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INTERNAL DOCUMENT 210

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Tide, Surge and Still Water Levels at Chesil Beach.

Graham Alcock.

Institute of Oceanographic Sciences

Bidston Observatory

Birkenhead.

June 1984.

NATURAL ENVIRONMENT RESEARCH COUNCIL

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1. Introduction

C.H. Dobbie (CHD) are acting as Consulting Engineers on a project concerning shore processes and protection at Chesil Beach, in conjunction with the Department of Civil Engineering at Imperial College, Hydraulics Research Ltd., Wessex Water Authority and Ministry of Agriculture, Fisheries and Food. CHD need to supply HRS with estimates of still water level (i.e. tide + surge) during the flood events of 13 December 1978, 13 February 1979, 20 December 1983, and 26 January 1984.

IOS were commissioned by CHD to provide and prepare a pressure gauge for deployment off of Chesil Beach, to process and analyse the record to yield tide and surge statistics, and to hindcast levels for the flood events.

2. Equipment

IOS provided and prepared a "Teleost" pressure gauge, no. 287. In this type of gauge, fluctuations in the total pressure of water and air above the gauge cause fluctuations in a pressure diaphragm which are transduced into a frequency signal by a Digiquartz sensor consisting of a quartz crystal resonator coupled by piezoelectric action to an electronic oscillator. A quartz crystal clock is used to control the frequency integration period and the sampling interval, both 15 minutes, and the data are recorded on 0.25 inch magnetic tape.

IOS designed and manufactured suitable brackets to enable the gauge to be mounted to an offshore sewage outfall pipe. The gauge was switched on at Bidston on 22 February 1984 and deployed by CHD - supplied divers on 25 February, 1984. The gauge was deployed about 70m offshore at a nominal position of 50^{o} 33.5'N, 02^{o} 26.8'W. The top of the gauge recorder handle was estimated to be 4.96m below Ordnance Datum Newlyn, therefore the pressure sensing level was estimated to be 5.25m below ODN. The gauge was recovered by divers on 12 May 1984 and switched off at Bidston on 15 May 1984.

3. Data Processing

The magnetic tape from the pressure gauge was copied onto a 9 track magnetic tape and the channel counts listed using the CAMAC work station at Bidston. There were no translation errors but there was a gap of 13 days and 14 hours in the data due to an encoder fault which prevented the data being encoded onto the tape but which then corrected itself. The cause of this, in our experience, unique fault is being investigated. The timing channel continued to work correctly throughout the period of deployment.

Pressure frequencies were calculated from the channel counts and the bottom pressure calculated from the pressure/frequency calibration and stored on disk. The $\frac{1}{4}$ hourly values of total pressure are plotted in Figure 1 and show a very good signal.

An interpolation programme was used to produce an output of hourly values, on the hour (GMT) of the total pressure record. This programme smoothed the data using a low-pass filter, FLPO3, of half length 18 and cut-off frequency (half-power point) of 0.35 cph (126^{o} h^{-1}) - thus the amplitude response of the sixth diurnal band was -0.08dB (1%). The resulting series was then interpolated using a cubic spline to obtain the hourly values. The time associated with each pressure value was taken as the mid-time of the integration period (15 minutes), and this was arranged in the laboratory to be close to $7\frac{1}{2}$ minutes past the hour to minimise interpolation errors. (Root mean square errors due to the interpolation method were of the order of 0.02mb).

The resulting total pressure record obtained was for the periods 1600 25 February to 0800 18 March and 0900 01 April to 0400 12 May, 1984, (all times in GMT).

Each hourly value of the pressure obtained was the total pressure measured by the gauge, i.e. the sum of the pressures due to the water column and air column above the sensor. No attempt was made to compute, and subtract, hourly values of atmospheric pressure at the gauge site. (A 29-day mean atmospheric pressure was computed for use with the tidal analysis, see below).

