INTERNAL REPORT NO. 15

Report on ad hoc numerical studies of the Foulness Project

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A proposal to reclaim land in the vicinity of Maplin Sands has initiated studies of the associated effects on the tidal regime by means both of hydraulic and hydrodynamical numerical models.

In July 1969 numerical model work commenced on two projects associated with the Maplin Sand reclamation. The first project was to investigate the effects of reclamation on water levels in the Thames upstream of Southend. The second project was to investigate the importance of geostrophic effects in the area to be covered by the hydraulic model of the Thames Estuary; this was deemed advisable since the hydraulic model cannot incorporate these effects.

M.O.R.A.S.S. (model of river and shallow sea) is the basic tool for the numerical model of the Thames southern North Sea region and has been devised by Miss J.E. Banks (1967). It is based on a finite difference scheme which accommodates a one-dimensional river model and a two-dimensional sea model in the same computational array. The river model, which uses non-linear hydrodynamical equations is that established by Rossiter and Lennon (1965). The design of the sea model is based on a previous formulation by Heaps (1969) but modified to include such non-linear terms as quadratic bottom friction; the facility for connecting the one- and two-dimensional schemes is unique to MORASS. Starting from initial conditions of elevation and flow, the hydrodynamical equations of continuity yield elevations at later times τ, 2τ, 3τ ... (where τ is the time step used in the iterative procedures) and the equations of motion yield river currents at $\tau/2$, $3\tau/2$, $5\tau/2$ ... and sea stream flows at τ, 2τ, 3τ ... . Along the closed coastal boundaries of the model the condition of zero normal flow is satisfied; along the open boundaries to the north and south tidal elevation is specified as a function of the time; at the head of the river the average daily fresh water flow is specified.

The area of the southern North Sea covered by MORASS extends from 50° 54·5'N to 52° 50·5'N as seen in diagram 1 which shows the deployment of grid points in the sea : elevation is evaluated at "circle" points and total flow at "cross" points. The elevation and stream points form two interlacing nets. Over the sea the grid spacing between successive stream points is 0·0666667° in latitude and 0·1133334° in longitude and along the Thames the sectional spacing between successive current sections is 4·89 miles. Locations of sections along the Thames are shown in diagram 2. In the iterative procedures a 3 minute time step is used.

Hydrographic data for the river (with only slight modifications) are that used by Rossiter and Lennon (1965). Throughout the sea region depths below mean sea level are specified at stream points, the minimum depth employed is 6 ft. below chart datum.

Project 1 : To investigate the effects of the reclamation of the Maplin Sands on water levels upstream of Southend.

Reclamation of up to 30,000 acres of the Maplin Sands proposed for the Foulness project represents, in terms of the MORASS grid, just less than two "squares". A first step, therefore, was to compare elevations upstream of Southend produced when the two squares representing the Maplin Sands were flooded and when they were reclaimed. In both cases the same open boundary elevations generated the tides within the southern North Sea. Should the reclamation of the sands produce any significant changes in the tidal regime then a more detailed study would be necessary.

For the sake of convenience, the period 13-16 February 1962, already under investigation for other purposes, was chosen for these studies.

Run 12 : Simulation of M_2 tide of 13th February to 16th February 1962 with Maplin Sands reclaimed.

Of the total period considered the 13th and 14th are regarded as the run-in period for the model and their calculations are performed in a single run. The rest of the period is divided into two separate runs with the recorded fresh water flow into the river being specified each day. Thus run 12 corresponds to 13th and 14th February using the average fresh water flow for these two days, run 12.I corresponds to 15th and run 12.II to 16th February each using their respective daily average of the fresh water flow. At the end of each run, values of elevation and stream flow are stored on magnetic tape for later use as input to any subsequent run.

Initial values fed into the computer comprise M_2 elevations, specified over the entire sea/river area, together with suitable depth mean currents. Only mean spring values of the latter were available, and this inhomogeneity of input had to be eliminated by allowing a 2-day run-in period. Values of the M_2 harmonic constants of the tide at each open boundary point were obtained from a combination of German and British co-tidal charts and Dutch off-shore tide gauge records carefully examined to give the best fit with analyses of coastal tide gauge recordings.

The subsequent elevations specified along the open boundaries then determine the elevations and depth mean currents generated within the enclosed area.

Amplitudes and phases of the M_2 tide output from this run were in reasonable agreement with the International Hydrographic Bureau and I.C.O.T. values obtained from analyses of observations.

<u>Run 1</u> : Simulation of M_2 tide of 13th to 14th February 1962 with Maplin Sands flooded.

For this run the area of the model was increased by two "squares" in the vicinity of Maplin Sands as shown in diagram 3. Revised values of depths in the vicinity are shown in diagram 4.

Initial values of elevation and current were extended to cover the additional two "squares" of area but otherwise they were identical to the initial values employed in run 12. Open-boundary values of run 12 were also used in this run so that the sea would be responding to identical boundary elevations.

<u>Results of comparing runs 1 and 12</u>

Comparison of elevations upstream of Southend are shown in graphs 1a, 1b and 1c. This shows that reclamation of these two squares (i.e. the model approximation to Maplin Sands) <u>produces no significant difference in upstream elevations</u>.

<u>Project 2</u> : To confirm whether the effects of the Coriolis force are significant in the area to be covered by the hydraulic model of the estuary.

For this project the boundary configuration of the model simulates Maplin Sands reclaimed.

Coriolis parameter is defined as $2\omega \sin\phi$ where ω is the angular speed of the earth's rotation about its axis and ϕ is the latitude of the point. In the computer program for MORASS the magnitude of ω forms part of the input data so by setting $\omega = 0$ the Coriolis parameter and hence the Coriolis force will be zero.

<u>Run 2.I</u> : No Coriolis force in the <u>whole</u> of the southern North Sea for the generation of the M_2 tide of 15th February 1962.

This run was performed with $\omega = 0$ so that there was no Coriolis force acting.

Input data for 0 hrs on 15th were taken from values calculated in run 12 and stored on magnetic tape at the end of that run. Open boundary values were identical with those of run 12.I which calculated tides for 15th and included the Coriolis effect. Thus in run 2.I and run 12.I the sea was responding to identical open boundary values so that comparison of these two runs would display the Coriolis effect.

Results of comparing runs 2.I and 12.I for Coriolis effect

Comparisons of elevations along the Thames produced with and without the Coriolis force are shown in graphs 2a, 2b and 2c. Without the Coriolis force the amplitude of the tide is increased by about 1 ft. and the phase lag is also increased by some 15°. These are the increases apparent in the second tidal cycle of the run. The magnitude of the differences in amplitude and phase due to the Coriolis force show that it has a significant effect in the area covered by MORASS. It was therefore necessary to confirm whether the effects of Coriolis force would still be significant in the somewhat limited area covered by the hydraulic model.

Run 3.I and 3.II : No Coriolis force in an area of the North Sea equivalent to that of the hydraulic model. (M_2 tide of 15-16 February 1962).

The area of MORASS approximating to the hydraulic model is shown in diagram 5 and values of depths used in diagram 5a. Open-boundaries to the model are shown as dashed lines and along these boundaries the elevations must be specified at each point at two hourly intervals; the program will then interpolate for values at intermediate time-steps. The necessary open boundary values were obtained from run 12.(I, II) output as were initial conditions of the elevation and current at 0 hrs on 15th February. Thus starting from identical tidal conditions at 0 hrs on 15.2.62 run 12.(I, II) and run 3.(I, II) were subject to the same tidal oscillation along this new open boundary. 15th February was regarded as run-in period for the response of the sea to the withdrawal of the Coriolis force.

Results of comparing runs 3.II and 12.II for Coriolis effects in the estuary

Graphs 3a to e show the effects of the Coriolis within the bounds of the hydraulic model during the 16th February. Again it can be seen that the amplitude of the tide is decreased by an order of 0·5 ft. by the Coriolis force and the phase lag is decreased by some 7·5°.

The experiments show that the effects of the Coriolis force in the area considered are to accelerate and diminish the tide. These results are in qualitative conformity with theory.

Conclusions

Reclamation of Maplin Sands does not seem likely to create substantial changes in the tidal regime of the Thames. Exclusion of the Coriolis force, however, creates significant differences in the tidal regime, which vary in magnitude over the area considered.

It seems probable that HRS would wish the computational results to be presented differently, and for other localities than appear in this report; this will present no difficulty.

Acknowledgements

I am indebted to Mr. A.C. Bamford and members of the Institute of Coastal Oceanography and Tides staff for their excellent assistance with the technical details of the work. My thanks are also due to Dr. J.R. Rossiter, Director of the Institute, for his valuable guidance throughout the project.

