Appendix B

Wave and Sediment Modelling Report (September 2007)

[Appendices not included]

Halcrow China Limited

AGREEMENT NO. CE 59/2005 (EP)
Development of a Bathing Beach at Lung Mei, Tai Po
Environmental, Drainage and Traffic Impact Assessments - Investigation

Working Paper 2.5 - Wave and Sediment Modelling Report

September 2007

The Government of Hong Kong Special Administrative Region
Civil Engineering and Development Department
Port Works Division

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1. INTRODUCTION

1.1 General

Civil Engineering and Development Department (CEDD) has appointed Halcrow China Limited to provide Consultancy Services in respect of the "Development of a Bathing Beach at Lung Mei, Tai Po – Environmental, Drainage and Traffic Impact Assessments – Investigation" under Agreement No. CE 59/2005 (EP), hereafter called "the Assignment"

Part of the Assignment is to look at the wave, tidal flow and sediment transport of the proposed bathing beach at Lung Mei, therefore, this working paper describes our verification of the work carried out in the feasibility study and our latest findings due to current data and information.

1.2 Brief Description of Project

The Assignment is to carry out detailed investigations for the development of a bathing beach at Lung Mei of Tai Po. The proposed site is at the seaside of Lung Mei and adjacent to a prominent leisure site, Tai Mei Tuk, with well-established facilities for holiday-makers and water-based recreation activities. However, in order to provide public swimming at Lung Mei, the proposed works include the development of a 200m long recreational beach, with the rate of loss of beach material controlled by the use of two groynes, a beach building, a car park, construction of retaining walls, drainage diversion works and other ancillary facilities.

A plan is presented on Figure 1.1, showing the location of the bathing beach and the study area.

1.3 Objectives

The objective of this working paper is to investigate and verify Delft's 'preferred option' and with current data and information, to progress to preliminary design of beach and groyne structures. The preliminary design of the beach and groyne structures will be discussed in a separate report, Working Paper 3.0 – Study of Alternative Options.

In the feasibility stage, Delft Hydraulics (Delft) had carried out a study of the Lung Mei beach based on numerical modelling of wave, tidal flow and sediment transport. Delft's work was presented in the April 2001 report 'Beach Improvement at Lung Mei Beach'. Therefore, in order to verify Delft's work, we used the information of wind data from the Delft Report, wind data from Tai Mei Tuk Station (2000-2006), extreme wind data from Port Works Design Manual, surveyed beach profiles, fetch lengths and sediment size and carried out limited modelling work. The locations of the wind data station is indicated on Figure 1.1. Consequently, our modelling results have been used to check Delft's modelling results.

Our independent modelling work included the following:

- Wave hindcasting based on the local wind data.
- Cross-shore sediment modelling using COSMOS.
- Long-shore sediment modelling based on wave and sediment data.

Subsequently, comparison of our modelling results with Delft's modelling results has been carried out. Therefore, conclusions have been drawn from the comparison.

Figures of the study area are shown in Figures 1.1 and 1.2. Figure 1.1 presents the overall location of the proposed beach development, Figure 1.2 shows the extent of various potential wave fetch length angles that apply to the location of the proposed beach development.

1.4 Structure of this report

The structure of this working paper is divided in the following sections:

- Section 2 describe the wave modelling
- Section 3 talks about the long shore modelling.
- Section 4 discusses the cross-shore modelling
- Section 5 gives the conclusion of the working paper.

2. WAVE MODELLING

2.1 Wave Hindcasting

According to the Delft report, there was no wave data available for the Lung Mei beach in their study. However, there are local wind data now available. Delft therefore carried out a hindcast analysis to generate the local wave climate. Using the same wind information, we have carried out an independent hindcasting analysis.

Since no measured wave data are available, the wave climate must be synthesised from a long term time series of measured wind data or from a wind frequency table, by a process known as hindcasting. In this process the characteristics of the waves arriving at the model boundary depend upon the wind speed, the period of time for which it has been blowing in that direction, the water depth, and the length of water across which it has been blowing (the 'fetch' length), which in turn is a function of the wind direction and the geography of the region. The result of this process is a time series or a frequency distribution of wave height and direction at the defined model boundary, which may be analysed for extreme events and to obtain a scatter plot of frequency of occurrence by wave height and direction, which identifies the wave conditions to use as boundary conditions for the area model. For this project the wave hindcasting results can be used directly for design purpose. The local wind data for the Lung Mei beach from the Delft Report is shown in Table 2.1. The wind rose for this data is provided in Figure 2.1.