4. Tidal Analysis

A tidal analysis of a 29 day period (02 to 30 April, 1984) of the hourly total pressure data was carried out using the IOS TIRA programme which utilises the harmonic method of analysis and which performs a least-squares fit to the data. The method models the tidal level as a finite number (N) of harmonic constituents with an amplitude (H) and angular speed (σ).

$$\zeta(t) = Z_o + \sum_{n=1}^{N} f_n(t) H_n \cos(\sigma_n t + V_n + u_n - G_n) . \qquad (1)$$

Z_o is the mean level referred to the sensor level, V is the initial phase at an arbitrary time origin t = 0, and G is the constituent's phase lag with respect to the equilibrium tide. f and u are slow modulating functions mostly with the period 18.6y of the lunar node. Table 1 gives the amplitude (H in m) and phase lag (G in ^{o}) relative to Greenwich epoch of 27 major and 8 related constituents, the time zone, being G.M.T. The constituents π_1, P_1, ψ_1, ϕ_1,

$2N_2$, ν_2, T_2, and λ_2 K_2 are not separable from the major harmonic constants with only one month of data, and so they were related to the major constituents using values derived from the harmonic analysis of 1 year of data from Portland. The atmospheric tidal signal is very small around the U.K. (less than 1mb at any frequency), and so its contribution to the total pressure record tidal analysis is negligible.

The amplitude of each harmonic constituent is given in units of elevation (metres). This has been obtained from the pressure value using the hydrostatic relation

$$H = P/\rho g, \qquad (2)$$

where H is elevation (metres), P is pressure (pascals) 1 Pa = 10^{-2}mb, ρ is sea water density (Kg m^{-3}) and g is acceleration due to gravity (ms^{-2}). Values of and g were taken to be 1027.3 Kg m^{-3} and 9.811 ms^{-2} respectively, the former based on winter mean surface and bottom temperature and salinity (Ref. 1) and the latter on a nominal latitude of 50° 33.5'N.

Table 1 also gives the mean value (Z_o, in metres) of the sea level above the sensor level for the 29 days' period. This has been computed by subtracting the mean atmospheric pressure at the Meteorological Office Daily Weather Report station at Exeter over the 29 days' period from the Z_o value of the total pressure record. (This was considered to be a good approximation to the actual mean atmospheric pressure at Chesil as the value of 1020.8mb compares well with that from the station at Hurn, 1020.9mb, indicating no significant mean pressure gradient between the stations). Application of equation 2 gives an approximate mean depth of +4.79m relative to the sensor level.

The values of M_2 and S_2 (converted to metres using equation 2) have been used to compute the tidal statistics of Mean High Water Springs, Mean High Water Neaps, Mean Low Water Neaps, and Mean Low Water Springs (MHWS, MHWN, MLWN and MLWS respectively), and these are given in Table 2.

5. Surge Analysis

The series of hourly values of total pressure contains components due to the astronomical tides and meteorological surges. The former component was predicted for the deployment period using the 29 day analysis and equation (1), and the latter component computed as the difference between the hourly values of the observed and predicted series.

The frequency distribution of the resulting hourly surge residuals is given in Figure 2. It is difficult to draw general conclusions about surges at Chesil from such a small population of events, but the distribution shows the same Gaussian appearance, with some asymmetry, as those from much longer data sets from other ports (Ref. 2). There is a negative skewness to the distribution with more negative surges than positive surges; however there is a greater frequency of large positive surges (over 40mb) than of large negative surges (below -40mb). The largest positive surge, of +63.1mb, and the largest negative surge, of -66.6mb, both occurred on the 11 May, 1984 and were due to the same surge event.

6. Extreme Tides, Surges and Still Water Levels

Highest and Lowest Astronomical Tide (HAT and LAT) are defined as the highest and lowest levels respectively which can be predicted to occur under average meteorological conditions and under any combination of astronomical conditions. These statistics should be extracted from an 18.6 year set of predictions generated from an analysis of at least one year's data in order to take into account seasonal and nodal tidal variations.

As this is impracticable, a similarity method has been used to estimate HAT and LAT by extrapolating MHWS and MLWS using the difference between these statistics at Portland. The estimated values are given in Table 2.

Estimates of surges and extreme total still water at Chesil cannot be made directly from the limited data set available. Statistical analyses of hourly sea level and storm surge residual elevation data covering 19 years at Newlyn and 1 year at Newhaven have been carried out by Pugh and Vassie (Ref. 2) and Alcock and Blackman (Ref. 3). The results allow estimates to be made of surges or total still water levels with arbitrary return period. In addition, simulations of tide and surge conditions over the North Sea and neighbouring areas have been carried out using a numerical model developed for use in operational storm surge prediction (Ref. 4).

