RECOMMENDED INTERIM METHODOLOGY

FOR CALCULATION OF WAVE ACTION

AND WAVE SET-UP EFFECTS

by

Robert G. Dean

Prepared For

Department of Housing and Urban Development
Washington, D. C.

Research Report CE-82-31

June 1979

DEPARTMENT OF CIVIL ENGINEERING
UNIVERSITY OF DELAWARE
NEWARK, DELAWARE
19711

TABLE OF CONTENTS

RECOMMENDED INTERIM METHODOLOGY
FOR CALCULATION OF WAVE ACTION AND WAVE SET-UP EFFECTS

I. INTRODUCTION

The intent of the National Flood Insurance Program is to provide insurance against flooding due to hurricanes and other severe storms. An attempt is made to establish the requirements for participation in the program so as to encourage prudent construction practices in accordance with the expected occurrence of potential damaging flood events. In addition to high water levels, these storms generate reasonably large wave heights which, through breaking, decrease as they propagate inland. The "high velocity zone" is defined as the zone seaward of which the 100 year wave height exceeds 3 ft.; the value considered to be potentially damaging to residential structures. Implicit in the definition of this high velocity zone is the assumption that the most damaging waves within a 100 year interval will accompany the 100 year storm tide event.

The delineation of this 100 year high velocity zone is the subject of this report. Under contract with HUD, a study was carried out to conduct laboratory, historical and analytical investigations to result in recommendations for a procedure to establish the high hazard zone. This report incorporates the results of three previous reports (1), (2), (3) developed during the study into a recommended procedure. This recommended procedure, detailed below is viewed as a reasonable interim procedure; at present the data base contains substantial uncertainties and additional studies are needed to reduce these uncertainties in a program impinging so directly on human life and substantial investment in the coastal zone.

II. SYNOPSIS OF PREVIOUS REPORTS

The procedure to be recommended is based, in part, on References 1, 2 and 3. The sections below provide a brief synopsis of each of these three references.

"Evaluation of Recommended Methodology for Calculating Wave Action for Insurance Purposes", December, 1978.

The intent of this study was to provide an early evaluation report on the methodology for calculating the high velocity zone as recommended by the NAS Panel ("Methodology for Calculating Wave Action Effects Associated with Storm Surges", Reference 4). Structural damage from seven hurricanes and one extra-tropical storm were reviewed.

The study recommended that the methodology proposed by the Panel be adopted on an interim basis, and that plans be initiated for a program to collect relevant storm data to further evaluate and refine the procedure. Problems requiring further clarification and/or incorporation into the procedure include: (1) wave run-up, particularly for the case of long waves; (2) erosion of the beach profile, thereby undermining structures and allowing larger waves to occur at a particular location; (3) reflection effects, especially at seawalls; and (4) storm duration.

"Recommended Procedure for Calculating Wave Damping Due to Vegetation Effects and Wave Instability", May, 1979.

This report is based on a series of wave tank tests to evaluate the decay of wave height as waves propagate through simulated vegetation. The tests were conducted in water of uniform depth and therefore the results are only strictly applicable to this case. The analysis of the wave tank results supported two significant mechanisms of wave damping. The first is related to the fluid drag forces occurring on the vegetation elements and the second, a "wave instability effect" occurs due to the somewhat delicate stability of a near-breaking wave. Once the "wave instability" mechanism (breaking) is initiated, dissipation will continue until the ratio of wave height to depth, H/h is approximately 0.3, considerably smaller than the customarily accepted value of 0.78.

It is recommended that both mechanisms of wave damping be included in the computation procedure with a value of 1.0 for the hydrodynamic drag coefficient. Analytical results are developed where either of the two mechanisms is dominant and a finite difference procedure is presented for the stiuation in which both effects are significant.

Examples are presented illustrating application of the method.

"Evaluation of Possible Bias in the Storm Surge Data Base Due to Wave Effects", May, 1979.

Available historical storm surge data obtained from tide records were compared with high water marks in an attempt to quantify any bias in the storm surge data base. In addition, several mechanisms were examined to evaluate their potential for contributing bias to high water marks.

It was concluded that, due to contamination by wave effects, there is significant but not consistent bias in the available reported high water marks. In some cases, tide gage records have been available but not given appropriate consideration in establishing the storm tide recurrence intervals.

Of the mechanisms examined for contributing bias, it was found that the two most likely were: (1) set-up inside buildings due to flow over sills, and (2) wave set-up inside the surf zone.

Examples were presented of computations to demonstrate the set-up that can occur across the surf zone with and without the effects of vegetation. The procedures used in these example computations form the basis for the "Recommended Methodology".

III. RECOMMENDED METHODOLOGY

Objective

In developing the recommended methodology, it is desired that: (a) the method represent, in a realistic manner, the range of variables encountered in nature, and (b) the method be readily applied without complications.

Description of the Phenomena Included in the Methodology

The methodology includes the effects of: (1) the wave instability breaking noted earlier, (2) wave set-down and set-up inside the surf zone, (3) bottom shear stress, and (4) drag due to vegetation elements. The effects of each of these factors is discussed briefly below:

Wave Instability - Once breaking has been initiated (at a presumed ratio of breaking wave height to water depth of 0.78), breaking will occur until, in uniform depth, a stable wave height of 30% of the depth is attained. On a mild slope, the height would be less than indicated by the 0.78 value and on a steep slope, the height could exceed the 0.78 value. Although the tests performed in conjunction with Reference 2 were for a uniform depth, the results have been extended to a variable depth as follows

$$\frac{d(H^2\sqrt{h + \overline{\eta}})}{dx} = - \frac{K}{\sqrt{(h + \overline{\eta})}} (H^2(x) - H_s^2) \tag{1}$$

which incorporates shallow water assumptions and in which x is the distance coordinate, H is the wave height, h is the local water depth, $\overline{\eta}$ is the local wave set-up, K is a constant (= 0.08) and H_s is the stable wave height

$$H_s = 0.3(h + \overline{\eta}) \tag{2}$$

Eq. (1) is incorporated into a computer program which includes effects of bottom shear stress and vegetation and also carries out the wave set-up computations.