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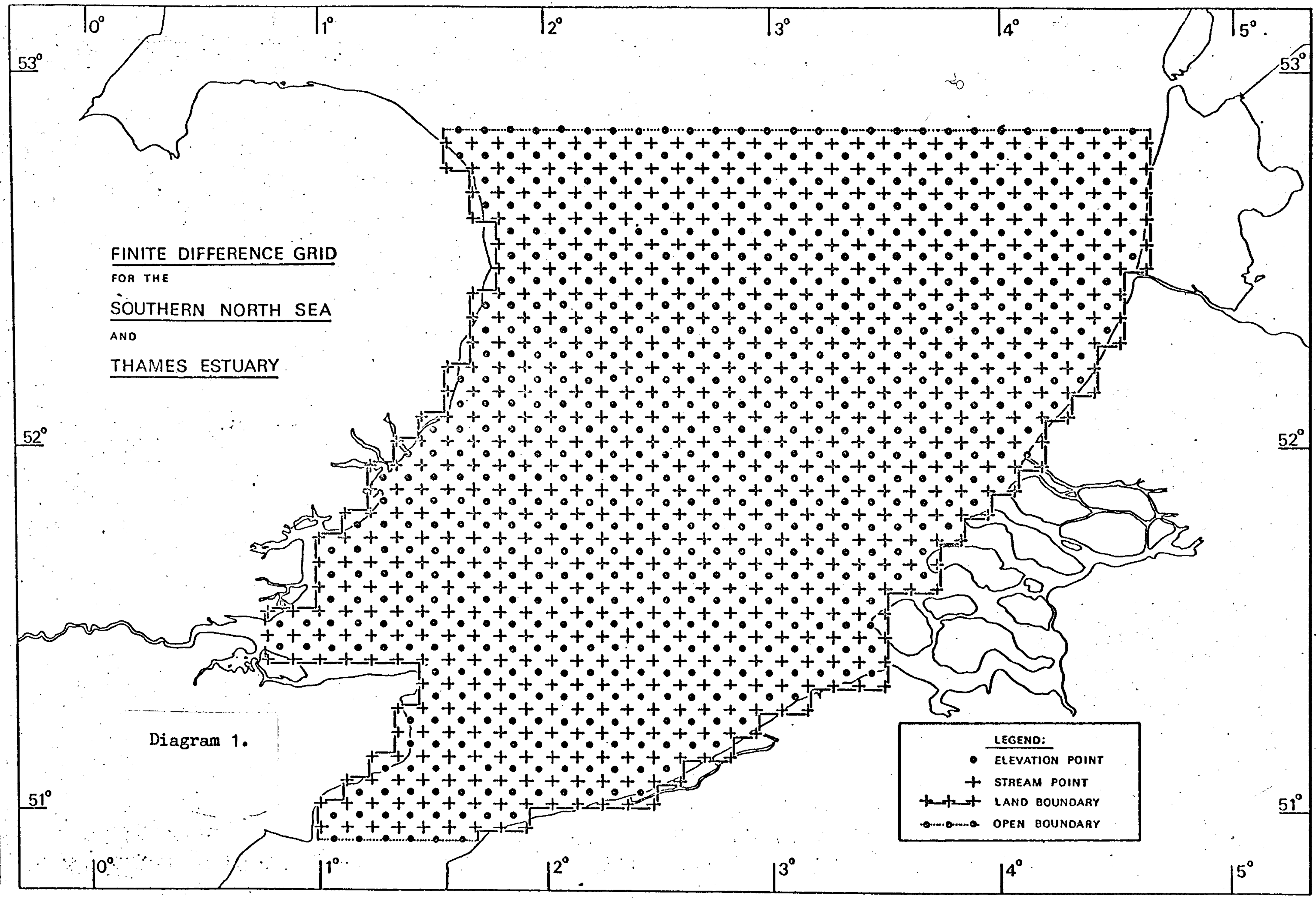

FINITE DIFFERENCE GRID
FOR THE
SOUTHERN NORTH SEA
AND
THAMES ESTUARY
Diagram 1.
LEGEND:
ELEVATION POINT
STREAM POINT
LAND BOUNDARY
OPEN BOUNDARY
0°
1°
2°
3°
4°
5°
51°
52°
53°

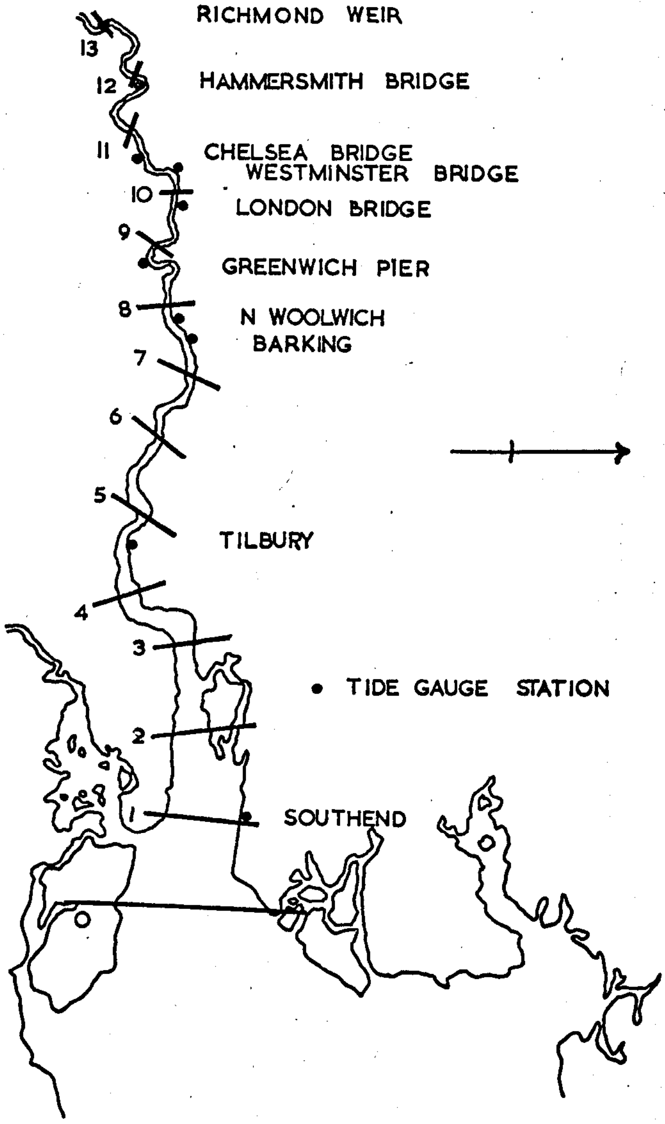


Diagram 2.

