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ROYAL OBSERVATORY, HONG KONG

TECHNICAL NOTE NO. 54

EVALUATING PEAK STORM SURGE HEIGHTS AND HIGH SEA LEVELS FROM SPLASH OUTPUTS

by

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CONTENTS

FIGURES

TABLES

1. INTRODUCTION

An operational Fortran Program has been devised to compute the peak storm surge heights and the accompanying high sea levels that can be expected at North Point and in Tolo Harbour during tropical cyclone passages across the northern part of the South China Sea. The Program utilises the Splash Nomograms for predicting peak open-coast surges, generates hourly astronomical tides for North Point and requires users to specify only the parameters pertaining to the movement and intensity of the tropical cyclone under consideration. Prior to the formulation of the Program, empirical regression equations (Cheng 1967) and joint probability considerations (Peterson 1975) have been used to compute storm surge heights and to assess high water levels in Hong Kong.

2. SPLASH NOMOGRAMS FOR PREDICTING PEAK OPEN-COAST SURGES

Open-coast storm surges depend primarily on SIX storm parameters. These are :-

i. the central pressure ;

ii. the direction of movement ;

iii. the speed of movement ;

iv. the radius of maximum wind ;

v. the distance of nearest approach ;

and vi. the landfalling location.

The U.S. Weather Bureau's operational storm surge programs - "Splash" I & II (Special Program to List the Amplitude of Surge Heights) have been developed to compute Peak Surge Heights along the open coast, given the SIX storm parameters as inputs, and given the bathymetry and coastline configuration of a stretch of the continental shelf.

The fundamental equations and theoretical expose of Splash were given in the two papers by C.P. Jelesnianski : Splash I - Landfall Storms (Jelesnianski 1972) & Splash II - General track and variant storm conditions (Jelesnianski 1974). Essentially, the two Splash Programs solve the set of hydrodynamical equations that governs the action of a moving pressure disturbance on the ocean surface. The subsequent shoreward propagation of the generated storm surges are simulated numerically in the computer.

In 1976, using a continental shelf and coastline configuration appropriate to Hong Kong, a series of 57 Splash Program runs were performed to obtain predictions of peak surge heights for various locations along the south China coast centring around Hong Kong. Meteorological inputs in these runs comprised of a set of 57 hypothetical storms. These storms were systemmatically assigned values for the following five parameters : central pressure, storm speed, storm direction, radius of maximum wind and distance from Hong Kong, for the time when the storms would be at their nearest approach to Hong Kong. The set of hypothetical storms used (Appendix I) was compiled by systemmatically varying one parameter at a time, so that two storms in the input set would differ by one parameter specification only.

In addition, data from 93 historical storms that affected Hong Kong were used (Appendix II) as input in a further series of 93 Splash runs for prediction of peak surge heights.

3. MERGING THE NOMOGRAMS BY NORMALISING TO A STANDARD STORM

With SIX storm parameters, the possible combinations of different storm tracks and intensities greatly exceed the number of Splash runs actually performed. A technique of normalising to a standard storm was employed to merge the nomograms.

The method is as follows : A standard storm is arbitrarily chosen with specified values for the SIX storm parameters, i.e. central pressure, storm direction, storm speed, radius of maximum wind, distance of closest approach and landfalling location. In each nomogram, the forecast peak surge height corresponding to the parameter value as specified for the standard storm is set to unity. All other forecast peak surge heights given by the nomogram are then scaled and normalised. The normalised values become effectively multiplying "correction" factors that can be used to equate a particular storm to the standard storm.

Assuming that the SIX storm parameters are mutually independent, and in the context of the storm surge nomograms, a particular storm can be equated to the standard storm by multiplying together the appropriate SIX correction factors. It follows that the forecast peak surge height for a particular storm, can be given by the forecast peak surge for the standard storm, multiplying by six appropriate correction factors.

In the actual case, the standard storm was chosen to have :

i. a central pressure of 973 millibars at nearest approach ;

ii. a movement on bearing 300° at nearest approach ;

iii. a speed of 10 knots at nearest approach ;

iv. a radius of maximum wind of 26 nautical miles at nearest approach ;

v. a nearest approach of 26 nautical miles ;

and vi. landfalling to the west of Hong Kong.

This standard storm was computed by Splash to have caused an open-coast peak surge of 1.92 metres at North Point.

Tables 1 to 6 are constructed giving the normalised correction factors for the SIX storm parameters.

For a particular storm, when the six appropriate correction factors are multiplied together and further multiplied by 1.92 metres (the Splash predicted peak surge height for the standard storm), one obtains the Splash Nomogram forecast peak surge for North Point. This rationale constitutes the basis for the Peak Storm Surge/High Sea Level Computation Program.

4. THE PEAK STORM SURGE/HIGH SEA LEVEL COMPUTATION PROGRAM

The Peak Storm Surge/High Sea Level Computation Program is written in Fortran requiring about 14K of computer memory.

It stores the six tables of correction factors, (Tables 1 to 6), accepts the input data, computes the storm track and initiates a table look-up procedure to obtain six appropriate factors, combining them to give a forecast Peak Surge.

A subroutine for generating hourly predicted astronomical tides for North Point is also included in the Program*. This subroutine enables the Program to output the expected High Sea Levels by simply appending the computed Peak Storm Surge to the base level constitued by the predicted astronomical tide around the time of the occurrence of the predicted Peak Storm Surge.

* Prediction of daily high high water, high low water, low high water and low low water for North Point are currently computed by the Institute of Oceanographic Science, Bidston, U.K.

5. PROCEDURE FOR USING THE PROGRAM

In 1979, forecasters on duty at the Royal Observatory adopted the following procedure for using the Program :-

> Whenever a Peak Storm Surge or High Sea Level forecast for North Point or for Tolo Harbour is required, forecasters enter the appropriate form - the "Peak Storm Surge/High Sea Level Computation Form" (see page 10 for layout) - and notify the computer operator who then schedules a computer run when computer time becomes available. The request for Peak Storm Surge computations is submitted with other requests such as for objective forecasts of tropical cyclone movements.