Table 2.1 Probability of wind occurring in the given speed and direction sectors at Tai Po Kau (in %).

Wind Speed	**Wind direction [ºN]**												
[m/s]	**0**	**30**	**60**	**90**	**120**	**150**	**180**	**210**	**240**	**270**	**300**	**330**	**Total**
<0.5	1.28	.26	.31	.68	.24	.60	.79	.88	.75	.97	.53	.53	7.83
0.5 – 1.8	.46	.47	1.40	3.57	3.65	7.25	4.74	1.55	1.77	2.23	.83	.59	28.50
1.8 – 3.3	.30	.27	1.66	8.97	6.98	3.31	4.18	.66	1.28	4.18	1.28	.69	33.76
3.3 – 5.4	.22	.14	1.64	8.98	5.71	.36	.24	.79	.13	2.12	2.80	.61	23.73
5.4 – 8.5	.04	.01	.22	3.79	.90	.01	.01	.04	.07	.11	.79	.01	6.03
8.5 – 11.0	.04			.10						.01			.15
Total	2.33	1.16	5.23	26.08	17.47	11.53	9.97	3.93	4.00	9.63	6.22	2.43	100.00

Note: Wind data are retrieved from Appendix A12: Hydraulic Modelling Study Report of 128ML – Feasibility Study for Proposed Beach Improvement Works at Lung Mei Beach, Tai Po. (April 2001).

The wind data in Table 2.1 were used to generate local wave data. The hindcast modelling was carried out using Jonswap method, which is recommended by the latest Costal Engineering Manual, and provides the basis for our analysis. For shallow water, evidence from Bouws et al. (1985) indicates that wave spectra in shallow water do not appear to have a noticeable dependence on variation in bottom sediments. Consequently, it is recommended that the deepwater wave growth formulae (Jonswap) be used for all depths, with the constraint that no wave period can grow past a limiting value as shown by the equation $Tp=9.78(d/g)^{0.5}$, where d is the water depth. The hindcasting results are shown in Table 2.2. The wave rose for this data is provided in Figure 2.2.

Table 2.2 Local wave conditions from wave hindcasting results for the proposed beach development

	Wind direction (deg. N)											
Wind speed	**90**			**105**			**120**			**135**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<0.5	0.01	0.38	0.34	0.01	0.41	0.23	0.01	0.41	0.12	0.01	0.69	0.21
0.5-1.8	0.02	0.58	1.79	0.02	0.63	1.81	0.02	0.63	1.83	0.05	1.05	2.73
1.8-3.3	0.04	0.71	4.49	0.04	0.77	3.99	0.04	0.77	3.49	0.09	1.29	2.57
3.3-5.4	0.06	0.84	4.49	0.07	0.91	3.67	0.07	0.91	2.86	0.14	1.52	1.52
5.4-8.5	0.09	0.98	1.90	0.10	1.06	1.17	0.10	1.06	0.45	0.22	1.77	0.23
8.5-11	0.12	1.06	0.05	0.13	1.15	0.03	0.13	1.15	0.00	0.29	1.93	0.00

	Wind direction (deg. N)											
Wind speed	**150**			**165**			**180**			**195**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<0.5	0.02	0.84	0.30	0.01	0.55	0.30	0.01	0.57	0.30	0.01	0.66	0.42
0.5-1.8	0.06	1.28	3.63	0.03	0.85	3.63	0.04	0.87	3.63	0.04	1.01	1.57
1.8-3.3	0.12	1.57	1.66	0.06	1.03	1.66	0.07	1.07	1.66	0.08	1.23	1.21
3.3-5.4	0.19	1.85	0.18	0.10	1.22	0.18	0.11	1.26	0.18	0.13	1.45	0.26
5.4-8.5	0.30	2.15	0.01	0.16	1.42	0.01	0.17	1.47	0.01	0.21	1.69	0.01
8.5-11	0.39	2.34	0.00	0.21	1.55	0.00	0.22	1.60	0.00	0.27	1.84	0.00