Wave Set-Down and Set-Up, Bottom Shear Stress and Forces on Vegetation - Wave set-down at the surf line is given by

$$\overline{\eta} = - \frac{H_b}{20} \tag{3}$$

H_b being the breaking wave height. The general governing equation for set-up is

$$\frac{\partial\overline{\eta}}{\partial x} = - \frac{1}{\rho g(h + \overline{\eta})} [\frac{\partial S_{xx}}{\partial x} + \overline{\tau}(x) + \overline{F}(x)] \tag{4}$$

in which ρ is the mass density of water, g is the gravitational constant, S_{xx} is the onshore flux of the onshore component of wave related momentum and for shallow water waves is given by

$$S_{xx} = \frac{3}{16} \rho g H^2 \tag{5}$$

In Eq. (4), $\overline{\tau}(x)$ and $\overline{F}(x)$ are respectively the net bed shear stress and net force on vegetation per unit plan area. Based on the stream function wave theory, approximate expressions for these quantities are given by

$$\overline{\tau}(x) = 0.002\ H^2 \tag{6}$$

$$\overline{F}(x) = 0.08\ C_D \frac{D}{s^2} H^2 (h + \overline{\eta}) \tag{7}$$

in which H is the wave height in feet, C_D is the hydrodynamic drag coefficient (recommended as 1.0), D is the diameter of the vegetative elements and s is the effective center-to-center spacing of these elements.

IV. COMPUTER IMPLEMENTATION OF RECOMMENDED METHODOLOGY

General Discussion

Finite difference versions of the equations presented in Section III have been programmed and a listing is presented in Appendix A and three examples presented later in this section. The objective is to establish, for reasonable ranges of wave heights, the location along a user-specified profile where the wave height will be approximately 3 ft. In accordance with the expected ranges of hurricane-generated wave heights, the program establishes the envelope of wave heights and storm tides including set-up for breaking heights of 10, 13 and 16 ft., respectively.

Description of Program Input and Output

Each card of the program input is described below. All values are in the English system of units; in particular linear dimensions are in feet.

First Card, [Format (20A4)] - This card is simply an identification card and is read in, then printed out at the top of a new page. The identification can extend over the full eighty column width of the card.

Second Card, [Format (2I6, 3F8.2)] - The variables and their descriptions on this card are:

JMAX = Number of pairs of distances and depths (XI(J), DPTI(J)), to be input to specify the profile. The profile can either be specified by a number of such points or by a uniform slope. In the latter case, there is no need to specify JMAX. Regardless of the method of specifying the profile, different pairs of (X, DPT) will be established at equally spaced (DX) intervals. The program is dimensioned to accept a maximum of 100 pairs of (XI(J), DPTI(J)).

NVEG = Number of profile segments across the profile for which vegetation characteristics will be specified. If it is not desired to represent vegetation on the profile, NVEG is set equal to zero. The program is dimensioned to accept up to ten different vegetated segments.

XM = Slope of the profile if the option is selected of representing the profile by a uniform slope. For reasons to be explained later, the vertical dimension of profile represented is 30 ft. and if the slope and DX are chosen such that more than 100 points are required to represent the profile, then the value of DX is increased above that specified such that 100 values is sufficient to represent the profile.

STTIDE = Computed one hundred year storm tide level; not accounting for any wave effects, such as set-up or run-up.

DX = Interval at which profile is to be represented for wave and set-up computations. (Also, see note under "XM" description).

Third Card or Group of Cards If XM Equals Zero [Format (8F8.2)] - This (or these) cards specify the pairs of distance, depths representing the profile in segments over which the variation of depth is reasonably linear. Note that if XM is not zero, these data are not input. There is one card per four pairs of distances and depths. The first distance should be zero and the first depth relative to mean sea level should be approximately 10 ft.

Third Card or Group of Cards If XM Unequal to Zero and NVEG Unequal to Zero. Fourth Card or Group of Cards if XM Equals Zero and NVEG Unequal to Zero [Format (8F8.2)] - This (or these) cards specify the relevant characteristics of the vegetated segments across the profile. The program is dimensioned to accept the characteristics of up to 10 vegetated segments. The first and second variable in the group of four variables defining the vegetated segments are the starting and ending x values of the segment, i.e. XSVEG (NV) and XEVEG (NV) respectively. The last two variables defining the characteristics for each segment are the diameter and equivalent center-to-center spacing of the elements. Each card can contain the characteristics of two segments.

Examples

Three examples will be presented to illustrate application of the program.

Example 1 - Consider the profile presented in Figure 1. There is no vegetation on the profile and the other relevant characteristics are

Profile Slope (XM) = 0.02
Storm Tide (STTIDE) = 10.0 ft.
Spacing at Which Computations are
to be carried out, (DX) = 50.0 ft.

In this case only two cards are required for the input data deck as presented in Figure 2. The output from the program is presented in Figure 3. The variation in wave height across the profile is presented in Figure 1.

Example 2 - The profile and vegetation characteristics are presented in Figure 4. There are two vegetated segments and the profile is approximated by a uniform slope. Other data are:

Number of Vegetated Segments (NVEG) = 2
Profile Slope (XM) = 0.02
Storm Tide (STTIDE) = 10.0 ft.
Spacing at Which Computations are
to be carried out = 50.0 ft.

The data deck is presented as Figure 5. The output for the program is presented in Figure 6. The variation in wave height across the profile is presented in Figure 4.

Example 3 - For this example, the profile is represented by three straight line sections (JMAX = 4) and there are two vegetated segments present as shown in Figure 7. The data deck is presented in Figure 8, the program output as Figure 9 and the variation in wave height across the profile in Figure 7.