The method adopted here consists of using model generated tide and/or surge data, in suitable combination, to derive relationships between elevations at Newlyn or Newhaven and the point corresponding to Chesil. These relationships, applied to the extreme parameters from the observations at Newlyn or Newhaven, give estimates of the equivalent values at Chesil.

The appropriate values of tide, surge, and total levels from the observations and statistical analyses at Newlyn and Newhaven are given in Table 3. HAT and LAT values for Newhaven have been taken from predictions for 1984, the year in which the nodal variation reaches a peak. Values of the tide and surge levels from the continental shelf sea model (CSM) are given in Table 4, to give an indication of the accuracy of the model results by comparing computed values of M_2, S_2 and P_2 with the observations at Newlyn, Newhaven and Chesil. Observed values of M_2, S_2 and P_2 from Table 3 were used in the following computations and model simulations of $S^{\pm}_{max}$, as given in Table 4.

To estimate surge levels at Chesil, the ratio

$$(S^{\pm}_{max})_{Chesil}/(S^{\pm}_{max})_{ref}$$

was derived from model simulations of a number of large storm surges of recent years, and where the reference port is Newlyn or Newhaven. Then, for example,

$$(S^{+}_{100})_{Chesil} = (S^{+}_{100})_{ref} \times (S^{+}_{max})_{Chesil}/(S^{+}_{max})_{ref}$$

For total levels, those combinations of tide and surge values approximating the level at the reference site are used to determine the ratio

$$(\text{tide+surge})_{Chesil} \;/\; (\text{tide+surge})_{ref}$$

where $(\text{tide+surge})_{ref} = (L_N)_{ref}$. Where combinations approximating L^{+}_{100} might be HAT + S^{+}_{1}, $P_2 + S^{+}_{max}$, $M_2 + S_2 + S^{+}_{100}$, all such combinations within $\pm$10% of the derived level were included.

Then for example,

$$(L^{+}_{100})_{Chesil} = (L^{+}_{100})_{ref} \times \left\{(\text{tide+surge})_{Chesil}/(\text{tide+surge})_{ref}\right\}_{mean}$$

The methods outlined above give the estimates (in metres) of surge and total still water levels at Chesil given in Table 5, based on statistics of observations at Newlyn and Newhaven. Surges at Chesil could be due to surges propagating either eastwards from the North Sea or westwards from the western approaches to the English Channel (Refs 5 and 6). It is not therefore immediately apparent which estimates, based on Newlyn or Newhaven, are the most appropriate.

Since Chesil is nearly equidistant from Newlyn and Newhaven, the mean of estimates is perhaps the most appropriate value to use. The S^{+}_{50} mean value of

1.04m agrees very well with the value of 1.03m predicted by the CSM. Also using the mean values, estimated positive and negative surges for the observation period of 62 days and 13 hours would be +0.67m and -0.68m respectively, which agrees well with the actual observed values of +0.63m and -0.66m respectively. It is therefore considered that the mean results represent the best estimates available.

The estimates in Table 5 are given to mean sea level. The relationship of msl to Ordnance Datum Newlyn (ODN) cannot be adequately determined from the 29 days' analysis because of i) the seasonal and annual variations of msl and ii) the difficulties of obtaining absolute measurements of water levels with a total pressure gauge (i.e. determination of atmospheric pressure, water density and accurate levelling of the gauge to a known datum). The best available estimate, that msl is 0.10m above ODN, is based on long term analyses of msl at Devonport and Portsmouth (ref 7). This value should be added to all estimates given in this report relative to msl to obtain values relative to ODN.

7. Hindcast Data

Predictions of the tidal levels occurring at Chesil during the flood events of 13 December 1978, 13 February 1979, 20 December 1983 and 26 January 1984 were computed using equation 1 and the harmonic constituents from the 29 day analysis. The mean level Z_o was set to zero, i.e. predicted tidal levels were computed to mean sea level.

The surges occurring on these days at Portland were computed by subtracting predicted High or Low Water from observed levels extracted from the tide gauge charts. (Both predictions and Portland tide gauge charts were supplied by the Tidal Branch of the Hydrographic Office). It was assumed that the surge levels at Portland were representative of those at Chesil, and therefore estimates of the still water level at Chesil were computed as the sum of predicted tide level at Chesil and observed surge level at Portland. The Continental Shelf Model predicts nearly identical maximum and minimum surges at model points corresponding to Chesil and Portland, and therefore this assumption was considered to be justified.