	Wind direction (deg. N)								
Wind speed	**210**			**225**			**240**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<0.5	0.01	0.60	0.44	0.01	0.63	0.41	0.01	0.66	0.41
0.5-1.8	0.04	0.92	0.78	0.04	0.96	0.83	0.04	1.01	0.83
1.8-3.3	0.07	1.13	0.33	0.08	1.18	0.49	0.08	1.24	0.49
3.3-5.4	0.12	1.33	0.40	0.12	1.39	0.23	0.13	1.46	0.23
5.4-8.5	0.18	1.55	0.02	0.20	1.62	0.03	0.21	1.70	0.03
8.5-11	0.24	1.69	0.00	0.25	1.76	0.00	0.27	1.85	0.00

Notes: Wave information where the percent occurrence is zero is not included in the analysis.
Wave conditions are calculated using Jonswap based on wind data presented in Appendix A12: Hydraulic Modelling Study Report of 128ML – Feasibility Study for Proposed Beach Improvement Works at Lung Mei Beach, Tai Po. (April 2001).

Comparison between the Delft wave conditions (Table 4.4 of the Delft report) and the present wave conditions in Table 2.2 show that the dominant wave direction is from 90° to 120° according to our results, but a dominant wave direction of 120° to 150° is found from the Delft Report. The maximum wave height from the Delft work is 0.24m, which is slightly lower than what we ascertain, which is 0.30m. The maximum wave period from the Delft work is 1.75s, which is also slightly bwer than our result of 2.15s. There is no detailed description of the hindcasting work in the Delft Report. It is therefore difficult to comment further on the normal wave conditions generated in the Delft Report. However, Delft's wave conditions were used in the Delft study of the long-shore sediment transport modelling. Further comments are given in the Section 4 for comparison of the Delft long-shore sediment transport results and our modelling results.

In order to better analyse the local generated waves at the Lung Mei beach, further wind records have been obtained from Tai Mei Tuk station. Those wind data are shown in Table 2.3. (see Figure 2.3 for the wind rose of this data) The original wind data were recorded at 55m high above the mean sea level and the wind speeds are daily averaged speeds. Those wind records are then converted to 10m high above the mean sea level and also converted to hourly mean speeds. Please note that the latest wind records have a dominant direction of 45°. This dominant wind direction is different from the dominant direction of 90° in Table 2.1, which is from the Delft Report.

Table 2.3 Probability of wind occurring in the given speed and direction sectors at Tai Mei Tuk (in %).

Wind Speed	**Wind direction [°N]**												
[m/s]	**0**	**15**	**30**	**45**	**60**	**75**	**90**	**105**	**120**	**135**	**150**	**165**	**180**
<2.0	0	0	0.2	2.8	1.1	0.3	0.2	0.2	0.6	1.8	0.5	0.3	0
2.0 – 4.0	0	1.6	4.7	18.1	3.9	4	1.9	2.6	1.2	5.1	2.3	0.2	0.1
4.0 – 6.0	0.1	1.8	3.1	4.5	0.8	5.3	3.9	1.9	0.1	0.4	0.2	0	0
6.0 – 8.0	0	0.5	0.9	0.6	0.1	1.4	0.9	0.3	0	0	0	0	0
8.0 – 10.0	0	0.2	0.2	0.1	0	0.7	0.2	0	0	0	0	0	0
10.0 – 12.0	0	0	0	0.1	0	0	0.1	0	0	0	0	0	0
12.0 – 14.0	0	0	0	0	0	0.1	0	0	0	0	0	0	0
Total	0.1	4.1	9.1	26.2	5.9	11.8	7.2	5	1.9	7.3	3	0.5	0.1

Wind Speed	Wind direction [°N]										
[m/s]	**195**	**210**	**225**	**240**	**255**	**270**	**285**	**300**	**315**	**330**	**345**	**Total**
<2.0	0	0	0	0.1	2.1	1	0	0	0	0	0	11.2
2.0 – 4.0	0.4	0.3	1.6	1	4.4	1.1	0	0	0	0	0	54.5
4.0 – 6.0	0	0.1	1.3	0.8	1.5	0.2	0	0	0	0	0	26
6.0 – 8.0	0	0	0.4	0.3	0.2	0	0	0	0	0	0	5.6
8.0 – 10.0	0	0	0	0	0	0	0	0	0	0	0	1.4
10.0 – 12.0	0	0	0	0	0	0	0	0	0	0	0	0.2
12.0 – 14.0	0	0	0	0	0	0	0	0	0	0	0	0.1
Total	0.4	0.4	3.3	2.2	8.2	2.3	0	0	0	0	0	99

Note: Wind data are recorded at Tai Mei Tuk station (January 2000 to July 2006).

