT Y= 9.79 FT	R= 0.84 FT X=-97.7 FT Y=10.04 FT	R= 0.79 FT X=-94.8 FT Y= 9.99 FT	R= 4.52 FT + +	R= 6.44 FT + +	* * *
5	R= 7.94 FT + +	R= 6.17 FT + +	R= 8.08 FT + +	R= 6.63 FT + +	R= 7.27 FT + +	R= 8.07 FT + +
6	R= 1.99 FT X=114.2 FT Y=11.19 FT	R= 1.60 FT X= 61.5 FT Y=10.80 FT	R= 1.57 FT X= 57.2 FT Y=10.77 FT	R= 1.88 FT X= 27.8 FT Y=11.08 FT	R= 2.03 FT X=-72.9 FT Y=11.23 FT	* * *
7	R= 1.76 FT X= 60.1 FT Y=10.96 FT	R= 2.32 FT X= 55.7 FT Y=11.52 FT	R= 2.49 FT X= 54.3 FT Y=11.69 FT	R= 3.04 FT X= 50.0 FT Y=12.24 FT	R= 5.16 FT + +	* * *
8	R= 1.62 FT X= 5.9 FT Y=10.82 FT	R= 1.41 FT X=-54.6 FT Y=10.61 FT	R= 1.41 FT X=-54.4 FT Y=10.61 FT	R= 1.89 FT X=-69.6 FT Y=11.09 FT	R= 2.69 FT X=-94.8 FT Y=11.89 FT	* * *
9	R= 1.80 FT X= 20.4 FT Y=11.00 FT	R= 2.42 FT X= 17.3 FT Y=11.62 FT	R= 2.43 FT X= 8.7 FT Y=11.63 FT	R= 3.57 FT + +	R= 4.30 FT + +	* * *
10	R= 1.66 FT X= 29.6 FT Y=10.86 FT	R= 2.10 FT X= 19.2 FT Y=11.30 FT	R= 2.19 FT X= 17.2 FT Y=11.39 FT	R= 2.74 FT X= 4.2 FT Y=11.94 FT	R= 2.88 FT X=-26.8 FT Y=12.08 FT	* * *
11	R= 2.24 FT X= 36.3 FT Y=11.44 FT	R= 2.85 FT X= 31.2 FT Y=12.05 FT	R= 2.90 FT X= 20.9 FT Y=12.10 FT	R= 2.82 FT X= -5.4 FT Y=12.02 FT	R= 3.52 FT X=-28.9 FT Y=12.72 FT	* * *
13	R= 2.50 FT X=109.4 FT Y=11.70 FT	R= 2.94 FT X=106.9 FT Y=12.14 FT	R= 3.39 FT X=104.4 FT Y=12.59 FT	R= 3.86 FT X=101.8 FT Y=13.06 FT	R= 4.26 FT X= 80.1 FT Y=13.46 FT	* * *
14	R= 3.26 FT X= 75.5 FT Y=12.46 FT	R= 3.79 FT X= 72.2 FT Y=12.99 FT	R= 4.45 FT X= 68.2 FT Y=13.65 FT	R= 4.94 FT X= 65.3 FT Y=14.14 FT	R= 5.67 FT X= 52.8 FT Y=14.87 FT	* * *