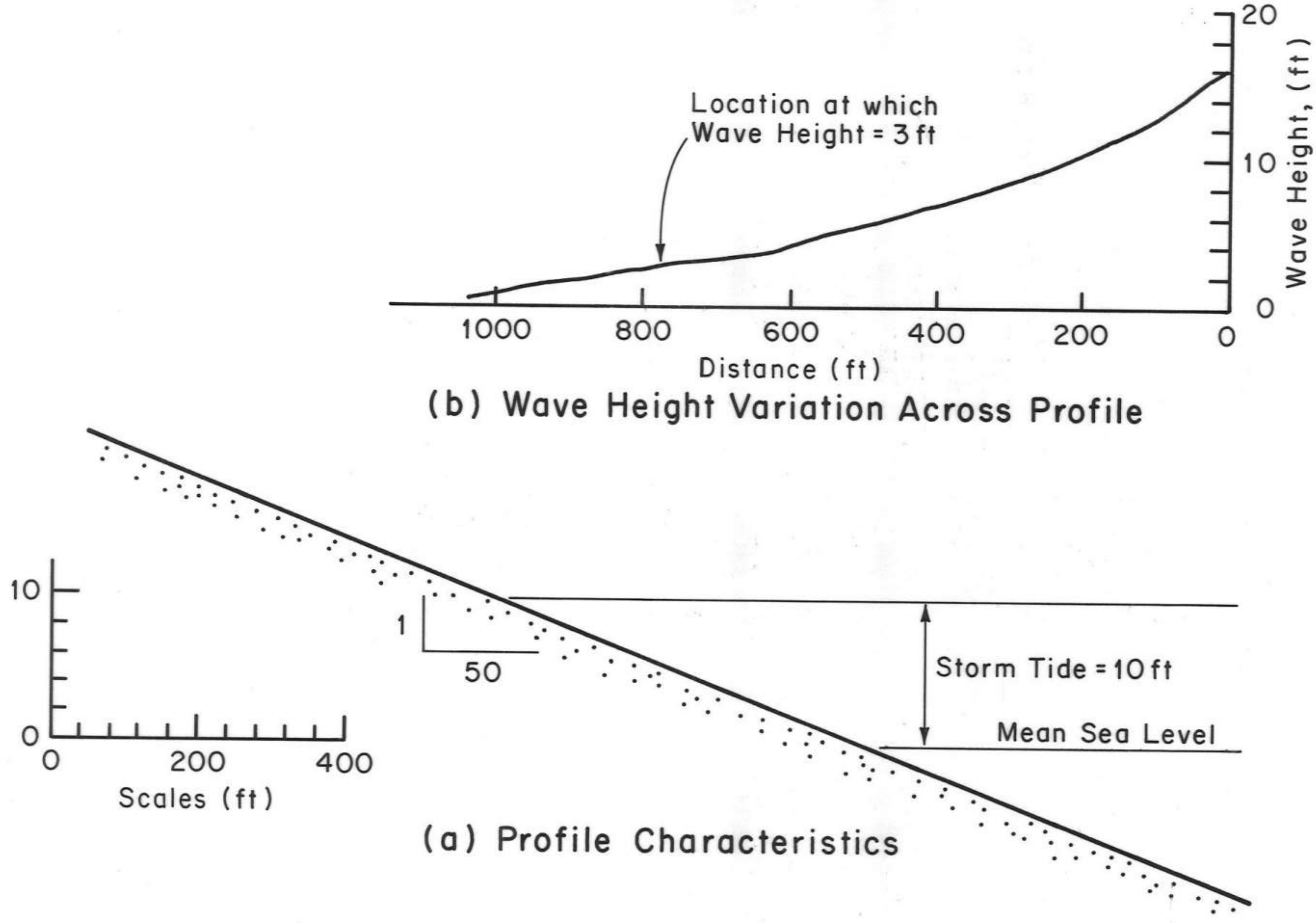

Figure 1. Example 1. Wave Height Reduction Across an Unvegetated Profile of Uniform Slope.

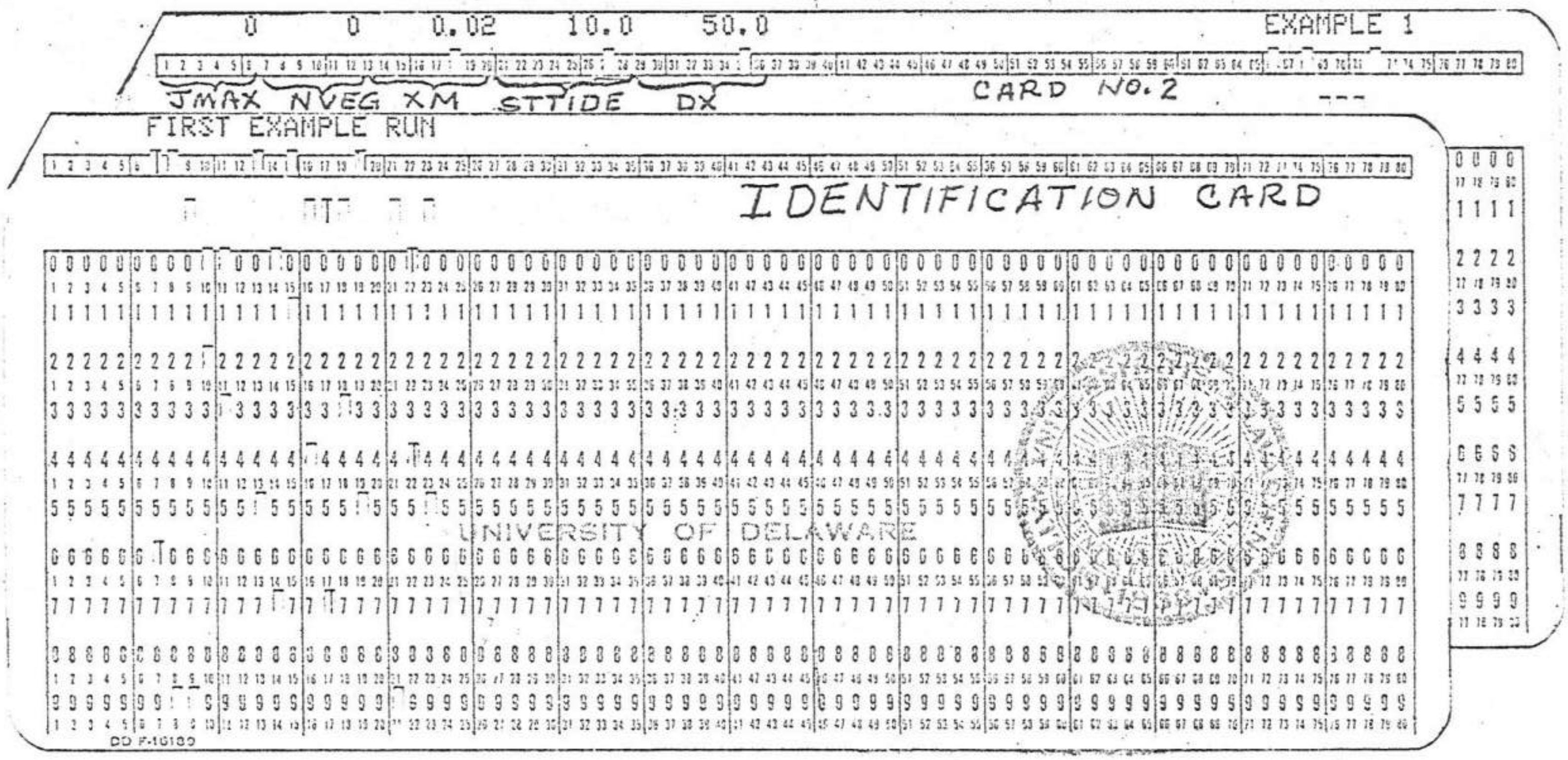

Figure 2. Input Deck For Example 1.