6. INPUTS REQUIRED/UNITS/DESCRIPTIONS

The Program requires 7 input entries which are described below :

i. Name of the tropical cyclone.

ii. Date, time of the first position :
(Date in Month/Day, time in GMT hours)

The Program requires two positions to define the track of the tropical cyclone under consideration. Any pair of successive storm positions, 24 hours apart may be used, preferably (but not necessarily) covering the time of closest approach to Hong Kong. The first position should precede the second position in time. The pair of positions may be actual positions, forecast positions or hypothetical positions.

iii. First position of the tropical cyclone :
(In degrees and tenths of latitude & longitude)

iv. Second position of the tropical cyclone :
(In degrees and tenths of latitude & longitude)

v. Estimated central pressure of the tropical cyclone during nearest approach.
(In millibars)

vi. Estimated radius of maximum wind during nearest approach :
(In nautical miles)

vii. Do you expect winds to exceed 22 knots in the bearing range (360° to 130°) at the Royal Observatory ?

Forecasters are required to delete either YES or NO. Answer to question 7 is required in order to compute the Peak Surge for Tolo Harbour.

A YES answer of this particular question provides a factor of 1.5 to convert the North Point Peak Surge to Tolo Harbour Peak Surge while a NO answer provides a factor of 1.2 for the conversion. Chan (1976) obtained an overall factor of 1.6. However, recent data have indicated that this value is probably high. The factors of 1.5 and 1.2 were empirically obtained by updating and categorising the basic tidal data set.

7. OUTPUT OF THE COMPUTATION PROGRAM

Output of the Computation Program will be in ONE page of line printer printout (see page 11 for layout).

The forecast Peak Splash Storm Surge at North Point and the expected time of occurrence will be given.

The forecast High Sea Levels at North Point and Tolo Harbour and the expected time of occurrences will be given, with High Sea Levels in metres above Chart Datum.

The predicted astronomical tides for North Point at (T-2) hours, (T-1), T, (T+1) and (T+2) hours from the time of closest approach (T) will be listed.

The various input information supplied together with the derived storm movement are also presented to facilitate checking.

8. GENERAL REMARKS

As a preliminary verification, data from a selection of the 25 recent storms were used as inputs to the Program. The comparison between the forecast Peak Surge Levels and the recorded Peak Surge Levels gave the following results :-

Mean error	=	-0.096 metre
Standard deviation	=	0.36 metre

The Program was found to be sensitive to the estimation of the central pressure of the tropical cyclone during its nearest approach to Hong Kong. For the case of rapid intensification, the Program is likely to underestimate the Peak Storm Surge level unless the intensification has been reflected in the input data. Conversely, in the more probable case of a weakening storm, the Program is likely to give an overestimate.

When reports are scarce near the storm centre, it is often difficult to assess its radius of maximum wind. In these situations, it is recommended that a radius of maximum wind of 30 nautical miles be entered.

Finally, the Program, although entirely based on outputs of Splash runs, represents at best a poor substitute of the operational Splash Programs. The number of runs required to compile a reasonable Splash Nomogram is at least an order of magnitude more than those actually performed. Users have to bear in mind this important point when utilising the Program.

9. TWO WORKED EXAMPLES

Two worked examples are given below to illustrate the input data requirements, the input data format, the contents on the output page and the general presentation of results of the Computation Program.

Example (1)

A hypothetical Severe Tropical Storm Bess was centred :

At 20.0°N, 114.0°E at 0600 GMT 28 April 1979, and is forecast to be at 22.8°N, 111.2°E at 0600 GMT 29 April 1979.

The central pressure of Bess is estimated to be 985 millibars during nearest approach.

The estimated radius of maximum wind of Bess is 30 nautical miles during nearest approach.

Winds are expected to exceed 22 knots in the bearing range (360° - 130°) at the Royal Observatory during the passage of Bess.

The input form duly completed for Example (1) is shown on page 10.

The output printout for Example (1) is given on page 11.

For Bess the Program predicted a Peak Storm Surge of 0.88 metre and a High Water Level of 2.48 metres above Chart Datum at North Point.

Bess was indicated to be landfalling to the west of Hong Kong and was 106 nautical miles from Hong Kong when closest.

Example (2)

Two positions were given for the hypothetical Typhoon Alice :

It was at 21.0°N, 113.0°E at 1200 GMT 31 May 1979 and at 23.2°N, 117.0°E at 1200 GMT 1 June 1979.

The central pressure for Alice when closest was given as 965 millibars.

The radius of maximum wind for Alice when closest was given as 40 nautical miles.

Winds are not expected to exceed 22 knots in the bearing range (360° - 130°) at the Royal Observatory during passage of Alice.

For Example (2), the completed input data form is shown on page 12, the output printout is given on page 13.

The Program forecast a Peak Storm Surge of 0.67 metre for Alice at North Point and a High Water Level of 1.99 metres above Chart Datum at North Point.

The track of Alice was computed as 10 knots, on a bearing of 061 degrees, landfalling to east of Hong Kong and was 34 nautical miles away when closest.

PEAK STORM SURGE/HIGH SEA LEVEL COMPUTATION FORM

(TO BE FILLED IN BY FORECASTERS WHEN REQUIRING A PEAK STORM SURGE/HIGH WATER LEVEL FORECAST)

TO COMPUTER OPERATOR :

INPUTS FOR PEAK STORM SURGE/HIGH WATER LEVEL COMPUTATIONS

1) Name of tropical cyclone S.T.S. BESS .

2) Date, time of the first position (MONTH/DAY/GMT HOURS) APRIL 28 0600 .

3) First position of the tropical cyclone* 20·0 N 114·0 E .

4) Second position of the tropical cyclone* 22·8 N 111·2 E .

5) Estimated central pressure during nearest approach 985 mbar .

6) Estimated radius of maximum wind during nearest approach 30 nautical miles.

7) Do you expect winds to exceed 22 knots in the bearing range (360° to 130°) at the Royal Observatory YES/~~NO~~ .+

* Any pair of successive storm positions, 24 hours apart, preferrably (but not necessarily) covering the time of closest approach to Hong Kong.

\+ Delete where appropriate

FOR OPERATOR USE ONLY
(To facilitate correct input card punchings)

DIR ROUTINE Program Name : SURGE

Only one input card and a multi-punch end card required.