The latest wind data in Table 2.3 were used to generate another set of local wave data. The hindcast modelling was carried out using the Jonswap method. The hindcasting results are shown in Table 2.4 (see Figure 2.4 for the wave rose of this data).

Table 2.4 Local wave conditions from wave hindcasting results for the proposed beach development

	Wind direction (deg. N)											
Wind speed	**90**			**105**			**120**			**135**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<2.0	0.02	0.60	0.2	0.02	0.65	0.2	0.02	0.65	0.6	0.05	1.09	1.8
2.0-4.0	0.04	0.76	1.9	0.05	0.82	2.6	0.05	0.82	1.2	0.11	1.37	5.1
4.0-6.0	0.07	0.87	3.9	0.07	0.94	1.9	0.07	0.94	0.1	0.16	1.57	0.4
6.0-8.0	0.09	0.96	0.9	0.10	1.03	0.3	0.10	1.03	0	0.21	1.73	0
8.0-10.0	0.11	1.03	0.2	0.12	1.11	0	0.12	1.11	0	0.26	1.87	0
10.0-12.0	0.13	1.09	0.1	0.15	1.18	0	0.15	1.18	0	0.32	1.98	0
12.0-14.0	0.15	1.15	0	0.17	1.25	0	0.17	1.25	0	0.37	2.09	0

	Wind direction (deg. N)											
Wind speed	**150**			**165**			**180**			**195**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<2.0	0.07	1.33	0.5	0.04	0.88	0.3	0.04	0.91	0	0.05	1.04	0
2.0-4.0	0.14	1.67	2.3	0.08	1.10	0.2	0.08	1.14	0.1	0.10	1.32	0.4
4.0-6.0	0.21	1.91	0.2	0.11	1.26	0	0.12	1.31	0	0.15	1.51	0
6.0-8.0	0.28	2.11	0	0.15	1.39	0	0.16	1.44	0	0.20	1.66	0
8.0-10.0	0.35	2.27	0	0.19	1.50	0	0.20	1.55	0	0.25	1.79	0
10.0-12.0	0.42	2.41	0	0.23	1.59	0	0.24	1.65	0	0.30	1.90	0
12.0-14.0	0.50	2.54	0	0.27	1.67	0	0.28	1.73	0	0.35	2.00	0

	Wind direction (deg. N)								
Wind speed (m/s)	**210**			**225**			**240**		
[m/s]	H_s	T_p	%	H_s	T_p	%	H_s	T_p	%
<2.0	0.04	0.96	0	0.05	1.00	0	0.05	1.05	0.1
2.0-4.0	0.09	1.21	0.3	0.09	1.26	1.6	0.10	1.32	1
4.0-6.0	0.13	1.38	0.1	0.14	1.44	1.3	0.15	1.51	0.8
6.0-8.0	0.17	1.52	0	0.18	1.58	0.4	0.20	1.66	0.3
8.0-10.0	0.22	1.64	0	0.23	1.71	0	0.25	1.79	0
10.0-12.0	0.26	1.74	0	0.28	1.81	0	0.30	1.91	0
12.0-14.0	0.30	1.83	0	0.32	1.91	0	0.35	2.01	0

Note: Wave conditions are calculated using Jonswap based on wind data of Tai Mei Tuk station (January 2000 to July 2006).

The wave data in Table 2.4 have been used for study of the long-shore sediment transport rate. Further comments are given in Section 4.

2.2 Extreme Wave Conditions

Extreme wind data are available from the Delft report as shown in Table 2.5. These extreme wind conditions are used as input data for hindcast modelling.

Table 2.5 Mean hourly wind speeds in Plover Cove for various return periods (in m/s).