FIRST EXAMPLE RUN

LISTING OF ENVELOPE STORM TIDES AND WAVE HEIGHTS

J	X(J)	DPT(J)	MAX TIDE(J)	MAX HEIGHT(J)
1	0.00	10.00	10.00	16.00
2	50.00	9.00	10.00	14.45
3	100.00	8.00	10.03	13.05
4	150.00	7.00	10.34	11.79
5	200.00	6.00	10.62	10.64
6	250.00	5.00	10.85	9.61
7	300.00	4.00	11.05	8.66
8	350.00	3.00	11.22	7.80
9	400.00	2.00	11.38	7.02
10	450.00	1.00	11.51	6.30
11	500.00	0.00	11.63	5.64
12	550.00	-1.00	11.73	5.04
13	600.00	-2.00	11.82	4.48
14	650.00	-3.00	11.91	3.96
15	700.00	-4.00	11.99	3.47
16	750.00	-5.00	12.06	3.02
17	800.00	-6.00	12.13	2.58
18	850.00	-7.00	12.19	2.15
19	900.00	-8.00	12.25	1.74
20	950.00	-9.00	12.32	1.33
21	1000.00	-10.00	12.38	0.93
22	1050.00	-11.00	12.43	0.54
23	1100.00	-12.00	12.49	0.00
24	1150.00	-13.00	0.00	0.00
25	1200.00	-14.00	0.00	0.00
26	1250.00	-15.00	0.00	0.00
27	1300.00	-16.00	0.00	0.00
28	1350.00	-17.00	0.00	0.00
29	1400.00	-18.00	0.00	0.00
30	1450.00	-19.00	0.00	0.00
31	1500.00	-20.00	0.00	0.00

Figure 3. Output for Example 1.

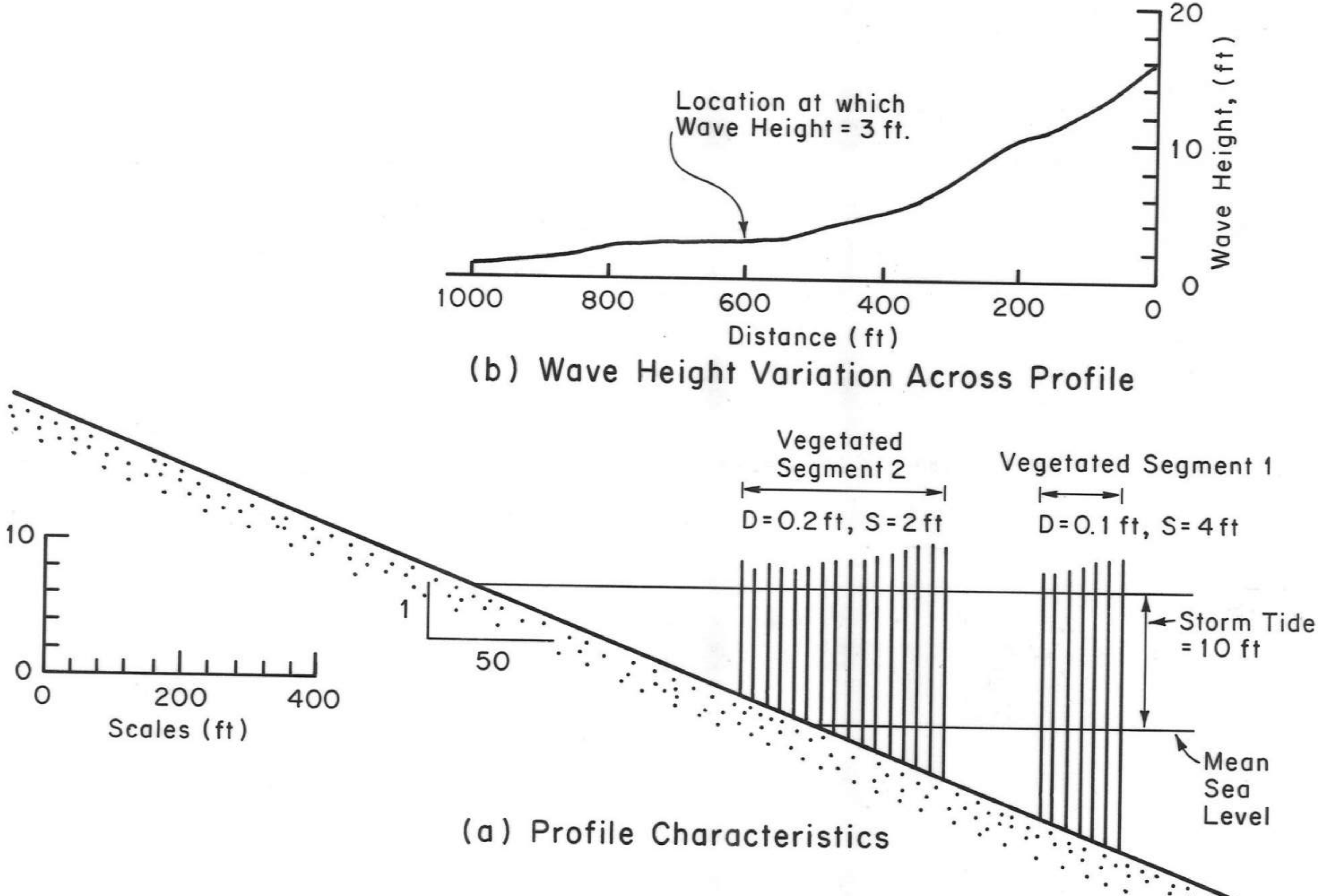

Figure 4. Example 2. Wave Height Variation Due to Two Vegetated Segments of Uniform Slope.