Tropical cyclone name

S	.	T	.	S	.		B	E	S	S					

1 … 16

*Y	Y	M	M	D	D	H	H
7	9	0	4	2	8	0	6

19 … 26

Latitude

La	La	La
2	0	0

29

Longitude

Lo	Lo	Lo	Lo
1	1	4	0

34

Latitude

La	La	La
2	2	8

40

Longitude

Lo	Lo	Lo	Lo
1	1	1	2

45

P	P	P	P
	9	8	5

51

D	D	D
	3	0

57

Y	E	S

62

or

	~~N~~	~~O~~

62

RUN TIME less than one minute

* Please fill in year if not given

FORECAST HIGH WATER LEVELS AT NORTH POINT
AND TOLO HARBOUR DURING THE PASSAGE OF S. T. S. BESS

(1) SUCCESSIVE STORM POSITIONS WERE GIVEN AS

AT 0600GMT APR 28 1979 : 20.0 N 114.0 E

AT 0600GMT APR 29 1979 : 22.8 N 111.2 E

BASED ON THIS TRACK

STORM SPEED WAS COMPUTED TO BE 10 KNOTS

STORM DIRECTION WAS COMPUTED TO BE 315 DEGREES COMPASS BEARING

DISTANCE OF NEAREST APPROACH WAS 106. NAUTICAL MILES

COMPUTED AS A WEST STORM IN THE CONTEXT OF THE NOMOGRAMS

(2) CENTRAL PRESSURE WAS GIVEN AS 985. MILLIBARS

(3) RADIUS OF MAXIMUM WIND WAS GIVEN AS 30. NAUTICAL MILES

FORECAST PEAK NOMOGRAM SURGE AT NORTH POINT = .88 METRES AT 1500GMT APR 28

PREDICTED ASTRONOMICAL TIDES NEAR THE TIME OF CLOSEST APPROACH (T) ARE :

AT TIME (T-2) HOUR, 1300GMT APR 28---- 1.21 METRES

AT TIME (T-1) HOUR, 1400GMT APR 28---- 1.44 METRES

AT TIME (T) HOUR, 1500GMT APR 28---- 1.58 METRES

AT TIME (T+1) HOUR, 1600GMT APR 28---- 1.59 METRES

AT TIME (T+2) HOUR, 1700GMT APR 28---- 1.48 METRES

HENCE

A HIGH WATER LEVEL OF 2.48 METRES ABOVE CHART DATUM IS EXPECTED AT NORTH POINT AROUND 1600GMT APR 28

A HIGH WATER LEVEL OF 2.92 METRES ABOVE CHART DATUM IS EXPECTED AT TOLO HARBOUR AROUND 1600GMT APR 28

PEAK STORM SURGE/HIGH SEA LEVEL COMPUTATION FORM

(TO BE FILLED IN BY FORECASTERS WHEN REQUIRING A PEAK STORM SURGE/HIGH WATER LEVEL FORECAST)

TO COMPUTER OPERATOR :

INPUTS FOR PEAK STORM SURGE/HIGH WATER LEVEL COMPUTATIONS

1) Name of tropical cyclone T. ALICE.

2) Date, time of the first position (MONTH/DAY/GMT HOURS) MAY 31 1200.

3) First position of the tropical cyclone* 21·0 N 113·0 E.

4) Second position of the tropical cyclone* 23·2 N 117·0 E.

5) Estimated central pressure during nearest approach 965 mbar

6) Estimated radius of maximum wind during nearest approach 40 nautical miles.

7) Do you expect winds to exceed 22 knots in the bearing range (360^o to 130^o) at the Royal Observatory ~~YES~~/NO.+

* Any pair of successive storm positions, 24 hours apart, preferrably (but not necessarily) covering the time of closest approach to Hong Kong.

\+ Delete where appropriate

FOR OPERATOR USE ONLY
(To facilitate correct input card punchings

DIR ROUTINE Program Name : SURGE

Only one input card and a multi-punch end card required.

Tropical cyclone name

T	.		A	L	I	C	E								

1 … 16

*Y Y M M D D H H

7	9	0	5	3	1	1	2

19 … 26

Latitude La La.La [2 1 0] (29) Longitude Lo Lo Lo.Lo [1 1 3 0] (34)

Latitude La La.La [2 3 2] (40) Longitude Lo Lo Lo.Lo [1 1 7 0] (45)

P P P P [9 6 5] (51)

D D D [4 0] (57)

~~Y E S~~ (62) or [N O] (62)

RUN TIME less than one minute

* Please fill in year if not given

FORECAST HIGH WATER LEVELS AT NORTH POINT
AND TOLO HARBOUR DURING THE PASSAGE OF T. ALICE

(1) SUCCESSIVE STORM POSITIONS WERE GIVEN AS

AT 1200GMT MAY 31 1979 : 21.0 N 113.0 E
AT 1200GMT JUN 1 1979 : 23.2 N 117.0 E

BASED ON THIS TRACK

STORM SPEED WAS COMPUTED TO BE 11 KNOTS
STORM DIRECTION WAS COMPUTED TO BE 061 DEGREES COMPASS BEARING
DISTANCE OF NEAREST APPROACH WAS 34. NAUTICAL MILES
COMPUTED AS A EAST STORM IN THE CONTEXT OF THE NOMOGRAMS

(2) CENTRAL PRESSURE WAS GIVEN AS 965. MILLIBARS

(3) RADIUS OF MAXIMUM WIND WAS GIVEN AS 40. NAUTICAL MILES

FORECAST PEAK NOMOGRAM SURGE AT NORTH POINT = .67 METRES AT 2000GMT MAY 31
PREDICTED ASTRONOMICAL TIDES NEAR THE TIME OF CLOSEST APPROACH (T) ARE :

AT TIME (T-2) HOUR, 1800GMT MAY 31---- 1.27 METRES
AT TIME (T-1) HOUR, 1900GMT MAY 31---- 1.30 METRES
AT TIME (T) HOUR, 2000GMT MAY 31---- 1.30 METRES
AT TIME (T+1) HOUR, 2100GMT MAY 31---- 1.30 METRES
AT TIME (T+2) HOUR, 2200GMT MAY 31---- 1.32 METRES

HENCE

A HIGH WATER LEVEL OF 1.99 METRES ABOVE CHART DATUM IS EXPECTED AT NORTH POINT AROUND 2200GMT MAY 31
A HIGH WATER LEVEL OF 2.13 METRES ABOVE CHART DATUM IS EXPECTED AT TOLO HARBOUR AROUND 2200GMT MAY 31

10. CRITERIA FOR MENTIONING "POSSIBLE SEA WATER FLOODING" IN THE SCHEDULED TROPICAL CYCLONE WARNING BULLETINS

The purpose of performing Peak Storm Surge forecasts and High Sea Level forecasts is to ascertain whether raised sea levels during a tropical cyclone passage are expected to cause sea flooding. In Hong Kong, a statement to alert the public of possible sea water flooding will be included in the scheduled tropical cyclone warning bulletins if the forecast peak water level at North Point exceeds 3 metres (above Chart Datum).