NOTE: " + " = ALL RUNUP ARE OVER TOPPING
" * " = BREAKING DEPTH IS LOWER THAN THE LOWEST STATION

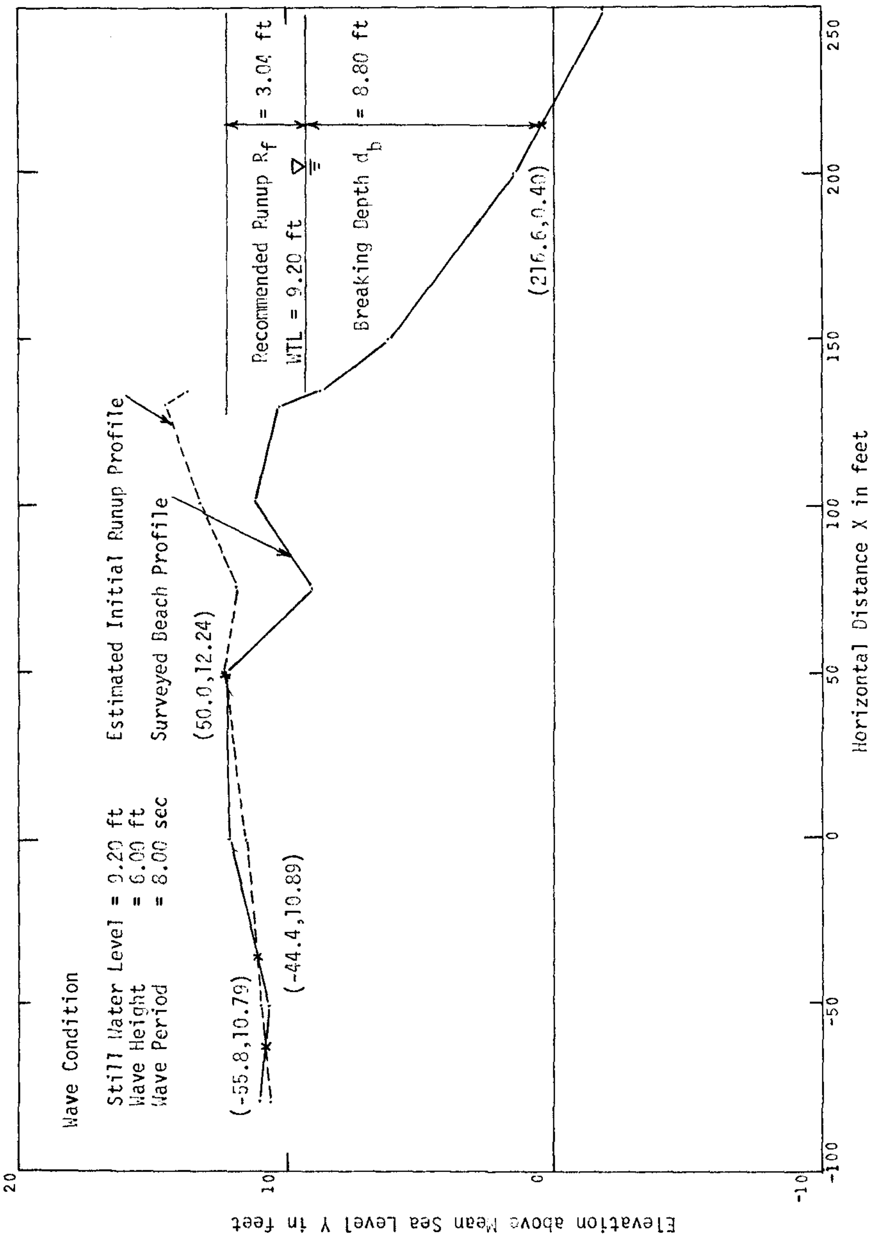

FIG. 7. - Surveyed Beach and Estimated Initial Runup Progiles, Range Number 7, St. Lucie County, Florida

APPENDIX I. - REFERENCES

1. Freeman, J. C., and LeMéhauté, "Wave Breakers on a Beach and Surges on a Dry Bed," Journal of the Hydraulics Division, ASCE, Vol. 90, No. HY2, Proc. Paper 3834, March, 1964.

2. LéMehauté, B., Koh, Robert C. Y., and Hwang, Li-San, "A Synthesis on Wave Run-up," Journal of the Waterways and Harbors Division, ASCE, Vol. 94, No. WW1, Proc. Paper 5807, February, 1968.

3. Machemehl, J. L., and Herbich, J. B., "Effects of Slope Roughness on Wave Run-up on Composite Slopes," Coastal Engineering Department, Texas A & M University, Report No. 129, August, 1970.

4. "Recommended Coastal Setback Line for St. Lucie County, Florida," Department of Coastal and Oceanographic Engineering, Engineering and Industrial Experiment Station, College of Engineering, University of Florida, Gainesville, June, 1972.

5. Savage, R. P., "Wave Run-up on Roughened and Permeable Slopes," Journal of the Waterways and Harbors Division, ASCE, Vol. 84, No. WW3, Proc. Paper 1640, May, 1958.

6. Saville, T., Jr., "Wave Run-up on Shore Structures," Journal of the Waterways and Harbors Division, ASCE, Vol. 82, No. WW2, Proc. Paper 925, April, 1956.

7. Saville, T., Jr., "Wave Run-up on Composite Slopes," Proceedings, 6th Conference on Coastal Engineering, Council on Wave Research, University of California, 1958.

8. Section 161.053, Coastal Construction and Excavation, Florida Statutes, Enacted by the Legislature of the State of Florida, June, 1971.

9. Shen, M. C., and Meyer, R. E., "Climb of a Bore on a Beach, Part 3, Run-up," Journal of Fluid Mechanics, Vol. 16, 1963, pp. 113-125.

10. "Shore Protection, Planning and Design," Technical Report No. 4, 3rd edition, Beach Erosion Board, Corps of Engineers, U. S. Department of the Army, Washington, D. C., 1966.

11. "Storm Tides in Florida as Related to Coastal Topography," Bulletin Series No. 109, Florida Engineering and Industrial Experiment Station, University of Florida, Gainesville, 1962.

12. Weggel, J. R., "Maximum Breaker Height," Journal of Waterways and Harbors Division, ASCE, Vol. 98, No. WW4, Proc. Paper 9384, November, 1972.

APPENDIX II. - NOTATION

The following symbols are used in this paper:

d = water depth at the toe of the structure;

d_b = breaking depth measured from still water level;

H_o' = equivalent deep water wave height;

R = wave runup, the vertical height above still water level;

R_f = recommended runup;

R_i = initial estimated runup at station i;

R_n = new estimated runup;

T = wave period;

TL = tolerance limit;

X = horizontal distance;

X_i = X-coordinate of beach station i;

X_r = X-coordinate of intersection point;

X_{db} = X-coordinate of breaking depth;

Y = elevation above mean sea level;

Y_i = Y-coordinate of beach station i;

Y_i' = Y-coordinate of runup at station i;

Y_r = Y-coordinate of intersection point;

Y_{db} = Y-coordinate of breaking depth;

WTL = still water level;

α = structure slope.