ELEVATION SECTIONS IN THE RIVER THAMES

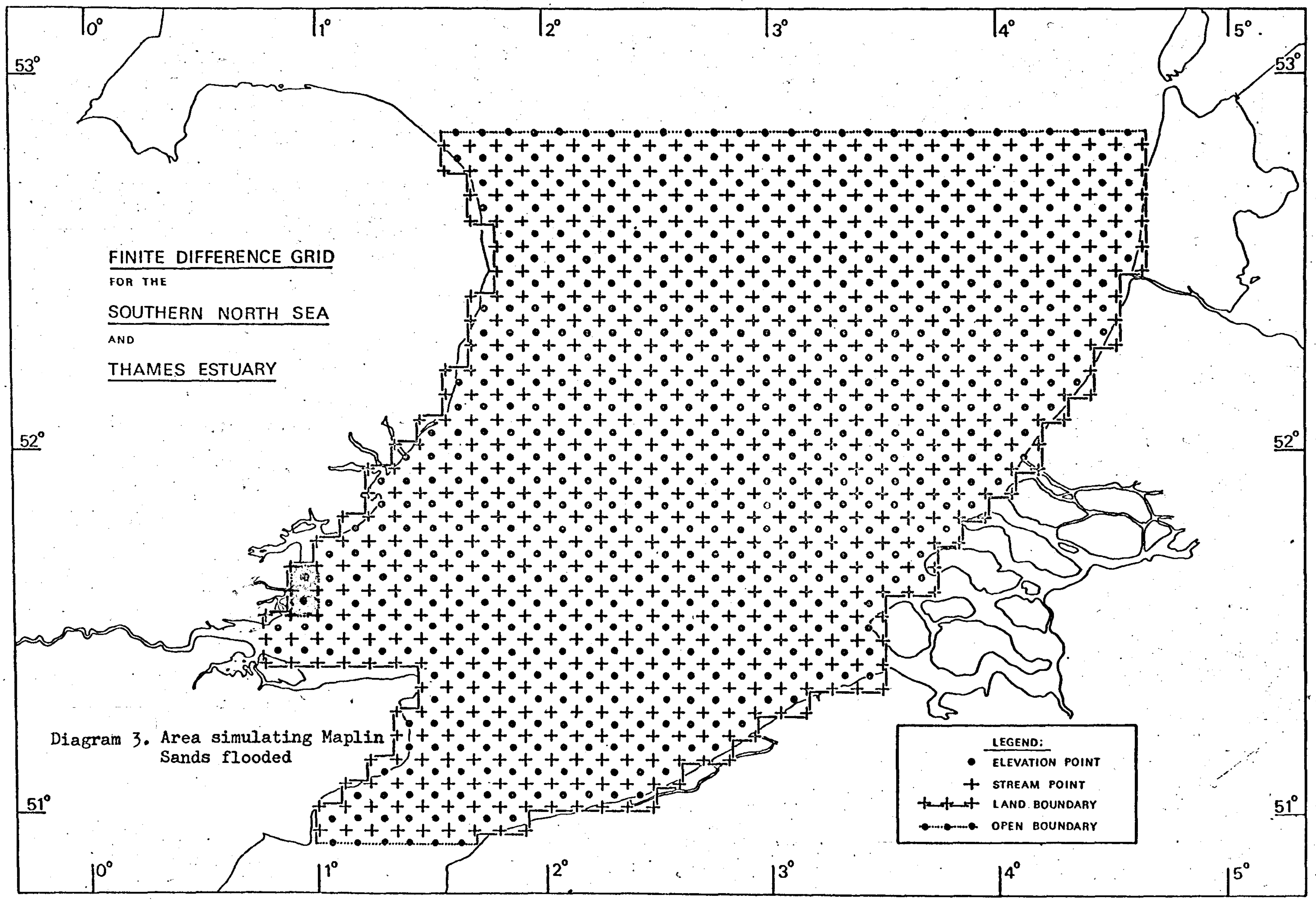


Diagram 3. Area simulating Maplin Sands flooded

							28	76	115	112	83	78	88	130	126	118	109	103	101	102	103	101	93	89	88	89	85	83	79	78	80	75	62	46
							18	35	60	79	83	80	44	129	127	123	114	108	103	99	97	95	93	92	91	89	85	82	79	83	80	69	57	32
								16	39	68	85	97	116	125	130	130	122	112	106	112	106	97	95	92	90	88	84	80	78	82	77	64	53	24
								16	34	67	83	100	118	138	143	138	141	131	113	120	113	100	97	84	86	90	84	77	75	70	67	58	47	12
									32	71	83	100	123	142	149	137	127	124	122	125	118	98	90	83	81	84	81	75	71	65	62	54	42	16
									31	82	101	113	130	139	141	132	122	118	119	123	122	96	88	86	83	78	73	71	69	65	59	51	39	18
								10	41	91	109	121	130	135	136	130	120	111	106	107	104	88	87	91	90	73	68	68	68	65	58	48	36	
								10	65	91	104	121	130	133	135	132	125	112	110	109	102	88	82	77	72	69	68	68	67	63	56	45	14	
								27	75	92	106	121	136	136	130	130	133	133	122	112	101	91	84	76	74	75	73	70	66	61	54	38	10	
							10	49	83	100	119	136	145	145	140	132	128	127	122	115	101	94	89	83	80	77	74	72	66	58	50	16		
							11	62	84	101	119	136	144	148	142	133	127	130	128	128	121	110	102	99	89	77	73	75	67	56	34	10		
						11	25	55	75	93	109	127	142	148	141	130	124	129	126	120	112	99	91	84	79	74	71	67	59	46	10			
					12	23	39	57	74	87	98	120	150	152	144	128	121	117	111	105	102	96	89	83	77	71	65	59	40	10				
				12	14	27	50	82	111	115	103	112	146	149	134	123	114	101	93	92	96	96	90	84	74	64	52	37	18	10				
				12	17	31	52	90	125	107	108	126	150	146	132	123	116	107	98	90	88	86	82	77	68	53	37	19	10					
			12	18	30	41	50	83	115	100	113	146	151	140	128	117	109	103	102	96	84	80	83	75	62	41	20	11						
		20	21	32	44	43	38	75	103	104	112	127	135	130	123	116	107	98	102	96	77	83	87	75	30	23	20							
	○	13	32	47	55	54	53	68	120	125	122	121	117	116	110	101	97	80	85	71	61	81	85	37	13	13								
	○	(14)	55	67	50	37	38	77	129	128	130	118	109	104	94	66	63	93	82	77	63	41	33	25	13	10								
15	17	34	49	45	40	50	77	99	115	113	118	103	91	93	86	77	75	107	88	80	63	34	23	14										
32	46	48	37	38	47	64	73	88	118	125	113	97	86	85	81	77	78	80	73	64	40	31	24	20										
14	14	15	17	21	31	44	63	83	115	137	125	105	89	74	66	70	75	66	57	44	27	25	29	33										
						21	60	98	114	122	117	107	102	96	77	64	65	57	47	33	22	17	14	13										
					15	33	67	111	116	112	109	105	92	79	63	48	46	42	31	15	13													
					16	47	88	111	113	100	103	94	71	64	51	38	28	20	15															
				15	26	89	121	107	106	107	89	70	65	49	34	29	24	14																
			17	61	102	118	127	108	90	88	77	73	62	24	16	15																		
		23	75	89	113	130	136	110	94	71	50	30	20	16	15																			
		36	86	109	132	148	141	72	27	16																								
		100	109	113	130	136	89	17																										

Diagram 4

Depths used in M.O.R.A.S.S.
(measured in feet below mean sea level)