The following criteria is currently in effect :

IF THE FORECAST PEAK WATER LEVEL AT NORTH POINT EXCEEDS 3 METRES (ABOVE CHART DATUM), FORECASTERS CAN INCLUDE, WHEN APPROPRIATE, A STATEMENT ON "POSSIBLE SEA WATER FLOODING IN LOW-LYING AREAS". TOLO HARBOUR CAN BE MENTIONED SPECIFICALLY IF THE FORECAST PEAK WATER LEVEL FOR TOLO HARBOUR EXCEEDS 4.5 METRES (ABOVE CHART DATUM).

11. SOME EXAMPLES OF SENTENCES ON SEA FLOODING THAT CAN BE INCLUDED IN THE TROPICAL CYCLONE WARNING BULLETINS

Tides are currently running about (0.8) metre above normal. A high tide will occur at (7) a.m. tomorrow morning when the water level is expected to reach (3.2) metres. Minor flooding may therefore occur over low-lying areas.

The sea level is expected to be about (1 to 1.5) metres above normal tide heights tonight. This may give rise to slight flooding in the low-lying areas during tonight's high tide at around (10) p.m.

A high tide of (2.2) metres will occur around (8) a.m. tomorrow. An additional (1.0) metre is expected as the winds strengthen. It is possible that some minor sea water flooding can occur in low-lying areas, especially during heavy rain.

.... When tides are commencing to fall :

As warned earlier, the sea level is over (3.3) metres. Water levels are now falling. The next high tide is not expected until (6) p.m. this evening.

High water this morning was running over (1.2) metres above the level of normal high tide. However, sea level should commence to fall significantly during the next two hours.

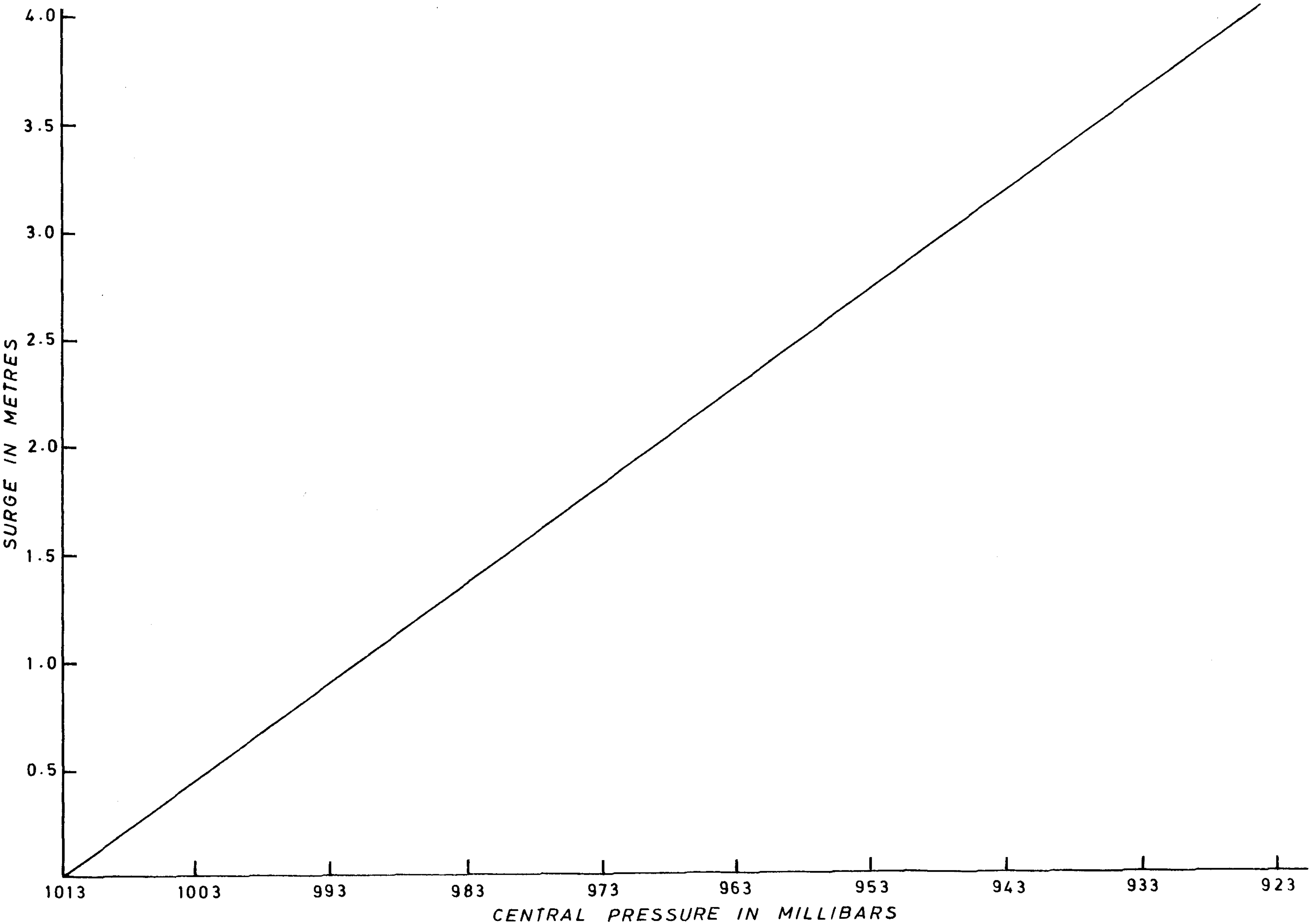

Figure 1. Splash nomogram – Splash computed North Point surge heights for various central pressure of storm