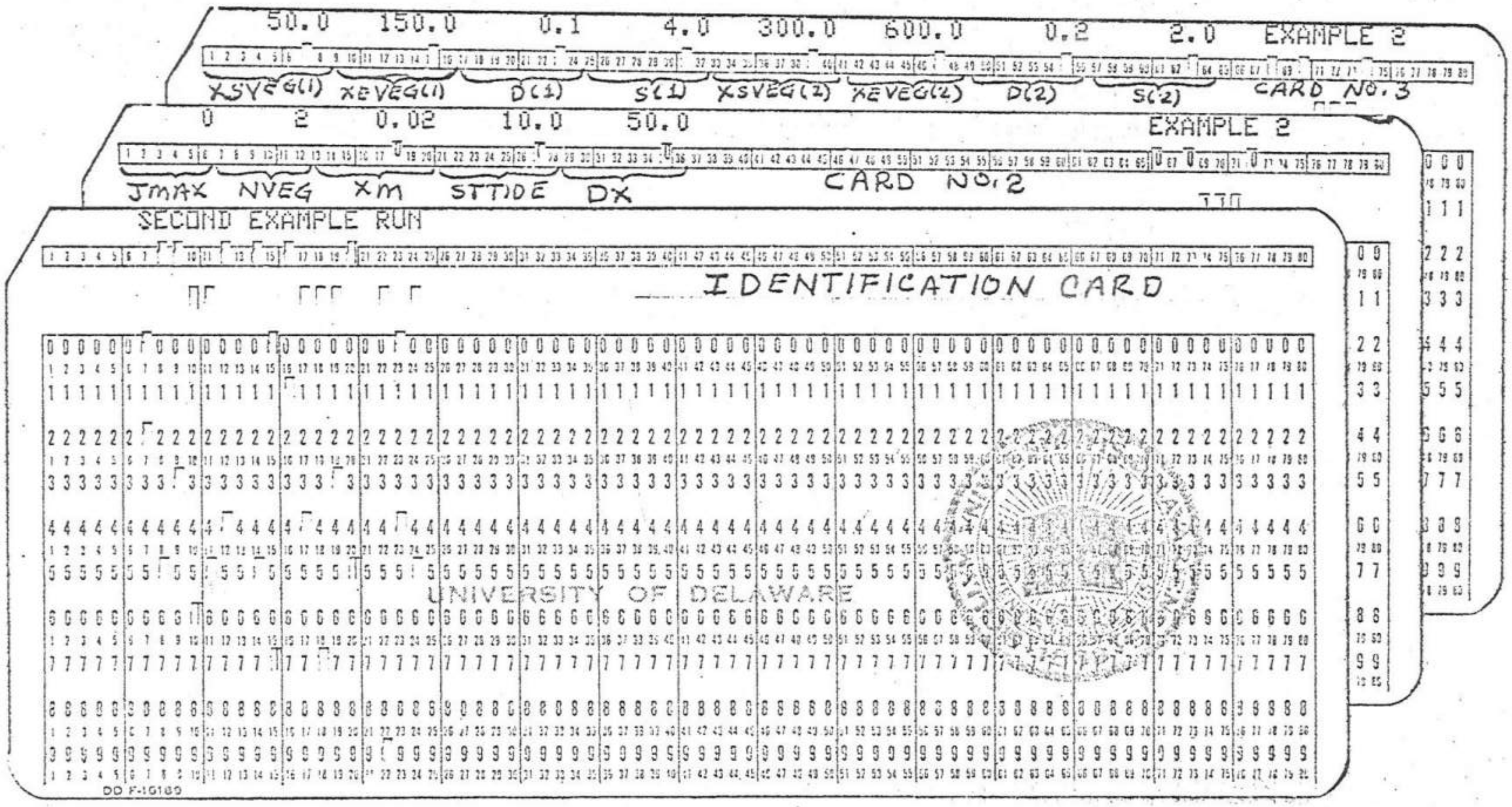

Figure 5. Input Deck for Example 2.

SECOND EXAMPLE RUN

LISTING OF ENVELOPE STORM TIDES AND WAVE HEIGHTS

J	X(J)	DPT(J)	MAX TIDE(J)	MAX HEIGHT(J)
1	0.00	10.00	10.00	16.00
2	50.00	9.00	10.00	14.02
3	100.00	8.00	10.09	12.36
4	150.00	7.00	10.34	11.21
5	200.00	6.00	10.57	10.16
6	250.00	5.00	10.78	9.20
7	300.00	4.00	11.13	7.03
8	350.00	3.00	11.21	5.68
9	400.00	2.00	11.26	4.76
10	450.00	1.00	11.28	4.12
11	500.00	0.00	11.29	3.64
12	550.00	-1.00	11.29	3.26
13	600.00	-2.00	11.30	2.94
14	650.00	-3.00	11.29	2.91
15	700.00	-4.00	11.31	2.75
16	750.00	-5.00	11.34	2.49
17	800.00	-6.00	11.39	2.16
18	850.00	-7.00	11.45	1.79
19	900.00	-8.00	11.50	1.39
20	950.00	-9.00	11.56	0.99
21	1000.00	-10.00	11.62	0.58
22	1050.00	-11.00	11.68	0.00
23	1100.00	-12.00	0.00	0.00
24	1150.00	-13.00	0.00	0.00
25	1200.00	-14.00	0.00	0.00
26	1250.00	-15.00	0.00	0.00
27	1300.00	-16.00	0.00	0.00
28	1350.00	-17.00	0.00	0.00
29	1400.00	-18.00	0.00	0.00
30	1450.00	-19.00	0.00	0.00
31	1500.00	-20.00	0.00	0.00

Figure 6. Output for Example 2.