(12) DEPTHS USED WHEN
(12) (25) SANDS ARE FLOODED

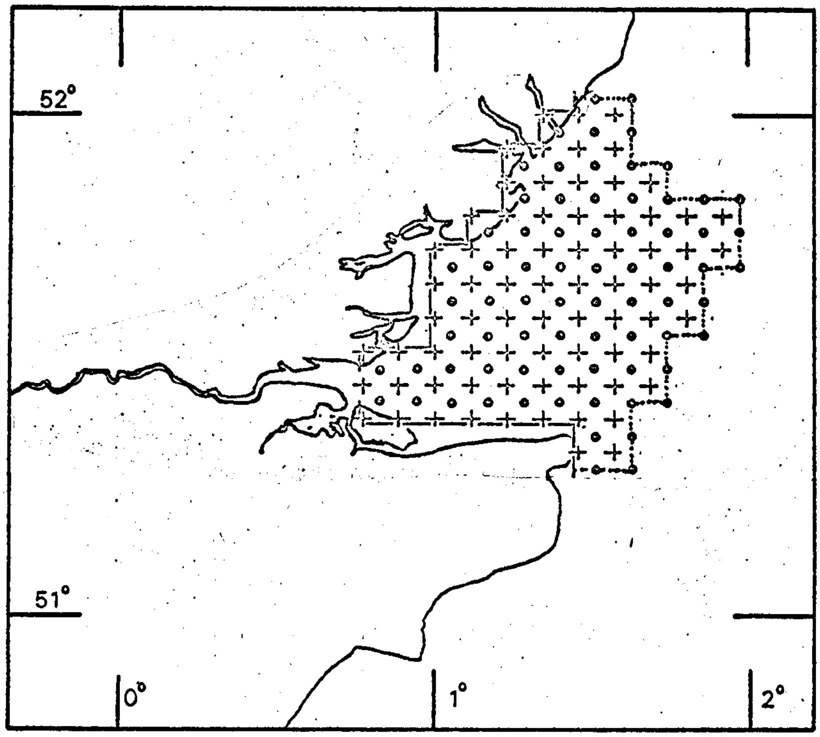


Diagram 5. Area simulating hydraulic model

Depths in feet

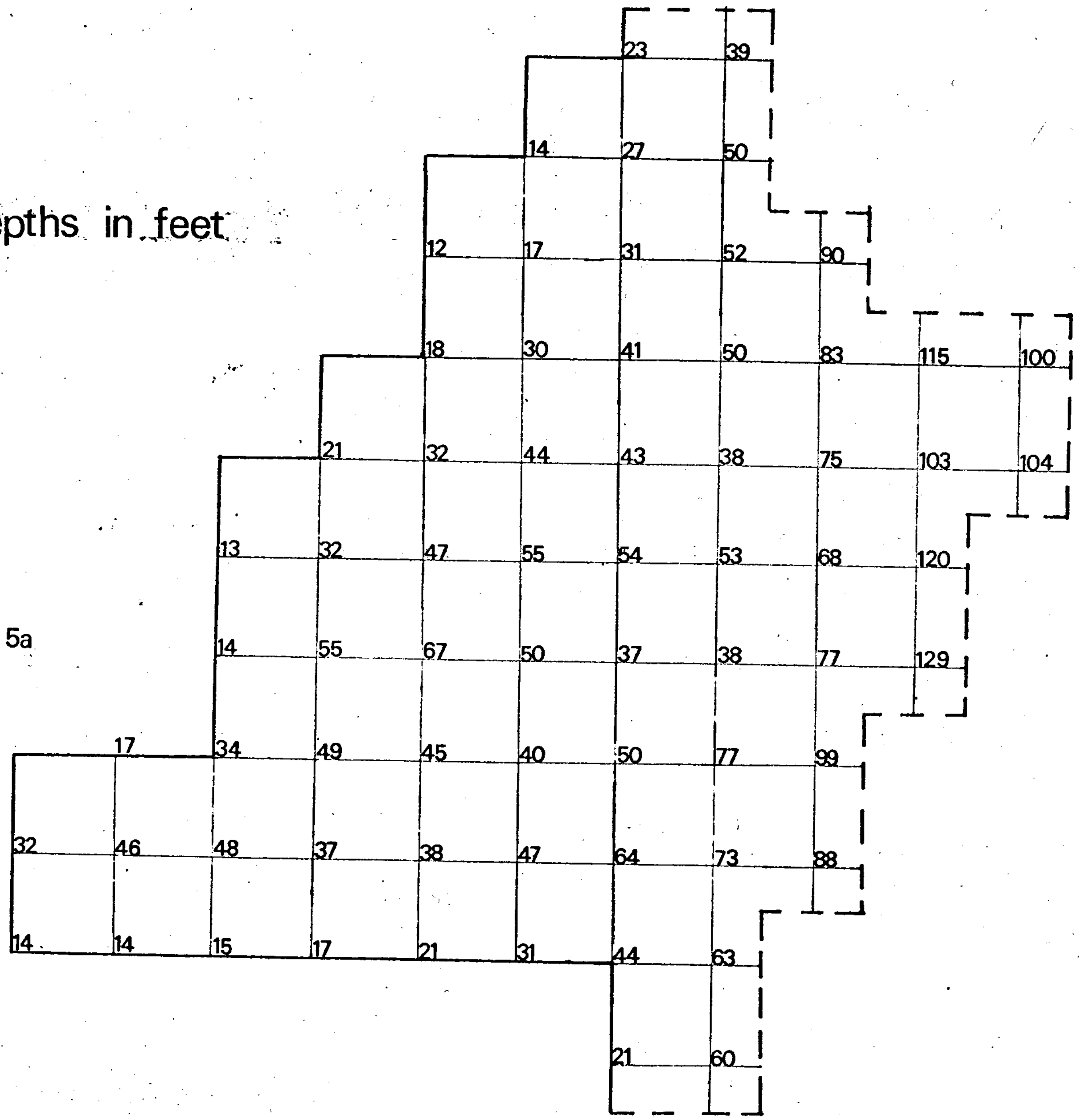
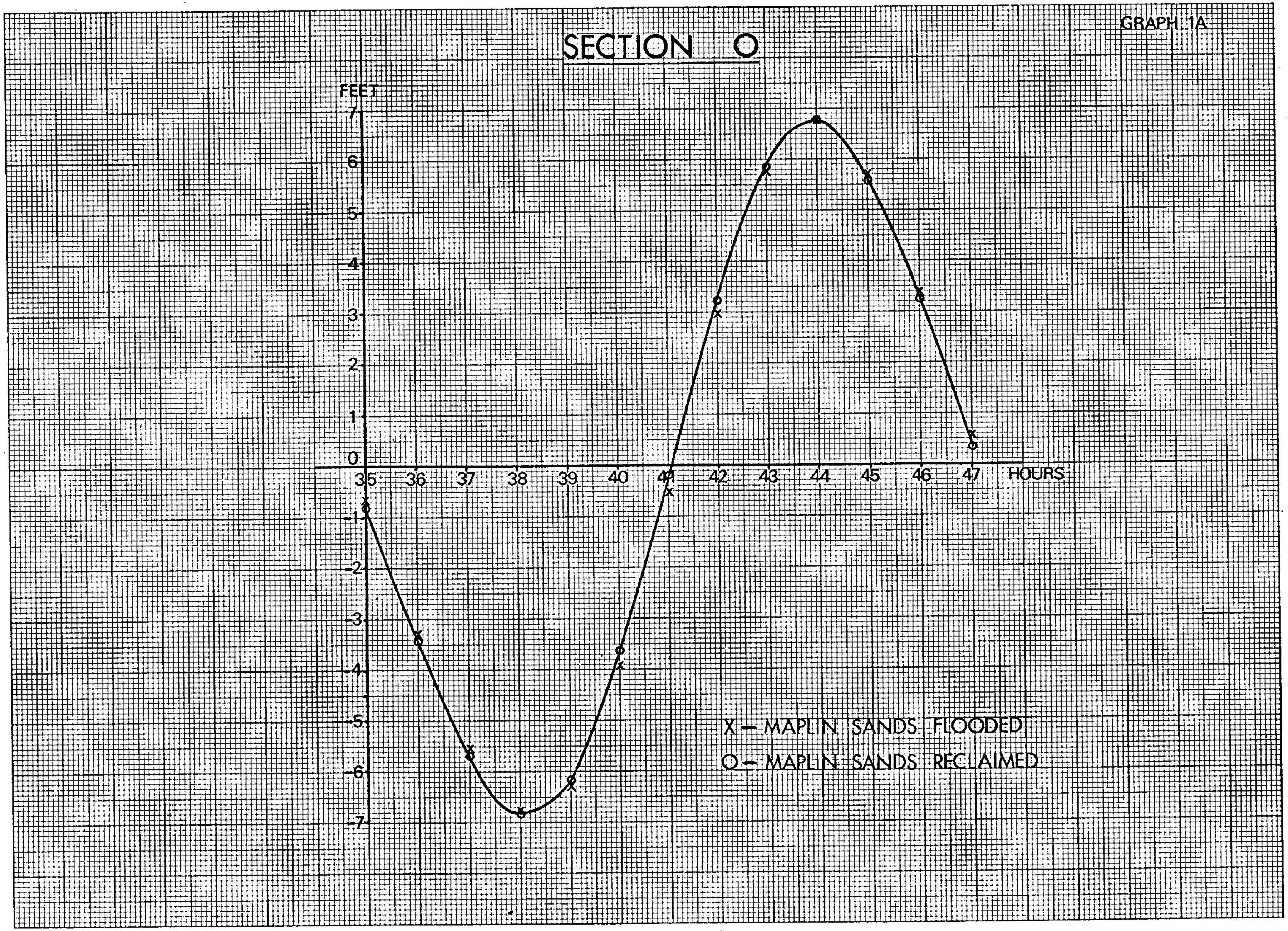
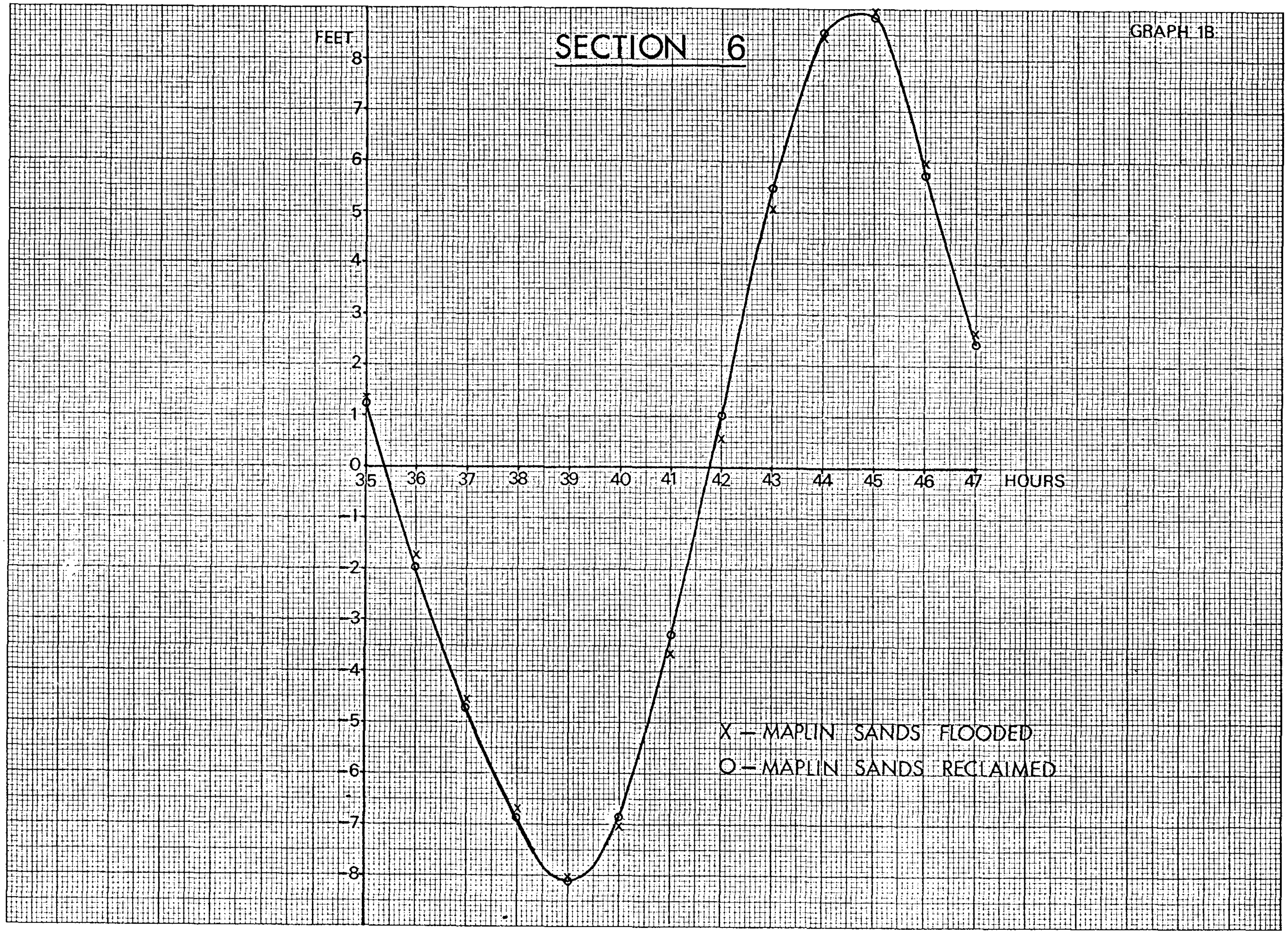