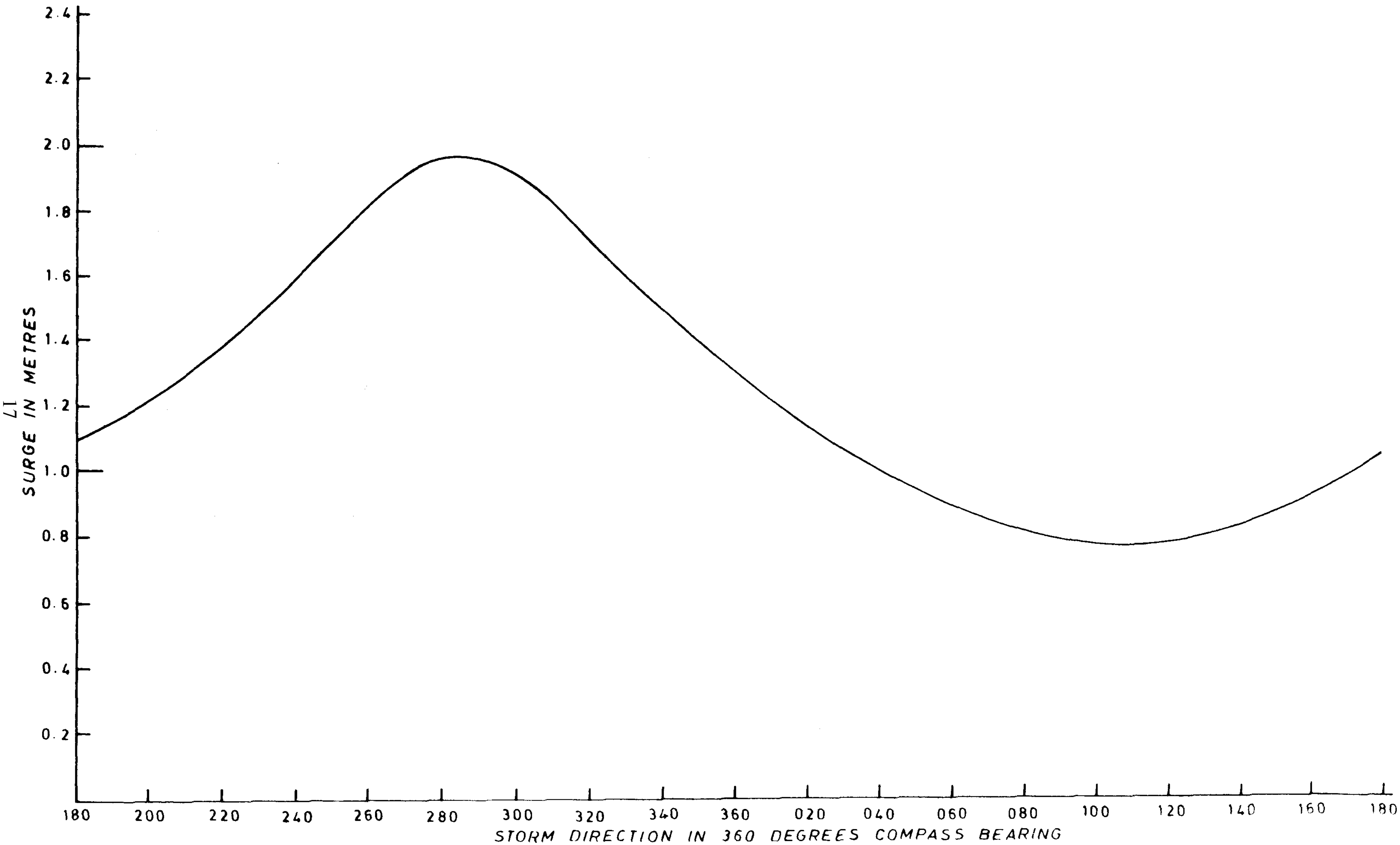

Figure 2. Splash nomogram – Splash computed North Point surge heights for various storm direction

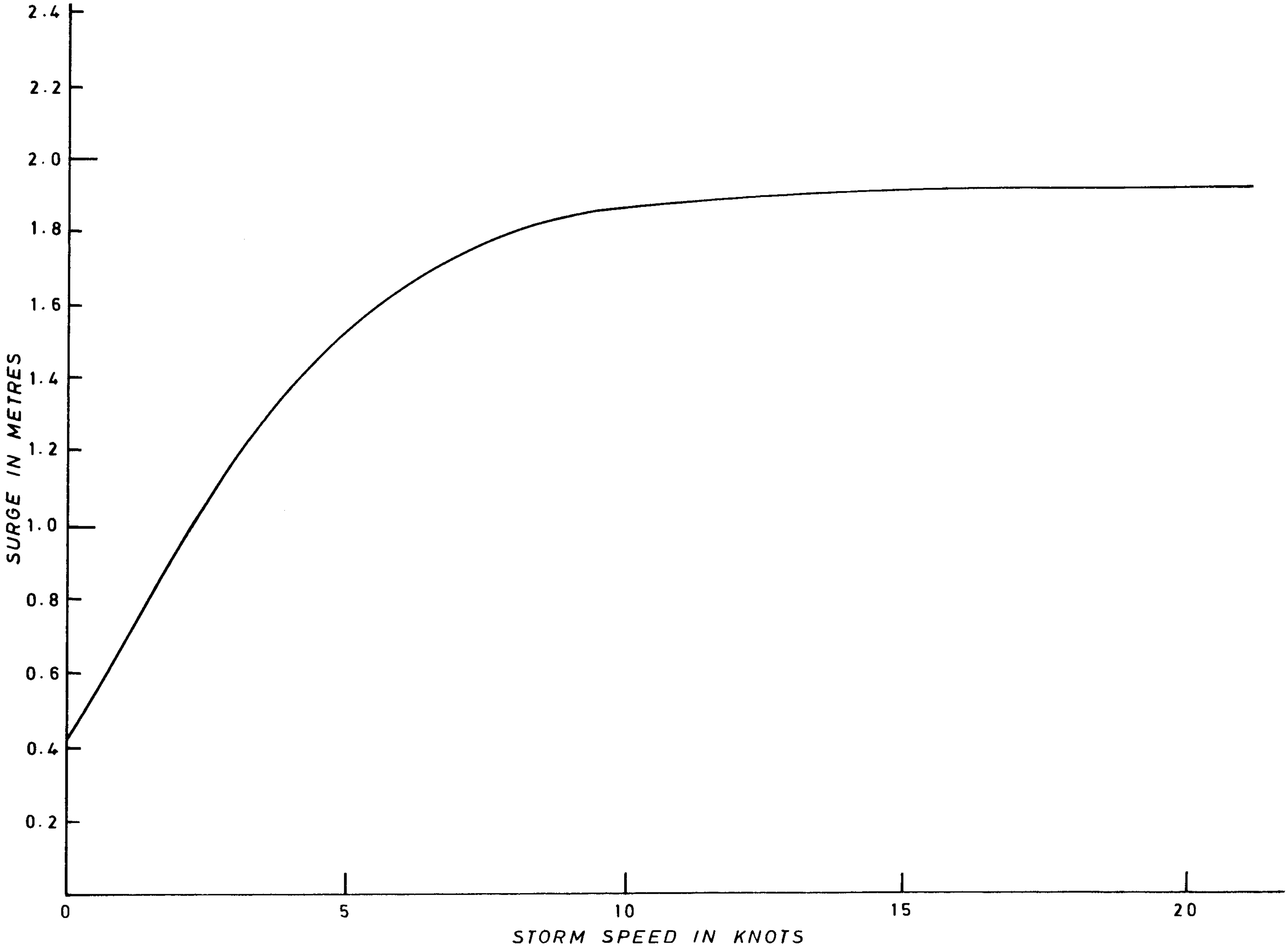

Figure 3. Splash nomogram – Splash computed North Point surge heights for various storm speeds