Estimated tide, surge, and still water levels for predicted High and Low Water times are given in Table 6, relative to msl. Reference to Table 5 shows that none of the levels are particularly extreme events and the inference is presumably that wave set-up and action must have been an important factor in the flooding events (see Ref 8 for a discussion of the flood of 13 February 1979).

8. Conclusions

Even with the gauge malfunction, a good record of total pressure has been obtained at Chesil Beach, yielding useful tide and surge statistics. Extreme tide, surge and total still water levels at Chesil have been estimated using combinations of observed and model-simulated statistics at Chesil, Newlyn and Newhaven.

Tide, surge and total still water levels have been hindcast for four flood events at Chesil using the tidal analysis of Chesil data and observed surges at Portland.

This work is based on a number of simplifications and assumptions and therefore all estimates should be treated with caution. At least 1 year of data is really needed to provide more reliable tide, surge and level statistics and predictions, so that seasonal and annual variations are adequately modelled and a good representative sample of surges obtained. However, the results presented in this report are considered the best that could be obtained with the limited data set available.

9. References

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TABLE 1

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List of Harmonic Constants.

Place: CHESIL BEACH

Latitude	Longitude L	Standard time S	Records: Length	Records: Central day
50° 33.5'N	02° 26.8'W	G.M.T.	29 days	16th April 1984

(nominal)
Teleost 287 Digiquartz gauge.
Analysis of total pressure record (unfiltered).
Units are metres, converted from millibars using density = 1027.3 Kg m^{-3} and g = 9.811 ms^{-2}.

Total variance = 8262.8 mb^2 (S.D. = 90.9mb).
Residual variance = 43.6mb^2 (S.D. = 6.6mb).

* Are related constituents using Portland analysis 1968.
Z_o is mean value related to sensor level.

	H	g		H	g		H	g		H	g
Z_0	4.790		$2Q_1$			OQ_2			MO_3	0.009	110.7
Sa			σ_1			MNS_2			M_3	0.009	182.5
Ssa			Q_1	0.007	259.7	* $2N_2$	0.014	284.8	SO_3		
Mm	0.028	128.8	ρ_1			μ_2	0.193	207.4	MK_3	0.007	182.7
MSf	0.030	117.9	O_1	0.058	345.1	N_2	0.202	172.8	SK_3		
Mf			MP_1			* ν_2	0.037	151.4	MN_4	0.034	4.9
			M_1	0.004	334.9	OP_2			M_4	0.108	53.7
			χ_1			M_2	1.080	187.5	SN_4	0.025	161.7
			* π_1	0.004	140.9	MKS_2			MS_4	0.082	111.5
			* P_1	0.031	111.1	λ_2			MK_4		
			S_1			L_2	0.111	160.4	S_4		
			K_1	0.075	111.0	* T_2	0.039	271.3	SK_4		
			* ψ_1	0.003	229.2	S_2	0.493	240.4	$2MN_6$	0.030	54.1
			* ϕ_1	0.002	133.9	R_2			M_6	0.055	97.1
			θ_1			* K_2	0.153	240.0	MSN_6	0.016	123.0
			J_1	0.008	226.9	MSN_2			$2MS_6$	0.066	129.9
			SO_1			KJ_2			$2MK_6$		
			OO_1	0.009	275.1	$2SM_2$	0.036	352.4	$2SM_6$	0.020	174.3
									MSK_6		

TABLE 2

Tidal Statistics at Cheshil Beach

		(m)
Z_o	relative to sensor level	4.79
HAT	relative to Z_o	+2.17
MHWS	relative to Z_o	+1.57
MHWN	relative to Z_o	+0.59
MLWN	relative to Z_o	-0.59
MLWS	relative to Z_o	-1.57
LAT	relative to Z_o	-1.87

Note All statistics are based on analysis of the 29 days from 02 April 1984 to 30 April 1984

TABLE 3

Tide, Surge and Total Levels from Observations and Statistical Analyses.