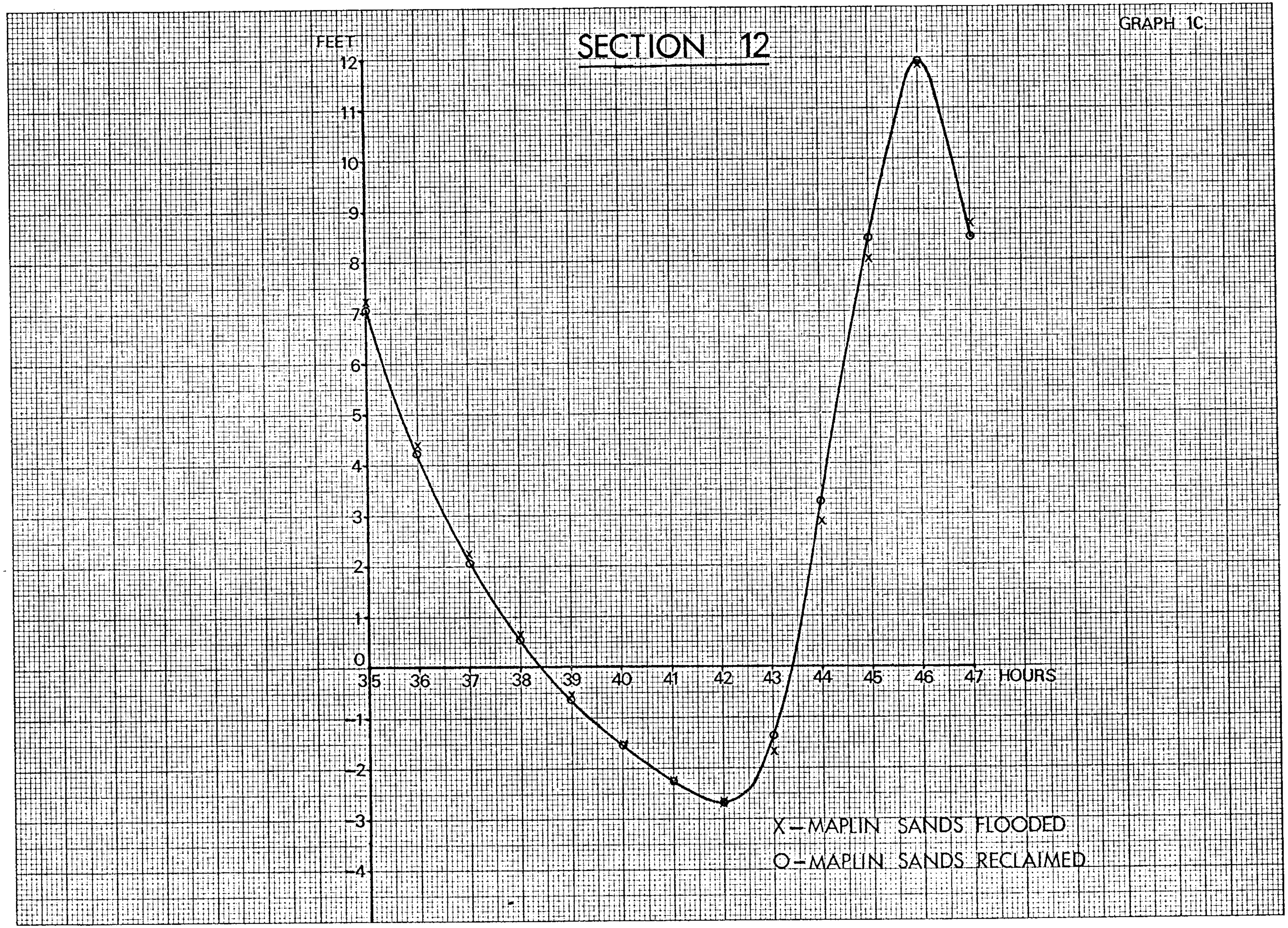
Diagram 5a

CHART WELL Graph Data Ref. 5501 mm, ½ and 1 cm




SECTION 6
GRAPH 1B
FEET
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
35
36
37
38
39
40
41
42
43
44
45
46
47
HOURS
X – MAPLIN SANDS FLOODED
O – MAPLIN SANDS RECLAIMED