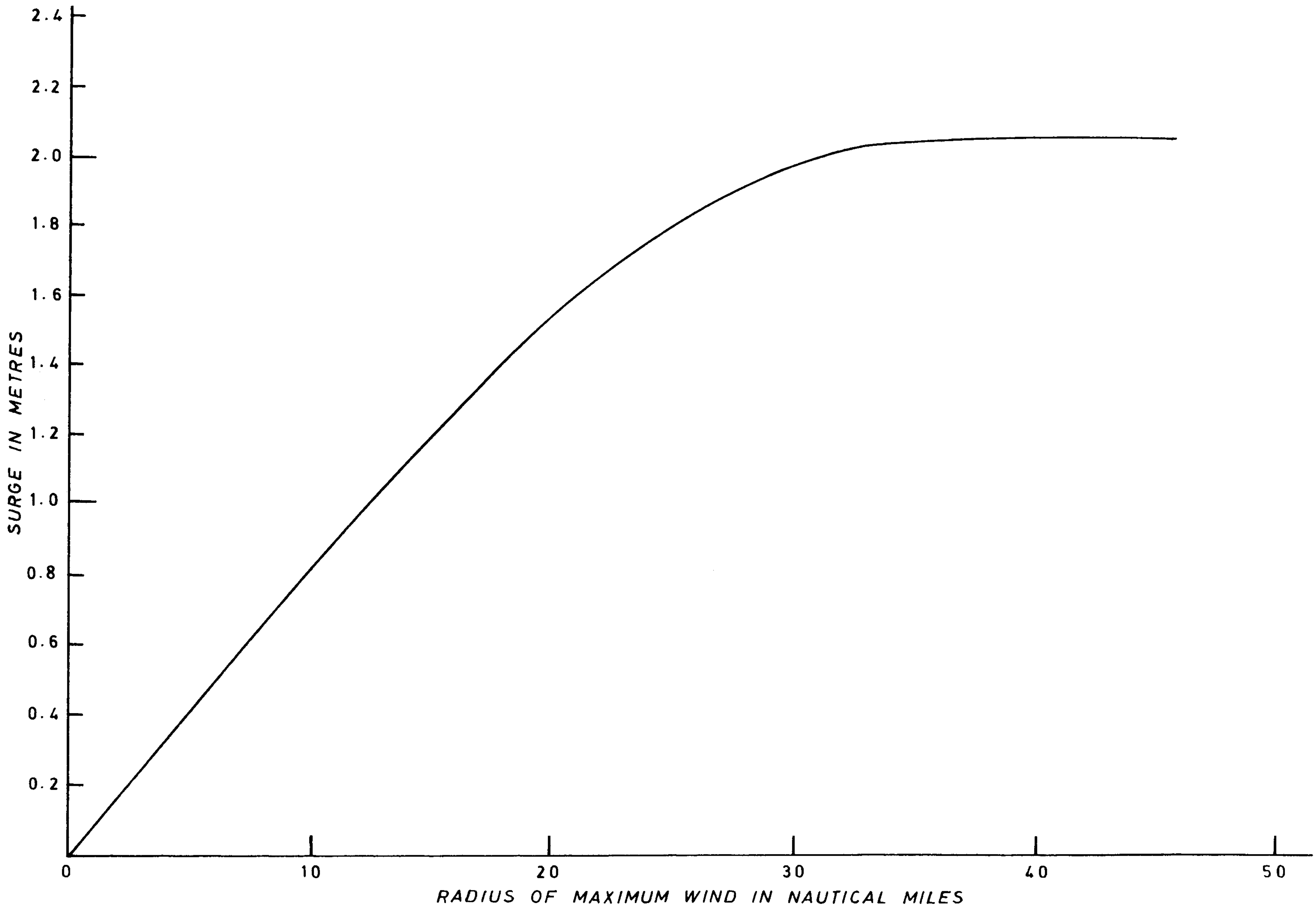

Figure 4. Splash nomogram – Splash computed North Point surge heights for various radius of maximum wind of storm