		Newlyn	Newhaven
Tides	M_2	1.70	2.24
	S_2	0.57	0.73
	P_2	2.85	3.73
to msl	HAT	2.91	3.55
	LAT	-2.93	-3.52
Surges	S^+_{100}	0.90	1.37
	S^+_{50}	0.87	1.30
	S^+_{10}	0.78	1.14
	S^+_{1}	0.67	0.91
	S^-_{1}	-0.58	-0.54
	S^-_{10}	-0.69	-0.63
	S^-_{50}	-0.77	-0.70
	S^-_{100}	-0.80	-0.73
	S^+_{max}	0.87	0.81
	S^-_{max}	-0.64	-0.44
Levels relative to MSL	L^+_{100}	3.43	4.03
	L^+_{50}	3.38	3.98
	L^+_{20}	3.29	3.93
	L^+_{10}	3.24	3.88
	L^+_{5}	3.17	3.81
	L^+_{1}	3.01	3.64
	L^-_{1}	-2.98	-3.42
	L^-_{5}	-3.09	-3.51
	L^-_{10}	-3.13	-3.55
	L^-_{20}	-3.17	-3.58
	L^-_{50}	-3.21	-3.62
	L^-_{100}	-3.23	-3.64

Note : See Table 4 for notation

TABLE 4

Tide and Surge Levels from the Model

	Newlyn	Newhaven	Chesil
M_2	1.73	2.29	1.19
S_2	0.56	0.67	0.49
P_2	2.88	3.72	2.11
S^{+}_{max}	0.37	1.12	0.59
S^{-}_{max}	-0.33	-0.49	-0.54

Notation for Tables 3, 4 and 5.

M_2, S_2	amplitudes of the tidal constituents
P_2	amplitude at perigean spring tide $= 1.25M_2$ x $1.28S_2$
HAT	highest astronomical tide
LAT	lowest astronomical tide
S^{+}_{N}	positive surge with return period N years
S^{-}_{N}	negative surge with return period N years
$S^{\pm}_{max}$	the maximum positive or negative surge in the sample of observations or model simulations
$L^{\pm}_{N}$	total still high or low water level with return period N years

TABLE 5

Estimated Surge and Total Levels at Chesil, based on Statistics of Observations at Newlyn and Newhaven

		Newlyn	Newhaven	Mean
Surges	S^{+}_{100}	1.44	0.72	1.08
	S^{+}_{50}	1.39	0.68	1.04
	S^{+}_{10}	1.24	0.60	0.92
	S^{+}_{1}	1.07	0.48	0.78
	S^{-}_{1}	-0.95	-0.60	-0.78
	S^{-}_{10}	-1.13	-0.69	-0.91
	S^{-}_{50}	-1.26	-0.77	-1.02
	S^{-}_{100}	-1.31	-0.80	-1.06
Levels relative to MSL	L^{+}_{100}	2.79	2.45	2.62
	L^{+}_{50}	2.76	2.42	2.59
	L^{+}_{20}	2.69	2.39	2.54
	L^{+}_{10}	2.63	2.35	2.49
	L^{+}_{5}	2.60	2.31	2.46
	L^{+}_{1}	2.47	2.20	2.34
	L^{-}_{1}	-2.49	-2.37	-2.43
	L^{-}_{5}	-2.58	-2.43	-2.51
	L^{-}_{10}	-2.59	-2.46	-2.53
	L^{-}_{20}	-2.61	-2.48	-2.55
	L^{-}_{50}	-2.63	-2.51	-2.57
	L^{-}_{100}	-2.67	-2.53	-2.60

TABLE 6

Hindcast Tide, Surge and Total Level at Chesil at Times of Predicted High (HW) and Low (LW) Water

13 December 1978		to MSL		
		T(m)	S(m)	(T+S) (m)
HW	0532	1.60	+0.5	2.10
LW	1112	-1.39	+0.6	-0.79
HW	1754	1.59	+0.6	2.19
LW	2329	-1.51	+0.5	-1.01

13 February 1979		to MSL		
		T(m)	S(m)	(T+S) (m)
LW	0053	-1.33	+0.3	-1.03
HW	0744	1.71	+0.5	2.21
LW	1320	-1.38	+0.5	-0.88
HW	2009	1.56	+0.4	1.96

20 December 1983		to MSL		
		T(m)	S(m)	(T+S) (m)
HW	0645	1.63	+0.4	2.03
LW	1215	-1.52	+0.5	-1.02
HW	1913	1.55	+0.4	1.95

26 January 1984		to MSL		
		T(m)	S(m)	(T+S) (m)
HW	0018	0.88	+0.6	1.48
LW	0537	-0.70	+0.5	-0.20
HW	1234	0.99	+0.5	1.45
LW	1824	-0.77	+0.4	-0.37