Return	N	NE	E	SE	S	SW	W	NW
5	14	16	19	16	15	15	13	10
10	16	18	22	20	18	18	15	11
20	18	21	24	24	20	22	18	12
50	20	24	28	28	24	25	21	14
100	22	26	30	30	26	28	23	16
200	24	28	32	34	29	30	25	17

Note: Wind data are retrieved from Appendix A12: Hydraulic Modelling Study Report of 128ML – Feasibility Study for Proposed Beach Improvement Works at Lung Mei Beach, Tai Po. (April 2001).

The extreme wave conditions are then generated and presented in Table 2.6. The fetch length from Figure 1.2 and the extreme wind speeds from Table 2.5 are used for hindcasting calculations.

Table 2.6 Extreme wave heights for the proposed beach development

		Wind direction (deg. N)										
Return period	**Wave height & period**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	**195**	**210**	**225**	**240**
5	H_s	0.21	0.22	0.21	0.37	0.56	0.29	0.30	0.37	0.33	0.35	0.36
	T_p	1.28	1.36	1.33	2.09	2.63	1.73	1.77	2.04	1.87	0.95	2.02
10	H_s	0.24	0.26	0.25	0.42	0.68	0.35	0.36	0.45	0.39	0.42	0.42
	T_p	1.34	1.44	1.42	2.18	2.83	1.84	1.89	2.17	1.99	2.07	2.14
20	H_s	0.26	0.29	0.29	0.48	0.80	0.41	0.40	0.48	0.49	0.51	0.51
	T_p	1.38	1.49	1.49	2.27	2.98	1.93	1.95	2.22	2.15	2.22	2.28
50	H_s	0.30	0.34	0.34	0.53	0.94	0.48	0.48	0.59	0.55	0.58	0.59
	T_p	1.45	1.57	1.57	2.35	3.15	2.04	2.07	2.38	2.23	2.31	2.39
100	H_s	0.33	0.37	0.37	0.58	1.02	0.52	0.52	0.63	0.62	0.65	0.66
	T_p	1.49	1.61	1.61	2.43	3.22	2.09	2.13	2.43	2.32	2.40	2.48
200	H_s	0.35	0.4	0.41	0.63	1.14	0.58	0.58	0.70	0.66	0.69	0.71
	T_p	1.52	1.65	1.67	2.50	3.35	2.18	2.21	2.54	2.37	2.46	2.54

Note: Wave conditions are calculated using Jonswap based on wind data presented in Appendix A12: Hydraulic Modelling Study Report of 128ML – Feasibility Study for Proposed Beach Improvement Works at Lung Mei Beach, Tai Po. (April 2001).

The extreme wave conditions in Table 2.6 are compared with the extreme wave conditions in the Delft report (Table 4.6). It shows that the maximum extreme wave height is from 150° for both our results and Delft’s results. The actual extreme wave condition from Delft’s work is very close to our result. For 1 in 100 years return period, the extreme wave height is 1.00m and the wave period is 3.07s in the Deft report, while our modelling work shows an extreme wave height of 1.02m and wave period of 3.22s. Therefore the design wave condition of 1 in 100 years return period recommended in the Delft Report is potentially acceptable.

Further extreme wind data are obtained from Port Works Design Manual for Waglan Island Station (1975-1999) and are converted to Plover Cove using the same coefficient of 0.675 as in the Delft Report. The latest extreme wind data are then shown in Table 2.7.

Table 2.7 Extreme mean hourly wind speeds in Plover Cove for various return periods (in m/s).

Return Period	N	NE	E	SE	S	SW	W	NW
5	16	17	18	17	16	15	12	9
10	18	20	21	20	19	18	15	11
20	21	22	24	25	22	22	17	13
50	25	27	28	30	28	27	20	16
100	28	30	30	34	30	30	22	17
200	31	32	33	37	34	33	25	18

Note: Wind data are obtained from Port Works Design Manual for Waglan Island Station (1975-1999)

The extreme wave conditions were calculated using the hindcasting method and are presented in Table 2.8. The fetch length from Figure 1.2 and the extreme wind speeds from Table 2.7 were used for the hindcasting calculations.