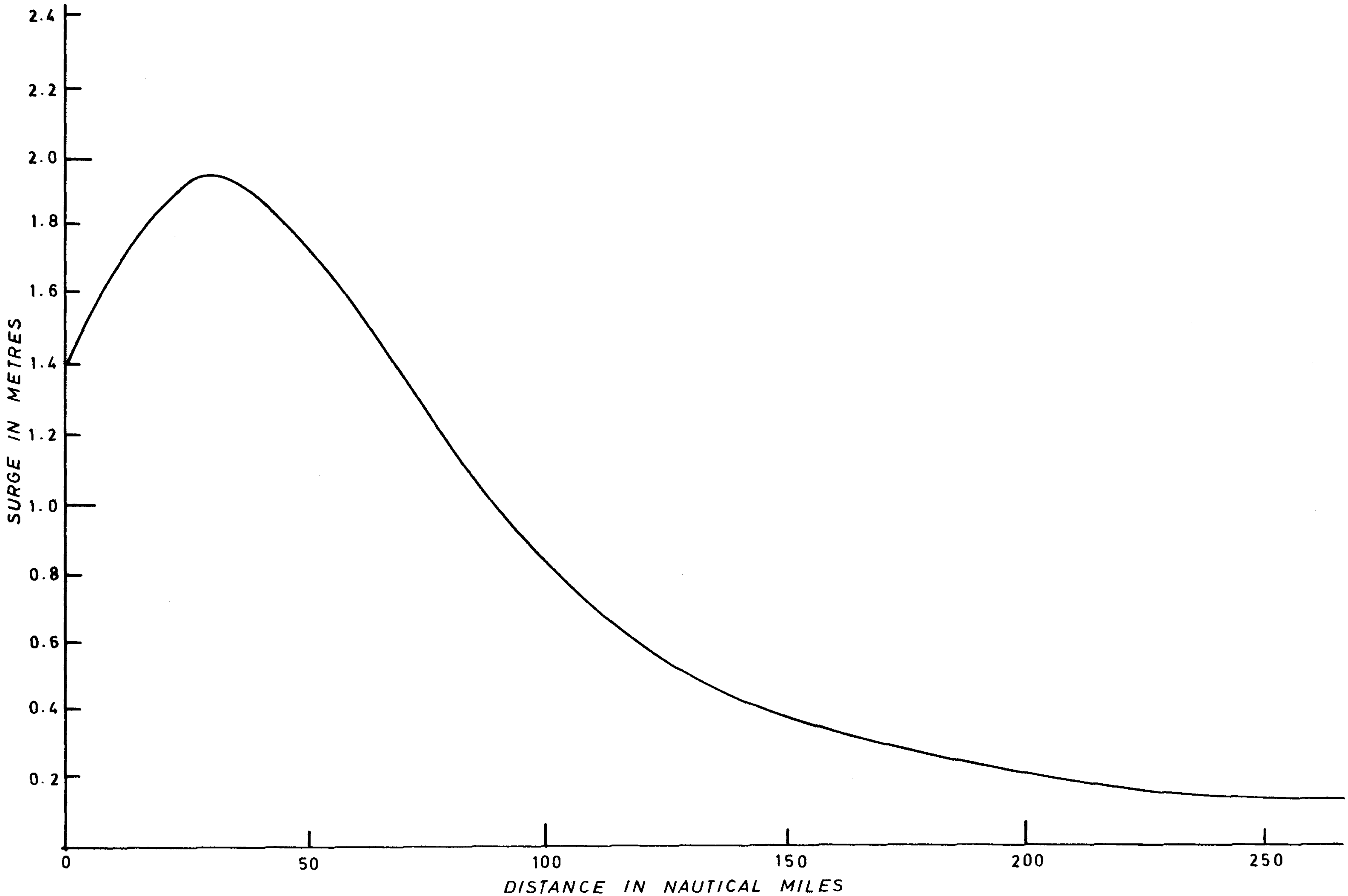

Figure 5. Splash nomogram — Splash computed North Point surge heights for various distance of nearest approach of storm

TABLE 1. CORRECTION FACTORS FOR CENTRAL PRESSURE FOR PREDICTING PEAK OPEN-COAST SURGE FOR NORTH POINT

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300° at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

PRESSURE(P) mbar	FACTOR	PRESSURE(P) mbar	FACTOR	PRESSURE(P) mbar	FACTOR
1000	0.325	983	0.750	966	1.175
999	0.350	982	0.775	965	1.200
998	0.375	981	0.800	964	1.225
997	0.400	980	0.825	963	1.250
996	0.425	979	0.850	962	1.275
995	0.450	978	0.875	961	1.300
994	0.475	977	0.900	960	1.325
993	0.500	976	0.925	959	1.350
992	0.525	975	0.950	958	1.375
991	0.550	974	0.975	957	1.400
990	0.575	973	1.000	956	1.425
989	0.600	972	1.025	955	1.450
988	0.625	971	1.050	954	1.475
987	0.650	970	1.075	953	1.500
986	0.675	969	1.100	952	1.525
985	0.700	968	1.125	951	1.550
984	0.725	967	1.150	950	1.575

TABLE 2. CORRECTION FACTORS FOR STORM DIRECTION FOR PREDICTING PEAK OPEN-COAST SURGE FOR NORTH POINT

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300° at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

DIRECTION(D) in degrees from north	FACTOR	DIRECTION(D) in degrees from north	FACTOR
010	0.635	190	0.600
020	0.595	200	0.635
030	0.560	210	0.683
040	0.524	220	0.730
050	0.492	230	0.778
060	0.465	240	0.833
070	0.441	250	0.892
080	0.424	260	0.952
090	0.413	270	1.002
100	0.408	280	1.032
110	0.408	290	1.032
120	0.413	300	1.000
130	0.424	310	0.949
140	0.443	320	0.892
150	0.465	330	0.837
160	0.492	340	0.778
170	0.529	350	0.725
180	0.571	360	0.678

TABLE 3. CORRECTION FACTORS FOR STORM SPEED FOR PREDICTING PEAK OPEN-COAST SURGE FOR NORTH POINT

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300^{o} at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

SPEED(V) in knots	FACTOR	SPEED(V) in knots	FACTOR
0	0.230	12	1.016
1	0.377	13	1.018
2	0.515	14	1.019
3	0.631	15	1.021
4	0.730	16	1.022
5	0.816	17	1.023
6	0.882	18	1.025
7	0.931	19	1.026
8	0.967	20	1.027
9	0.989	21	1.029
10	1.000	22	1.030
11	1.012	23	1.031

TABLE 4. CORRECTION FACTORS FOR RADII OF MAXIMUM WINDS FOR PREDICTING PEAK OPEN-COAST SURGE FOR HONG KONG

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300° at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

RADIUS OF MAX. WIND in nautical miles	FACTOR	RADIUS OF MAX. WIND in nautical miles	FACTOR
5	0.226	35	1.098
10	0.275	40	1.098
15	0.646	45	1.098
20	0.829	50	1.098
25	0.974	55	1.098
30	1.064	60	1.098

TABLE 5. CORRECTION FACTORS FOR CLOSEST DISTANCES FOR PREDICTING PEAK OPEN-COAST SURGE FOR NORTH POINT

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300° at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

DISTANCE(X) in nautical miles	FACTOR	DISTANCE(X) in nautical miles	FACTOR
0	0.672	150	0.476
5	0.770	160	0.448
10	0.841	170	0.418
20	0.973	180	0.393
30	1.043	190	0.377
40	1.057	200	0.364
50	1.031	210	0.359
60	0.980	220	0.357
70	0.919	230	0.354
80	0.841	240	0.349
90	0.788	250	0.344
100	0.723	260	0.342
110	0.648	270	0.341
120	0.588	280	0.340
130	0.550	290	0.339
140	0.502	300	0.339

TABLE 6. CORRECTION FACTORS FOR LANDFALLING STATE FOR PREDICTING PEAK OPEN-COAST SURGE FOR NORTH POINT

Factors below are generated on the basis that the Splash programs predicted a Peak Surge of 1.92 metres at North Point for the tropical cyclone with the following intensity and movement :-