CHARTWELL Graph Data Ref. 5501 mm, ½ and 1 cm



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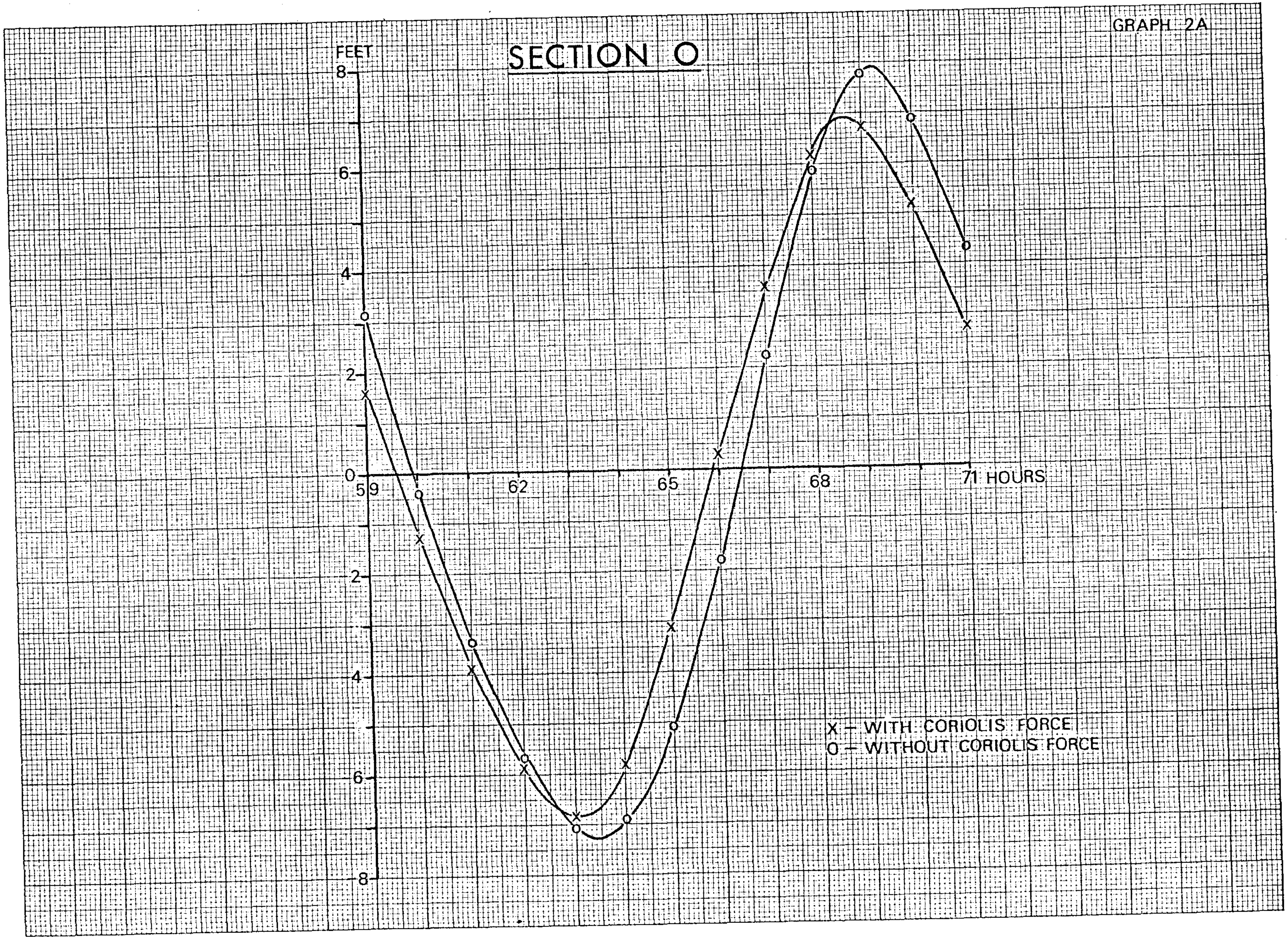
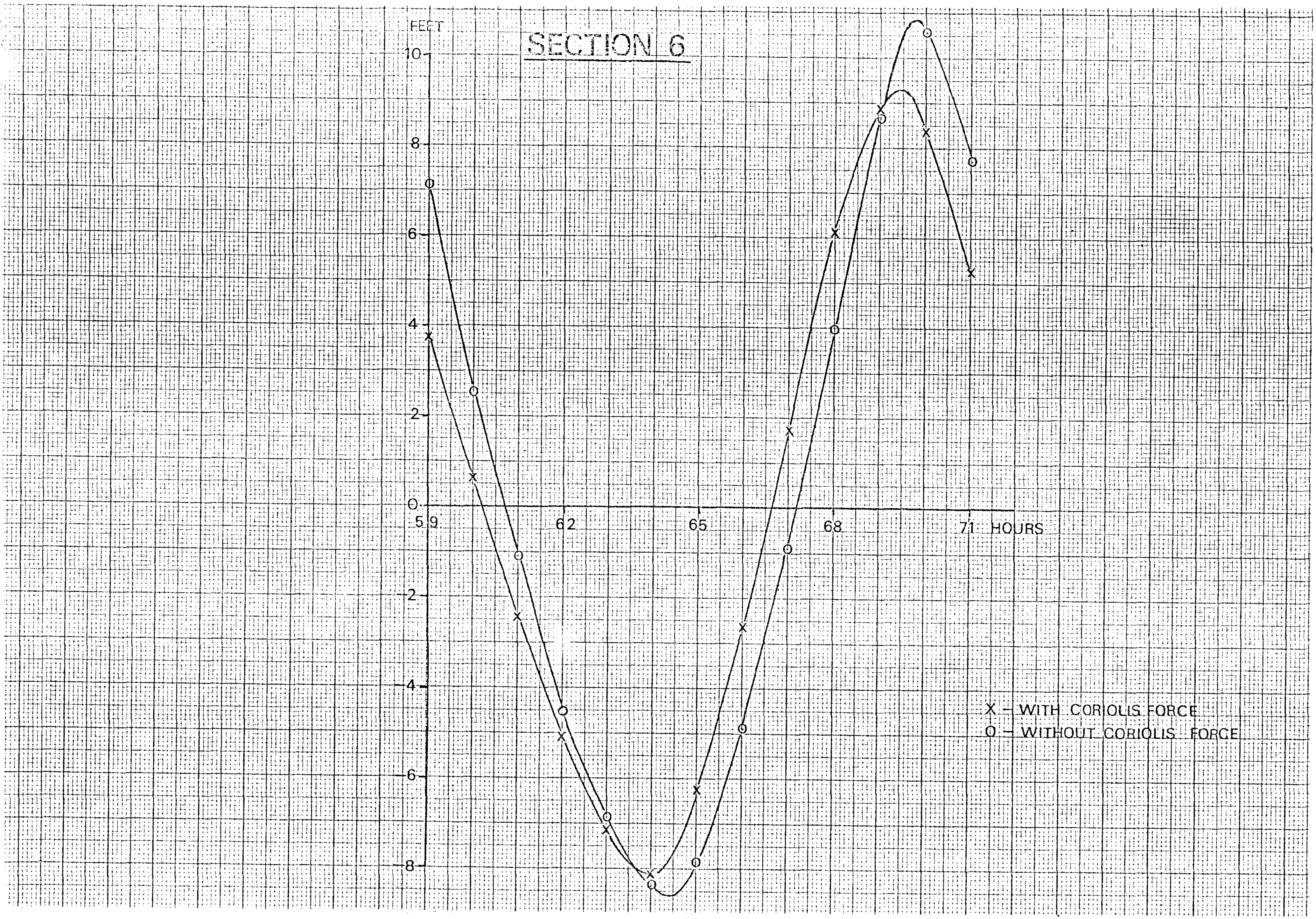
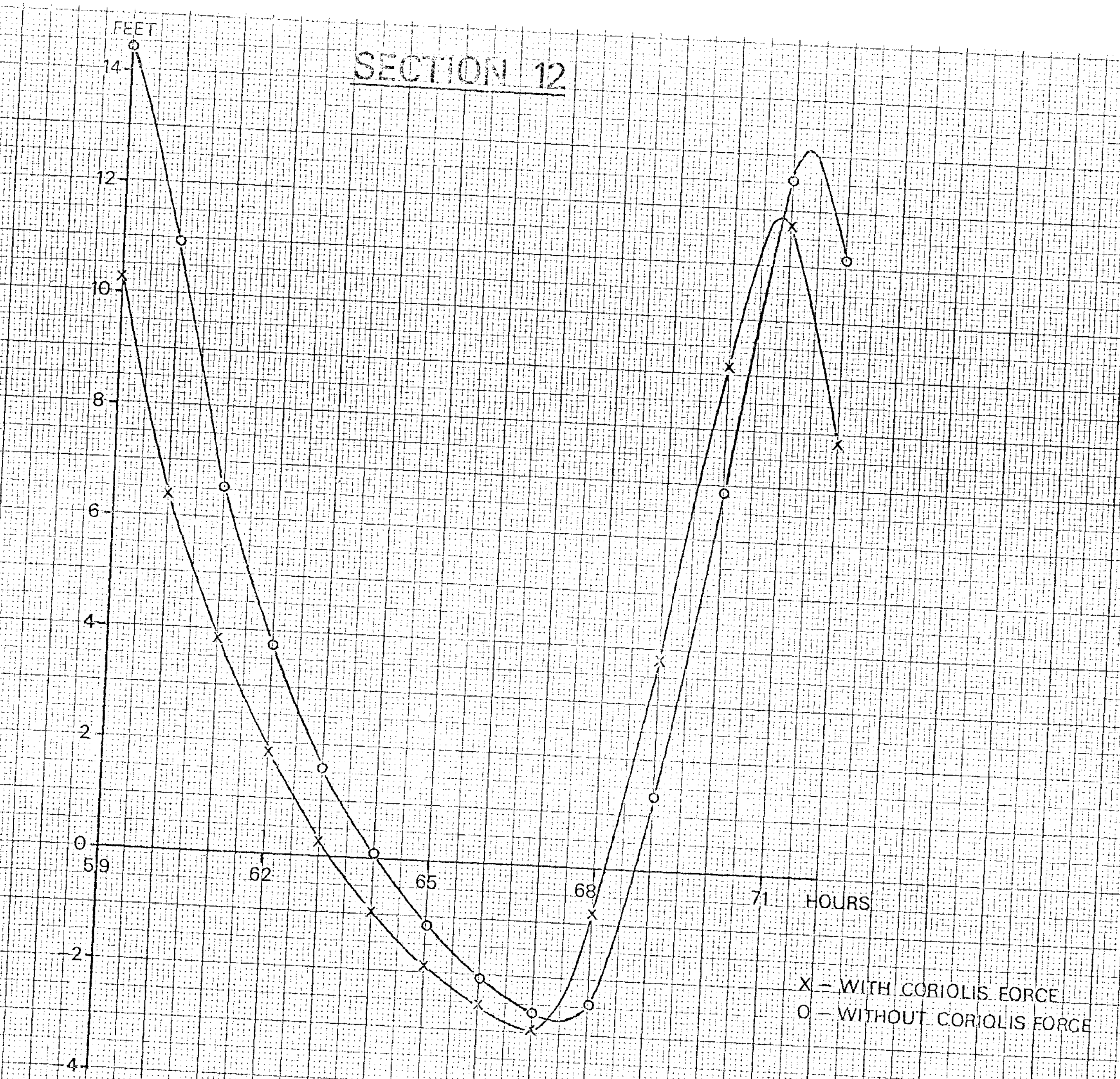
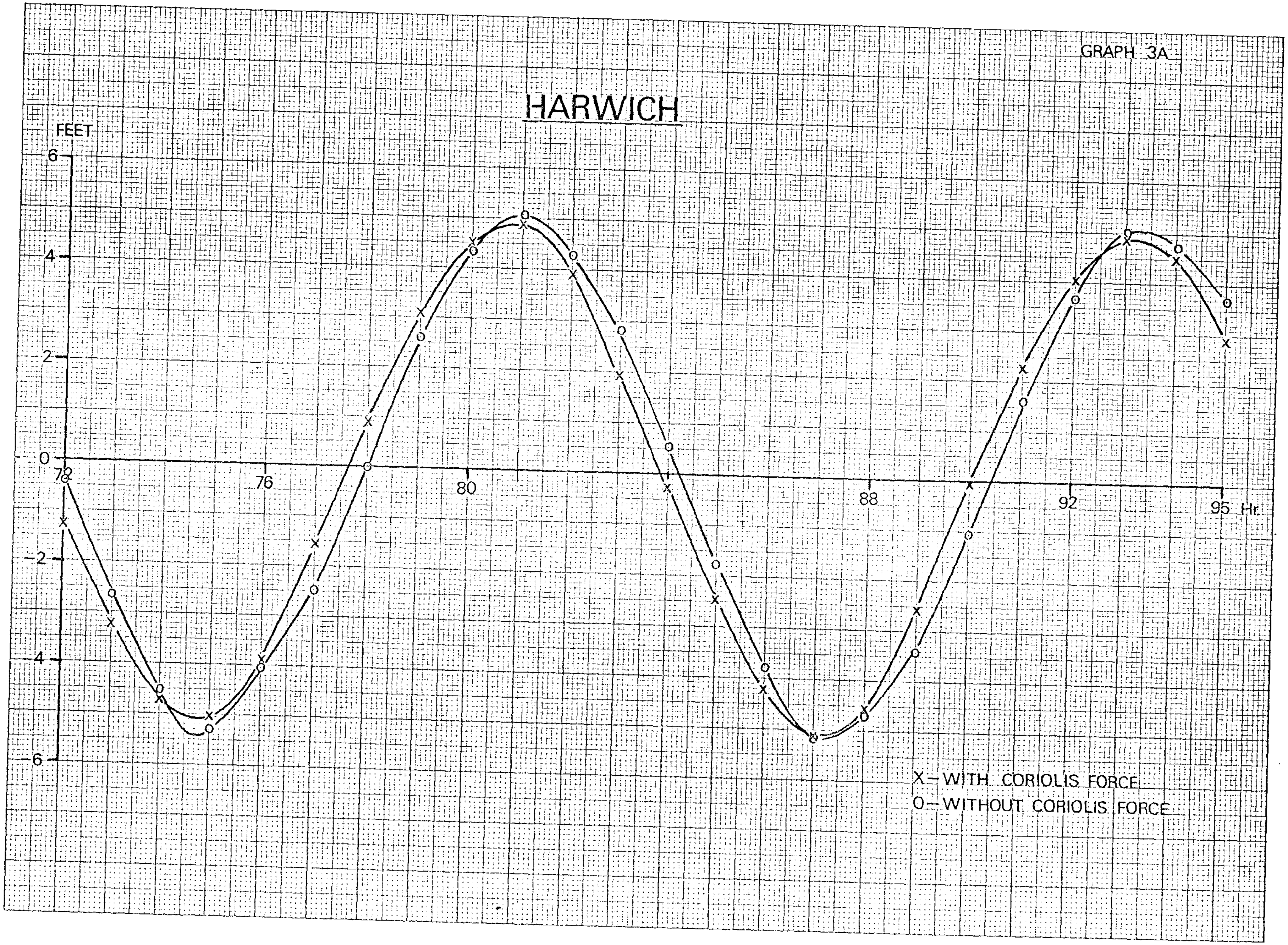