Table 2.8 Extreme wave heights for the proposed beach development for various return periods

		Wind direction (deg. N)										
Return period	**Wave height & period**	**90**	**105**	**120**	**135**	**150**	**165**	**180**	**195**	**210**	**225**	**240**
5	H_s	0.20	0.22	0.21	0.45	0.58	0.30	0.31	0.39	0.32	0.34	0.35
	T_p	1.26	1.35	1.34	2.22	2.68	1.75	1.79	2.08	1.86	1.95	2.00
10	H_s	0.23	0.25	0.25	0.53	0.70	0.37	0.38	0.47	0.39	0.42	0.43
	T_p	1.32	1.42	1.42	2.36	2.85	1.87	1.92	2.22	1.99	2.08	2.14
20	H_s	0.26	0.29	0.30	0.66	0.85	0.44	0.45	0.56	0.46	0.50	0.50
	T_p	1.37	1.49	1.50	2.53	3.04	1.98	2.02	2.34	2.11	2.20	2.26
50	H_s	0.31	0.35	0.36	0.80	1.04	0.54	0.55	0.69	0.58	0.62	0.61
	T_p	1.46	1.59	1.60	2.70	3.25	2.12	2.18	2.51	2.27	2.37	2.42
100	H_s	0.33	0.38	0.40	0.89	1.15	0.60	0.61	0.75	0.66	0.70	0.69
	T_p	1.49	1.63	1.65	2.80	3.36	2.19	2.24	2.59	2.37	2.47	2.52
200	H_s	0.36	0.42	0.44	0.98	1.27	0.66	0.67	0.84	0.71	0.76	0.76
	T_p	1.54	1.68	1.71	2.89	3.48	2.27	2.32	2.68	2.43	2.54	2.60

Note: Wave conditions are calculated using Jonswap based on wind records taken at Waglan Island Station.

The extreme wave conditions in Table 2.8 are also compared with the extreme wave conditions in the Delft report (Table 4.6). It again shows that the maximum extreme wave height is from 150° for both our results and Delft's results. For 1 in 100 years return period, the extreme wave height is 1.00m and the wave period is 3.07s from the Delft Report, while our modelling work shows an extreme wave height of 1.15m and wave period of 3.36s. Please note that our results are based on the latest wind data, at Waglan Island from the Port Works Design Manual, Part 1.

3. CROSS-SHORE MODELLING

3.1 Background

Mathematical modelling has been used to simulate and predict the littoral processes occurring along the beach profiles in the proposed development area. Our sediment transport model COSMOS-2D has been used in this project for the littoral transport study. The model has been applied to locations on the proposed Lung Mei beach. The purpose of this modelling is to determine the distribution of littoral drift across the beach area. This is important when considering the possible erosion / accretion due to wave-driven beach sediment movement. The modelling results determine the stability of the proposed beach.

3.2 Description of COSMOS

COSMOS-2D is a two-dimensional vertical plane sediment transport model, built to simulate the wave transformation and sediment transport along a cross-shore beach profile (ie normal to the shoreline). The model is formulated to include both suspended and bed sediment loads under the action of the oscillatory flow associated with breaking waves on a beach. Details of the model can be found in Nairn and Southgate (1993). The model assumes a straight coastline with parallel depth contours, and is intended for investigation of cross-shore beach stability under specified wave conditions.

The initial cross-shore profile and time series of wave height and direction are specified by the user, and the model determines wave, current and sediment transport parameters at each grid point. The model was developed jointly by Halcrow, HR and Imperial College. A detailed description of COSMOS-2D is presented in Appendix A.

COSMOS-2D includes the following physical processes:

(a) Wave transformation by refraction (by depth variations and currents), shoaling, Doppler shifting, bottom-friction and wave breaking. For random waves, a Battjes and Janssen (1978) framework is used for determining the distribution of wave height and the fraction of time that waves are breaking at any point.

(b) Wave set-up determined from the gradient of wave radiation stress.

(c) Driving forces for long-shore wave-induced currents, determined directly from the spatial rate of wave energy dissipation.

(d) Long-shore currents from pressure-driven tidal fortes and wave-induced forces, and the interaction between the two types of current.

(e) Cross-shore undertow velocities, using a three-layer model of the vertical distribution of cross-shore currents.

(f) Transition zone effects (the transition zone is the distance between where a wave starts to break and where turbulence becomes fully developed).

(g) Cross-shore and long-shore sediment transport rates using an ‘energetics’ approach.