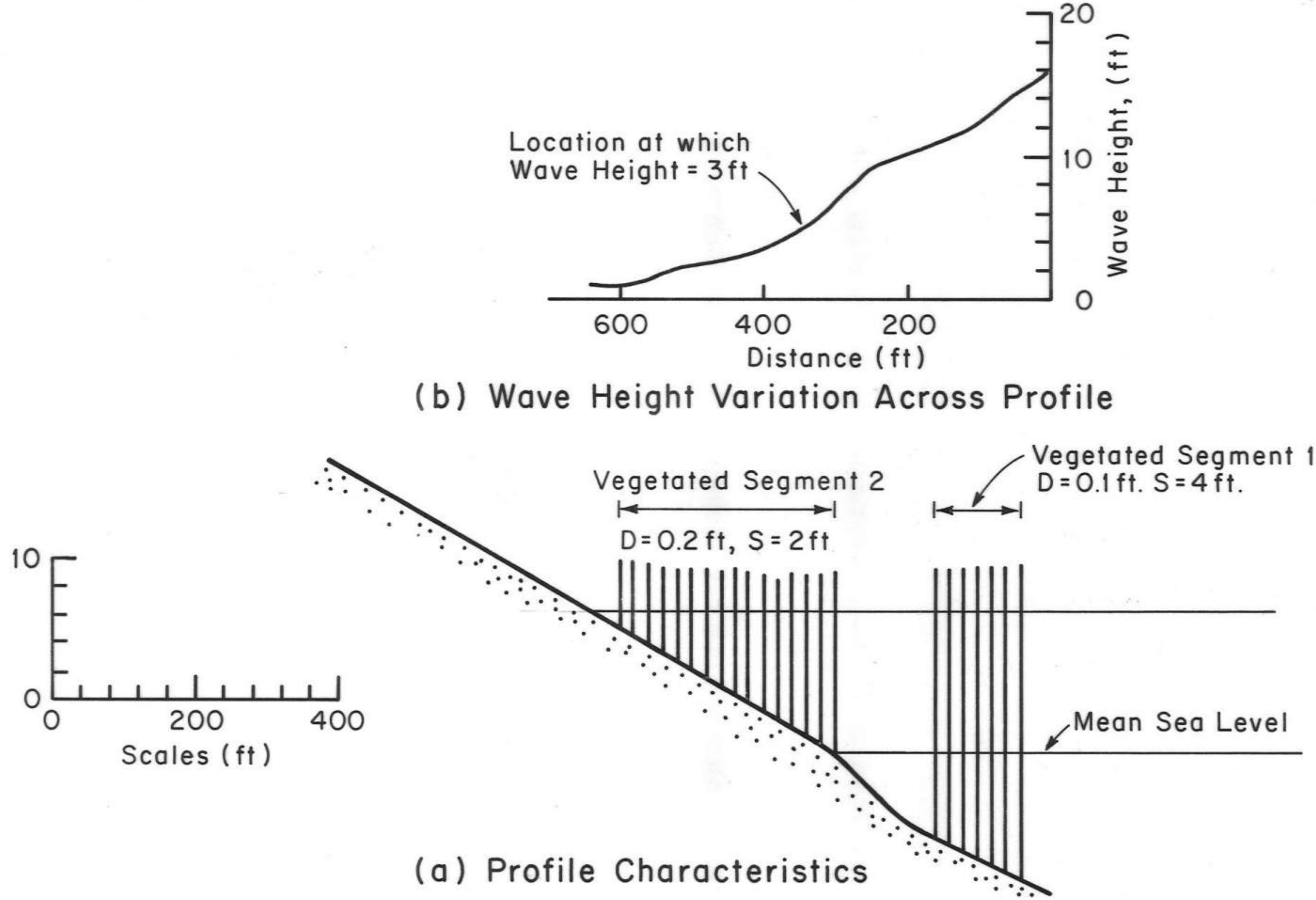

Figure 7. Example 3. Wave Height Variation Due to Two Vegetated Segments Across Non-Uniform Profile.

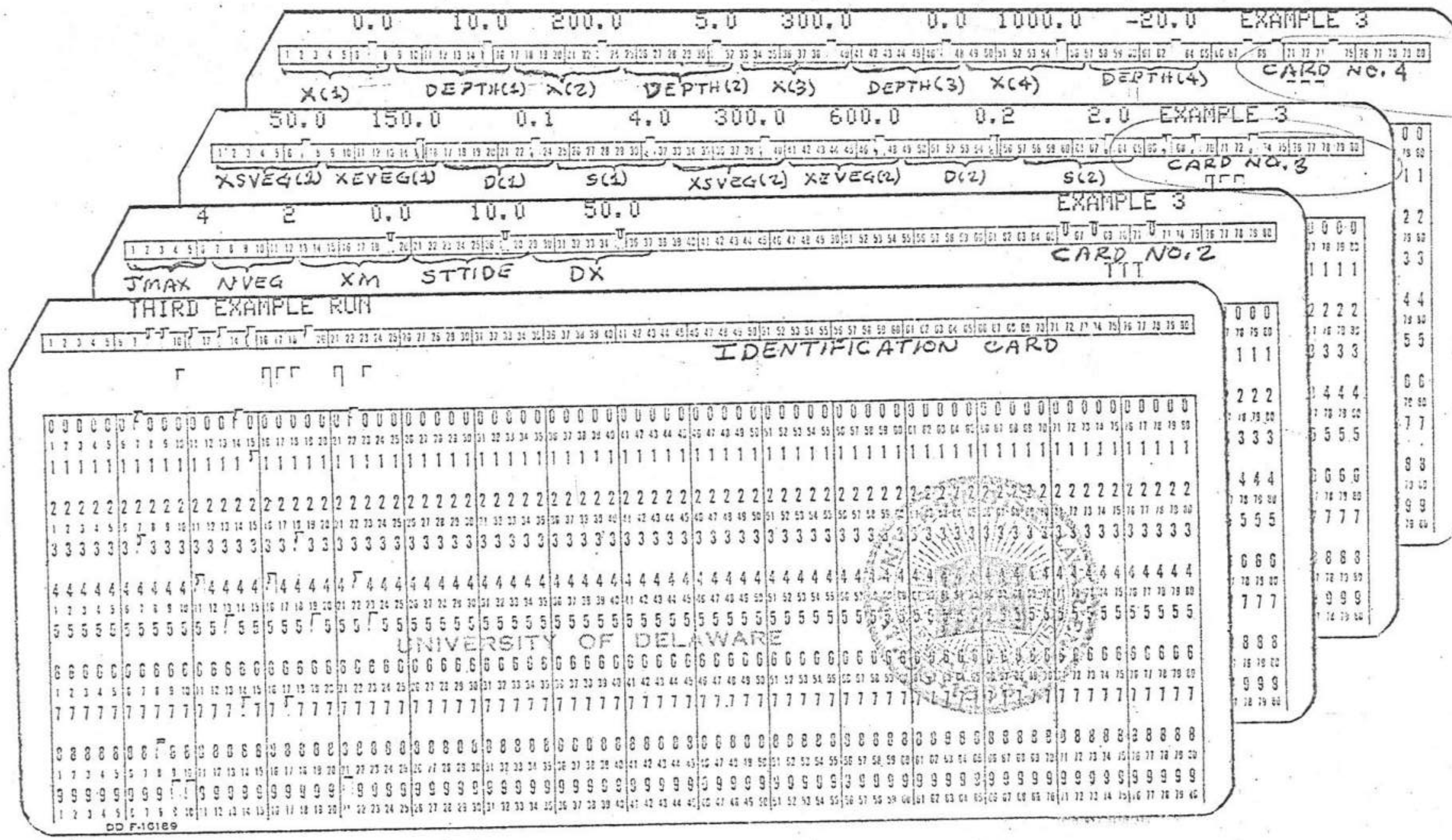

Figure 8. Input Deck for Example 3.