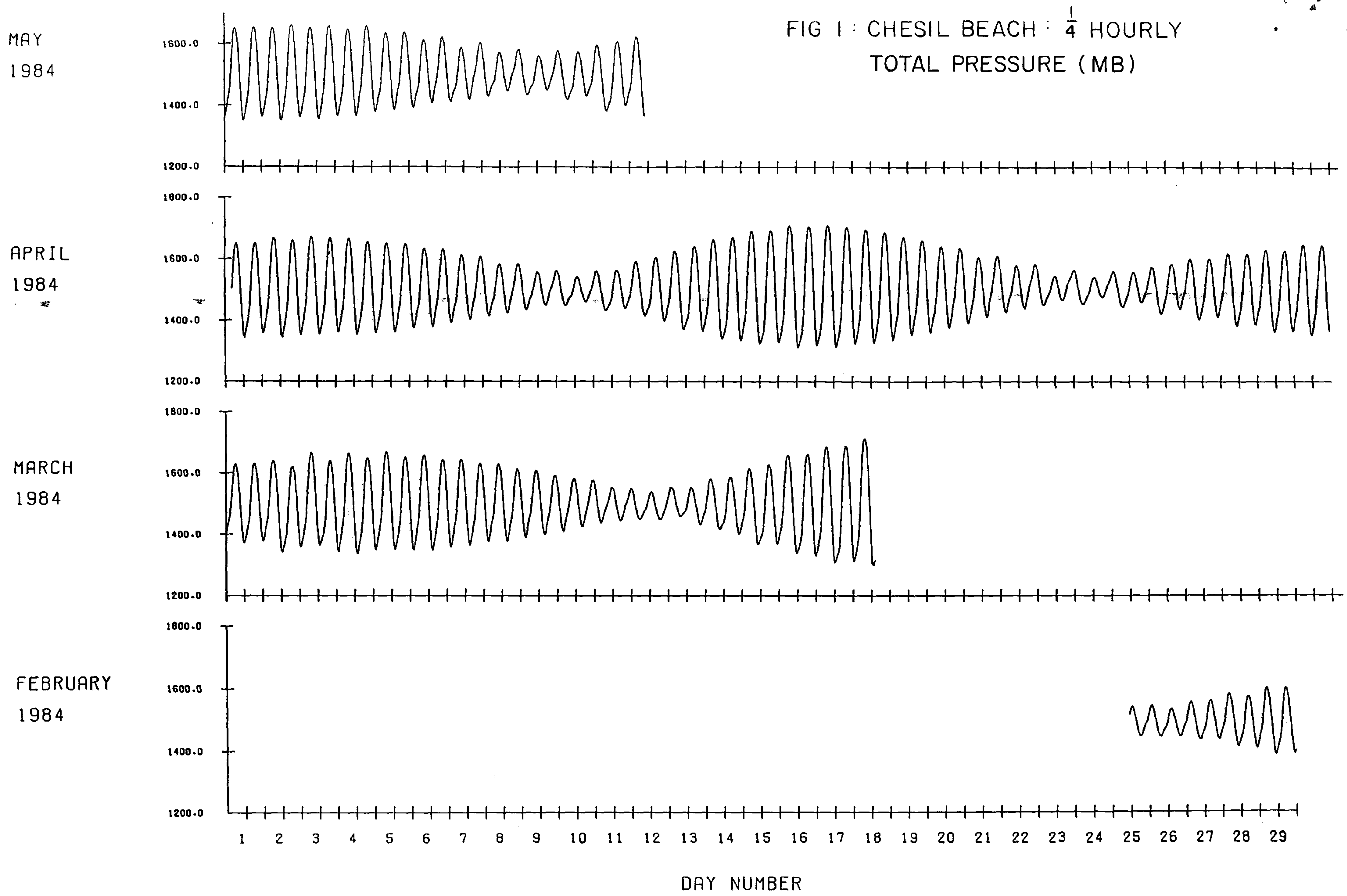

FIG I : CHESIL BEACH : $\frac{1}{4}$ HOURLY
TOTAL PRESSURE (MB)

FIG 2 CHESIL BEACH : HOURLY SURGE RESIDUALS

(1600 GMT 25/01/84 to 0800 18/03/84
and 0900 01/01/84 to 0400 12/05/84)