(i) with a central pressure of 973 mbar

(ii) moving on a bearing of 300° at closest approach

(iii) moving at a speed of 10 knots at closest approach

(iv) with a radius of maximum wind of 26 nautical miles at closest approach

(v) at a distance of 26 nautical miles from Royal Observatory at closest approach

(vi) landfalling to the west of Hong Kong

LANDFALLING TO THE WEST OR EAST OF HONG KONG	FACTOR
Centre landfalling to the west of Hong Kong	1.000
Centre landfalling at more than 20 nautical miles to the east of Hong Kong	0.542
Centre landfalling at equal to or less than 20 nautical miles to the east of Hong Kong	1.000

REFERENCES

1) Chan, H.F. 1976 — A Study of the Characteristics of Storm Surges at Hong Kong
M. Phil. Thesis, University of Hong Kong

2) Cheng, T.T. 1967 — Storm Surges in Hong Kong
Royal Observatory Tech. Note 26

3) Jelesnianski, C.P. 1965 — A Numerical Calculation of Storm Tides Induced by a Tropical Storm Impinging on a Continental Shelf
Monthly Weather Reveiw Vol. 93 No. 6

4) Jelesnianski, C.P. 1966 — Numerical Computations of Storm Surges Without Bottom Stress
Monthly Weather Reveiw Vol. 94 No. 6

5) Jelesnianski, C.P. 1967 — Numerical Computations of Storm Surges With Bottom Stress
Monthly Weather Reveiw Vol. 95 No. 11

6) Jelesnianski, C.P. 1972 — Landfall Storms
NOAA, Tech. Mem., NWS TDL-48

7) Jelesnianski, C.P. 1974 — General track & variant storm conditions
NOAA, Tech. Mem., NWS TDL-52

8) Jelesnianski, C.P. 1975 — A sheared co-ordinate system for storm surge equations with a mildly ceiwed coast
Doc. IVG9 XVI Gen. Assembly

9) Peterson, P. 1975 — Storm Surge Statistics
Royal Observatory Tech. Note (Local) 20

APPENDIX I

Hypothetical storms used as input in Splash runs and the parameter specifications.

	Central Pressure in Millibars	Direction of Movement Compass bearing	Speed of Movement in knots	Radius of Maximum wind in nautical miles	Distance of nearest approach to Hong Kong in nautical miles
1.	1003	300	10	26	26
2.	993	300	10	26	26
3.	983	300	10	26	26
4.	973	300	10	26	26
5.	963	300	10	26	26
6.	953	300	10	26	26
7.	943	300	10	26	26
8.	973	010	10	26	26
9.	973	030	10	26	26
10.	973	050	10	26	26
11.	973	070	10	26	26
12.	973	090	10	26	26
13.	973	110	10	26	26
14.	973	130	10	26	26
15.	973	150	10	26	26
16.	973	170	10	26	26
17.	973	190	10	26	26
18.	973	210	10	26	26
19.	973	230	10	26	26
20.	973	250	10	26	26
21.	973	270	10	26	25
22.	973	290	10	26	26
23.	973	310	10	26	26
24.	973	330	10	26	26
25.	973	350	10	26	26

	Central Pressure in Millibars	Direction of Movement Compass bearing	Speed of Movement in knots	Radius of Maximum wind in nautical miles	Distance of nearest approach to Hong Kong in nautical miles
26.	973	300	0	26	26
27.	973	300	2	26	26
28.	973	300	4	26	26
29.	973	300	6	26	26
30.	973	300	8	26	26
31.	973	300	10	26	26
32.	973	300	12	26	26
33.	973	300	14	26	26
34.	973	300	16	26	26
35.	973	300	18	26	26
36.	973	300	20	26	26
37.	973	300	22	26	26
38.	973	300	24	26	26
39.	973	300	10	4	26
40.	973	300	10	9	26
41.	973	300	10	13	26
42.	973	300	10	17	26
43.	973	300	10	22	26
44.	973	300	10	26	26
45.	973	300	10	30	26
46.	973	300	10	35	26
47.	973	300	10	39	26
48.	973	300	10	43	26
49.	973	300	10	26	35
50.	973	300	10	26	52
51.	973	300	10	26	69
52.	973	300	10	26	87
53.	973	300	10	26	104
54.	973	300	10	26	122
55.	973	300	10	26	139
56.	973	300	10	26	156
57.	973	300	10	26	174

APPENDIX II

Meteorological data from the following historical storms that affected Hong Kong were used in Splash computer runs.

Ruby	6/76	Freda	6/71	Agnes	7/63
Violet	7/76	Gilda	6/71	Carmen	8/63
Ellen	8/76	Lucy	7/71	Faye	9/63
Iris	9/76	Rose	8/71	Wanda	8/62
T.D.	6/75	Della	9/71	Alice	5/61
T.D.	8/75	Elaine	10/71	Olga	9/61
Alice	9/75	Ruby	7/70	Sally	9/61
Betty	9/75	T.D.	8/70	Mary	6/60
Doris	10/75	Violet	8/70	Olive	6/60
Elsie	10/75	Georgia	9/70	Kit	10/60
Flossie	10/75	Iris	10/70	Wilda	7/59
Dinah	6/74	Joan	10/70	Nora	9/59
T.D.	6/74	Viola	7/69	T.D.	5/58
Ivy	7/74	Nadine	7/68	T.D.	8/58
Trix	9/74	Rose	8/68	T.D.	7/57
Bess	10/74	Shirley	8/68	Wendy	7/57
Carmen	10/74	Wendy	9/68	Gloria	9/57
Elaine	10/74	Bess	9/68	T.D.	10/57
Gloria	11/74	Iris	8/67	Vera	7/56
Irma	11/74	Kate	8/67	Charlotte	8/56
Dot	7/73	Emma	11/67	Jean	10/56
Georgia	8/73	Lola	7/66	Billie	6/55
Joan	8/73	Mamie	7/66	Kate	9/55
Nora	10/73	Ora	7/66	Ida	8/54
Ruth	10/73	Freda	7/65	Pamela	11/54
T.D.	6/72	Elaine	11/65	Ruby	11/54
Ora	6/72	Viola	5/64	Susan	9/53
Susan	7/72	Winnie	7/64	Un-named	9/1937
Pamela	11/72	Ida	8/64	Un-named	8/1936
		Ruby	9/64	Un-named	8/1929
		Sally	9/64	Un-named	8/1923
		Dot	10/64	Un-named	9/1906