THIRD EXAMPLE RUN

LISTING OF ENVELOPE STORM TIDES AND WAVE HEIGHTS

J	X(J)	DPT(J)	MAX TIDE(J)	MAX HEIGHT(J)
1	0.00	10.00	10.00	16.00
2	50.00	8.75	10.00	14.07
3	100.00	7.50	10.10	12.40
4	150.00	6.25	10.36	11.23
5	200.00	5.00	10.62	10.13
6	250.00	2.50	10.82	9.30
7	300.00	0.00	11.38	6.67
8	350.00	-1.43	11.64	4.81
9	400.00	-2.86	11.77	3.68
10	450.00	-4.29	11.85	2.92
11	500.00	-5.71	11.91	2.34
12	550.00	-7.14	11.96	1.85
13	600.00	-8.57	12.02	1.37
14	650.00	-10.00	12.08	1.01
15	700.00	-11.43	12.21	0.00
16	750.00	-12.86	0.00	0.00
17	800.00	-14.29	0.00	0.00
18	850.00	-15.71	0.00	0.00
19	900.00	-17.14	0.00	0.00
20	950.00	-18.57	0.00	0.00
21	1000.00	-20.00	0.00	0.00

Figure 9. Output for Example 3.

The locations and water depths at which the wave height is approximately 3 ft. for each of the three examples above are summarized in Table I.

TABLE I

LOCATIONS AT WHICH WAVE HEIGHT ≈ 3 Ft.

Example	Location at Which Wave Height ≈ 3 ft.	Water Depth Including Nominal Storm Tide at Which Wave Height ≈ 3 ft.	Profile Characteristics
1	750 ft.	5.0 ft.	Uniform Slope (= 0.02), Unvegetated
2	600 ft.	8.0 ft.	Uniform Slope (= 0.02), Two Vegetated Segments
3	450 ft.	5.7 ft.	Non Uniform Slope, Two Vegetated Segments

V. SUMMARY

Based on the results and methodology presented in References 1, 2 and 3, a procedure is described and implemented into a computer program to calculate the limit of the high-velocity zone, i.e., seaward of which the wave height exceeds three feet. Variable bottom topography and stands of vegetation are allowable features in the computer program. The methodology includes wave set-up and a breaking wave representation that allows for wave height reduction below the usual depth-proportional factor. To allow for the ranges of wave conditions expected in a hurricane, the envelope of wave heights within the breaking zone is determined for breaking heights of 10, 13 and 16 ft. Three examples illustrating application of the computer program are presented and for the case in which no vegetation is present, the high velocity zone is approximately at the same location as would result from the NAS Panel methodology.

It is stressed that the recommended methodology as incorporated into the computer program should be viewed as appropriate on an interim basis. Features of the general coastal flooding problem that merit serious and immediate attention include:

a) Collection of more and better field data to provide a basis for evaluating existing high velocity zone methodology and, where necessary, developing new methodologies. This would require the design of a field procedure (including types of observations, reporting procedures, etc.) to be implemented immediately after a storm.

b) Identification and, where present, removal of the wave effects bias in the existing data base for storm surges. In some cases, it appears that this bias is substantial and may lead to serious overestimates in the local data available (high water marks) for numerical model calibration. Due to the lack of documentation associated with much of the data, a concerted and effective field program should be implemented also to collect unbiased storm surge data. A combination of fixed and portable installations would be most effective in meeting this goal.

c) Development of a procedure to account for the modification during a storm to natural and seawalled profiles. Erosion can undermine structures and, by causing greater depths, allow breaking to occur closer to shore.

d) Incorporation/evaluation of run-up effects, especially for the case of long waves.

e) Incorporation/evaluation of the effect of augmented wave height due to reflection from a seawall.

f) Incorporation/evaluation of the effect of storm duration on structural damage and profile modification.

VI. REFERENCES

1. Dean, R. G. and J. N. Sharma, "Interim Report: Evaluation of Recommended Methodology for Calculating Wave Action for Insurance Purposes", Report to the Department of Housing and Urban Development, University of Delaware, Department of Civil Engineering, December, 1978.

2. Dean, R. G., "Recommended Procedure for Calculating Wave Damping Due to Vegetation Effects and Wave Instability", Report to the Department of Housing and Urban Development, University of Delaware, Department of Civil Engineering, May, 1979.

4. Dean, R. G., "Evaluation of Possible Bias in the Storm Surge Data Base Due to Wave Effects", Report to the Department of Housing and Urban Development, University of Delaware, Department of Civil Engineering, May, 1979.

4. National Academy of Sciences Panel on Wave Action Effects Associated with Storm Surges, "Methodology for Calculating Wave Action Associated with Storm Surges", Washington, D. C., 1977.