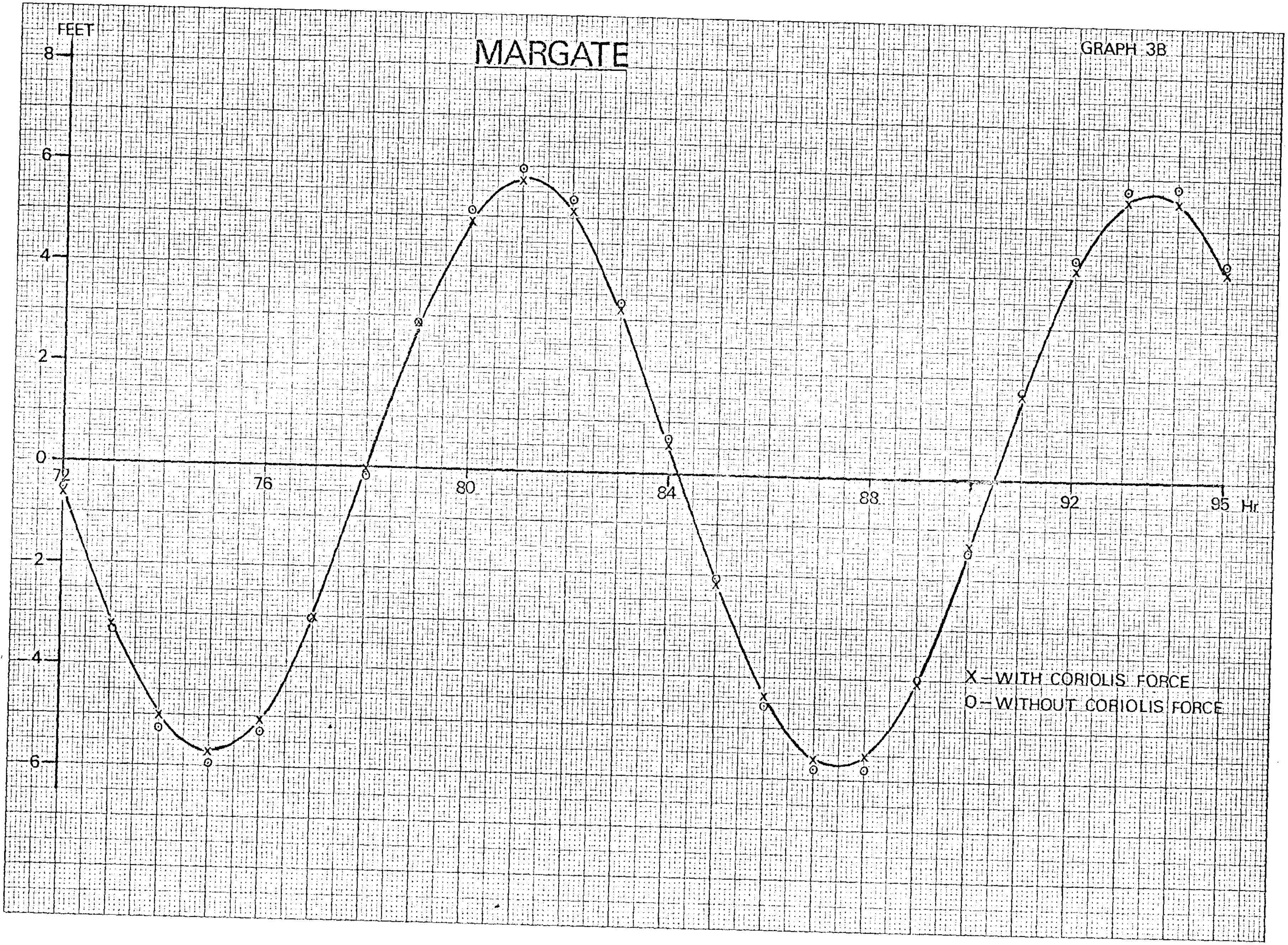

SECTION 6
FEET
10
8
6
4
2
0
-2
-4
-6
-8
59
62
65
68
71 HOURS
X – WITH CORIOLIS FORCE
O – WITHOUT CORIOLIS FORCE

SECTION 12

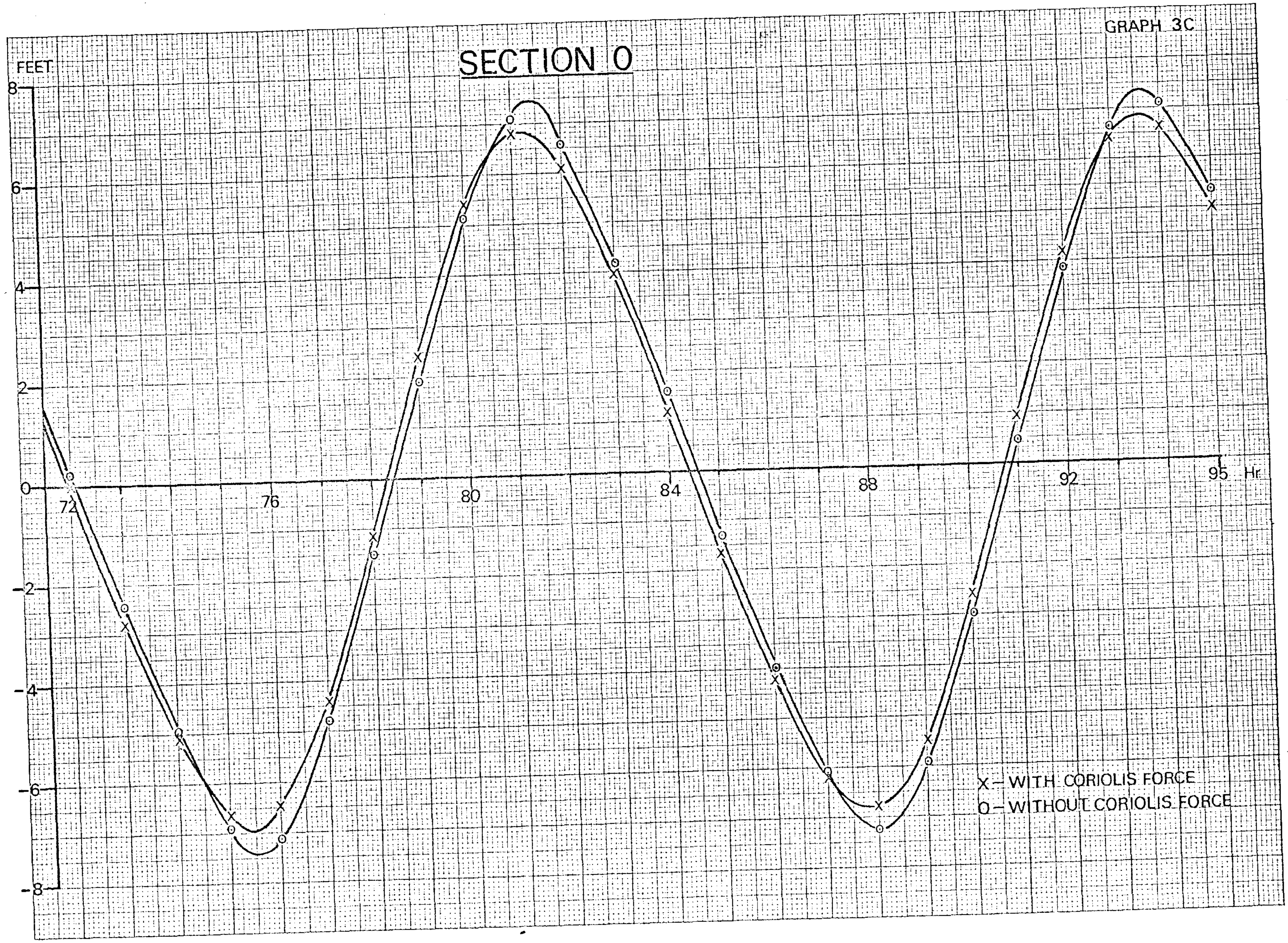

FEET
14
12
10
8
6
4
2
0
-2
-4
59
62
65
68
71
HOURS
X – WITH CORIOLIS FORCE
O – WITHOUT CORIOLIS FORCE

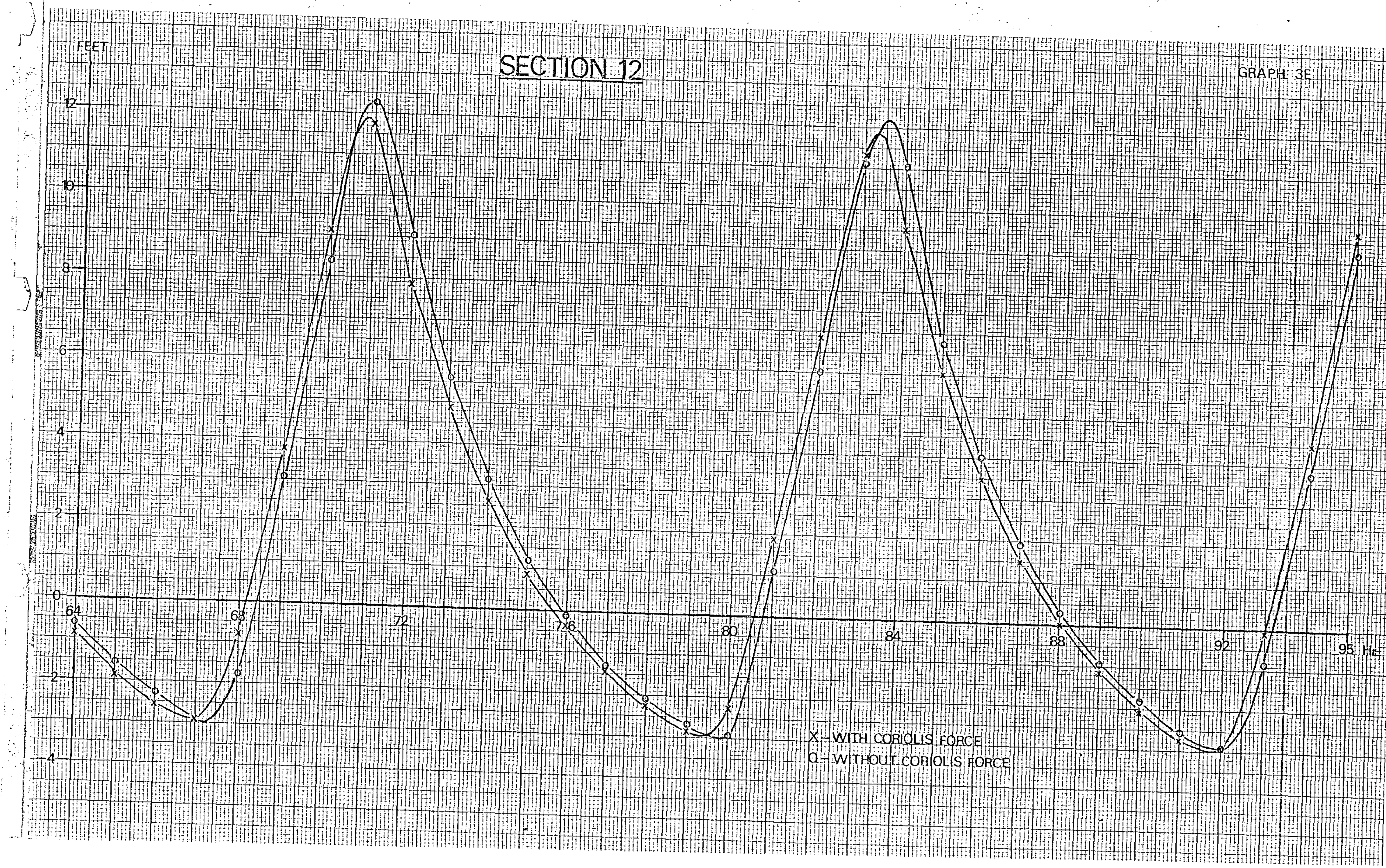

GRAPH 3A
HARWICH
FEET
6
4
2
0
-2
-4
-6
72
76
80
88
92
95 Hr.