APPENDIX A

LISTING OF COMPUTER PROGRAM FOR COMPUTING ENVELOPE OF WAVE HEIGHTS

```
      DIMENSION DPT(100),H(100),ETA(100),WORD(20),Z(3),ETMX(100)
     *,F(100),TAU(100),XSVEG(10),XEVEG(10),D(10),S(10),DPTI(100),
     *XI(100),X(100),ELEV(100),HMAX(100)
  100 FORMAT (20A4)
  101 FORMAT(1H1,10X,20A4)
  102 FORMAT (I6,2F8.2)
  104 FORMAT (8F8.2)
  105 FORMAT (8F8.2)
  110 FORMAT (5X,I6,5F10.2)
  112 FORMAT(2I6,6F8.2)
C     ESTABLISH INPUT PARAMETERS
      XK=0.08
C     READ IN AND WRITE OUT CASE DESCRIPTION
      READ (5,100) (WORD(I),I=1,20)
      WRITE (6,101) (WORD(I),I=1,20)
      READ (5,112 ) JMAX,NVEG,XM,STTIDE,DX
      IF (DX.EQ.0.0) DX=50.0
C     READ IN AND WRITE OUT PROFILE CHARECTERISTICS
      IF (XM.EQ.0.0) GO TO 10
      JMAX=30.0/(XM*DX)+1
      IF (JMAX.GT.100) JMAX=100
      DX=30.0/((JMAX-1)*XM)
      DPT(1)=10.0
      X(1)=0.0
      DO 4 J=2,JMAX
      X(J)=X(J-1)+DX
    4 DPT(J)=DPT(J-1)-DX*XM
      GO TO 11
   10 READ (5,104) (XI(I),DPTI(I),I=1,JMAX)
      X(1)=0.0
      DPT(1)=DPTI(1)
      JMAX=(XI(JMAX)-XI(1))/DX+1
      IF (JMAX.LT.100) GO TO 9
      JMAX=100
      DX=(XI(JMAX)-XI(1))/(JMAX-1)
    9 II=1
      DO 142 J=2,JMAX
      X(J)=X(J-1)+DX
  138 IF (X(J).LE.XI(II+1)) GO TO 142
  140 II=II+1
      GO TO 138
  142 DPT(J)=DPTI(II)+(X(J)-XI(II))/(XI(II+1)-XI(II))*
     *(DPTI(II+1)-DPTI(II))
   11 CONTINUE
   15 Z(1)=10.0
      Z(2)=13.0
      Z(3)=16.0
      IF (NVEG.EQ.0) GO TO 16
      READ (5,104) (XSVEG(NV),XEVEG(NV),D(NV),S(NV),NV=1,NVEG)
   16 DO 12 J=1,JMAX
      HMAX(J)=-10.0
      TAU(J)=0.0
      H(J)=0.0
      F(J)=0.0
      ETA(J)=STTIDE
```

Figure A-1. Listing of Computer Program (Page 1 of 3 Pages).

```
      ETMX(J)=STTIDE
   12 IF(ETA(J)+DPT(J).LE.0.0) ETMX( J)=0.0
      DO 80 L=1,3
      H(1)=Z(L)
      DO 60 K=1,3
C     ESTABLISH INITIAL BREAKING INDEX
      NB=0
      NV=1
      DO 20 J=2,JMAX
      JA=J
      IF (DPT(J)+ETA(J-1).LE.0.0) GO TO 22
      A=SQRT(DPT(J)+ETA(J-1))
      AM1=SQRT(DPT(J-1)+ETA(J-1))
      IF(H(J).EQ.0.0) H(J)=H(J-1)
      B2=0.0064*((H(J-1)/AM1)**3+(H(J)/A)**3)/A
      IF (NB.EQ.1) GO TO 221
      AB=0.78*(DPT(J)+ETA(J))
      IF (H(J-1).GE.AB) NB=1
      IF (NVEG.EQ.0) GO TO 222
  221 IF (XEVEG(NV).GT.X(J)) GO TO 222
      IF (NV.GE.NVEG) GO TO 222
      NV=NV+1
      GO TO 221
  222 B=0.0
      C=0.0
      IF (NVEG.EQ.0.0) GO TO 228
      IF (X(J).LE.XEVEG(NV).AND.X(J).GE.XSVEG(NV)) GO TO 226
      GO TO 228
  226 B=0.106*D(NV)/S(NV)**2*(H(J-1)**3/AM1+H(J)**3/A)/A
  228 HST=0.3*(DPT(J-1)+ETA(J-1))
      IF (NB.EQ.1) C=XK/(A*AM1)*(H(J-1)**2-HST**2)
C     CALCULATE UPDATED WAVE HEIGHTS
      HSQ=AM1/A*H(J-1)**2-(B+B2+C)*DX
      IF (HSQ.LT.0.0) HSQ=0.0
   20 H(J)=SQRT(HSQ)
      GO TO 23
   22 DO 24 J=JA,JMAX
      H(J)=0.0
   24 ETA(J)=0.0
C     CALCULATE UPDATED STORM SURGES
   23 CONTINUE
      IF (NVEG.EQ.0) GO TO 36
      NV=1
      DO 30 J=1,JMAX
   31 IF (XEVEG(NV).GT.X(J)) GO TO 32
      IF(NV.GE.NVEG) GO TO 32
      NV=NV+1
      GO TO 31
   32 F(J)=0.0
      IF (X(J).LE.XEVEG(NV).AND.X(J).GE.XSVEG(NV)) F(J)=0.08*
     *D(NV)/S(NV)**2*H(J)**2*(DPT(J)+ETA(J))
   30 CONTINUE
   36 DO 38 J=1,JMAX
   38 TAU(J)=0.002*H(J)**2
      ETA(1)=STTIDE-H(1)/20.0
      DO 40 J=2,JMAX
      IF (ETA(J-1)+DPT(J).LT.0.0) GO TO 41
      FBAR=0.5*(F(J-1)+F(J))
      TAUBAR=0.5*(TAU(J-1)+TAU(J))
      DBAR=0.5*(DPT(J-1)+DPT(J))
```

Figure A-1. Listing of Computer Program (Continued).
(Page 2 of 3 Pages).

```
      ETABAR=0.5*(ETA(J-1)+ETA(J))
      ETA(J)=ETA(J-1)-0.1875/(ETABAR+DBAR)*(H(J)**2-H(J-1)**2)
     *-DX/(64.0*(ETABAR+DBAR))*(FBAR+TAUBAR)
   40 CONTINUE
C     GENERATE OUTPUT
   41 CONTINUE
   60 CONTINUE
      DO 62 J=1,JMAX
      IF (ETA(J).GT.ETMX(J)) ETMX(J)=ETA(J)
   62 IF (H(J).GT.HMAX(J)) HMAX(J)=H(J)
   80 CONTINUE
      CALL OPUT(JMAX,X,DPT,ETMX,H)
      RETURN
      END
```

\##

```
      SUBROUTINE OPUT(JMAX,X,DPT,ETMX,H)
      DIMENSION DPT(100),X(100),ETMX(100),H(100),ELEV(100)
  100 FORMAT(//,5X,'J',10X,'X(J)', 11X,'DPT(J)',6X,'MAX TIDE(J)',3X,
     1 ' MAX HEIGHT(J)',//)
  102 FORMAT(I4, 4(5X,F12.2) )
  103 FORMAT(//,10X,' LISTING OF ENVELOPE STORM TIDES AND WAVE HEIGHTS')
      WRITE(6,103)
      WRITE (6,100)
      DO 20 J=1,JMAX
   20 WRITE(6,102) J,X(J),DPT(J),ETMX(J),H(J)
      RETURN
      END
```

\##

Figure A-1. Listing of Computer Program (Continued). (Page 3 of 3 Pages).