X– WITH CORIOLIS FORCE
O– WITHOUT CORIOLIS FORCE

Graph Data Ref. 5501   mm, ½ and 1 cm



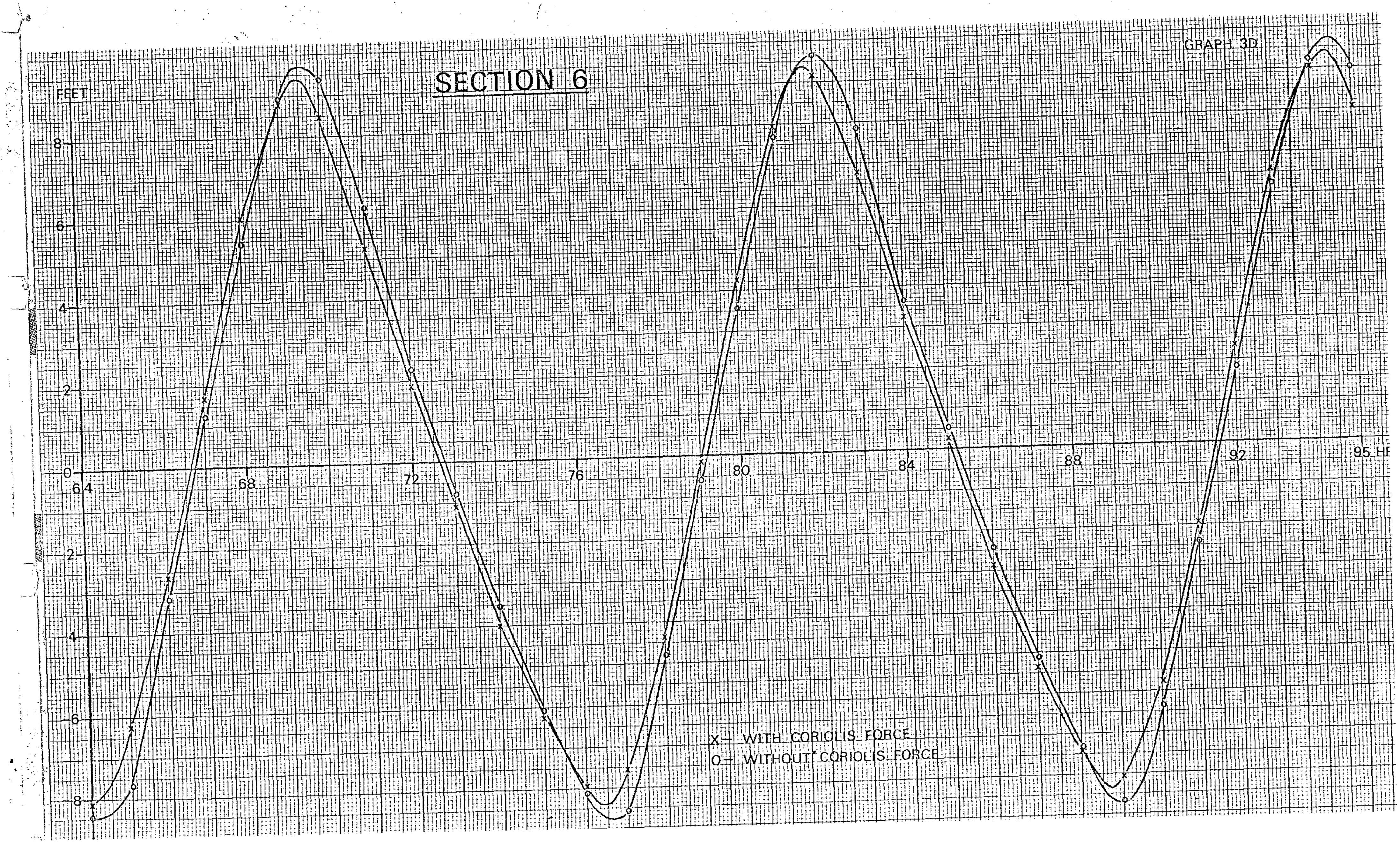
CHARTWELL Graph Data Ref. 5501 mm, ½ and 1 cm





FEET
SECTION 12
GRAPH 3E
12
10
8
6
4
2
0
-2
-4
64
68
72
76
80
84
88
92
95 Hr.
X - WITH CORIOLIS FORCE
O - WITHOUT CORIOLIS FORCE

SECTION 6



GRAPH 3D
FEET
8
6
4
2
0
2
4
6
8
64
68
72
76
80
84
88
92
95 HR
X— WITH CORIOLIS FORCE
O— WITHOUT CORIOLIS FORCE