(h) Seabed level changes due to cross-shore sediment transport using a Lax-Wendroff scheme.

(i) Down-cutting of a cohesive profile due to abrasion by a covering layer of sand.

The model can be run for a single wave and tidal condition or for a long sequence of wave/tidal conditions at specified time increments.

3.3 Model Set-up and Results

The objective of the COSMOS-2D model application is to assess the cross-shore stability of the beaches under extreme wave conditions. Eight beach profiles were examined: three profiles from the surveyed bathymetry, one profile from the planned beach (Delft Report), two design construction profiles (Halcrow) and two design equilibrium profiles (Halcrow). The planned beach data are taken from the Delft report. In order to verify Delft’s cross-shore modelling results and also investigate the beach stability, a wave condition of 1 in 50 years return period was used. It is standard practice to use the 1 in 50 years return period wave condition for the STORM wave condition to study the cross-shore beach response, as opposed to the 1 in 100 year return period that is used for the structural design of the groynes.

Wave conditions of Hs=1.04m and Tp=3.25s, representing a 1 in 50 year storm, were applied in conjunction with a storm surge level of +4.15mPD, which is taken from the Delft Report for 1 in 50 years return period and we have checked that this figure is reasonable The sediment sizes used for the modelling were 0.2mm, 0.25mm, 0.3mm and 0.5mm.

Figures A3.1 to A3.8 in Appendix A present model results for the eight beach profiles with sediment size D_{50} of 0.2mm. Profiles A, B and C, as shown on Figure A3.0, represent existing beach profiles and these three profiles show no significant changes during the storm events modelled. However, 'Design Profile D' and 'Design Profile E' are typical design profiles, which could be applied to anywhere in the proposed bathing beach between the two groynes. The overall results imply that the existing beach profile is stable. However, Figure A3.4 in Appendix A shows that the planned profile will be susceptible to storm attack. The beach will be eroded above bed level 2.8mPD. Nevertheless, the amount of erosion is unlikely to be significant due to the wave heights in this area being relatively small. The results shown in Figure A3.4 are compared with the cross-shore modelling results in the Delft Report (Figure A3.33). The wave condition used in the Delft Report is different from the wave condition used in this study - the present wave condition being based on the latest extreme wind data. The wave height used in the Delft Report was 0.9m and the wave period was 3.0s, while the wave height used in the present study is 1.04m and the wave period is 3.25s. Considering that the wave height in the Delft Report is lower than the wave height in this study, it is expected that the Delft cross-shore modelling profile has less erosion/accretion compared to our modelling output. The present modelling study indicates that the planned cross-shore beach is reasonably stable and the conclusion from the Delft report is also acceptable.

With the same wave and water level conditions, the COSMOS-2D was used with different sediment sizes. Figures A3.9 to A3.32 in Appendix A show the modelling results for D_{50}s of 0.25mm, 0.3mm and 0.5mm. As expected, the beach is more stable with coarser sediment grain sizes. In general, there is no significant problem with cross-shore sediment movement under storm wave conditions.

3.4 Option Development Model set-up and Results.

Subsequent to the Working Paper 2.5 - Wave and Sediment Modelling Report (Rev. 1) being presented to CEDD in October 2006, we had been requested to further investigate another scenario whereby the design wave return period was reduced and as such the reclamation area was also reduced.

Following the work undertaking in section 3.3 and the development of a beach design, changes were made to assumptions and design standards to offer savings to beach recharge quantities. Therefore further COSMOS-2D modelling was required to assess the storm response upon a new design construction profile (Halcrow) and a design equilibrium profile (Halcrow). The design wave condition was reduced from a 1 in 50 years return period to a 1 in 20 years return period.

Wave conditions of Hs=0.8m and Tp=2.98s, representing a 1 in 20 year storm were applied in conjunction with a storm surge level of +3.80mPD. The sediment sizes used for the modelling were focused upon 0.4mm as this had been identified as the most probable sediment size used, however sediment size runs for 0.2mm, 0.25mm, 0.3mm and 0.5mm were also undertaken.

Figures 3.41 to 3.50 are the output results undertaken for the further beach development options. Figures 3.47 and 3.48 represent the storm response on a constructed profile and an equilibrium profile respectively for a grain size of 0.4mm. The plots continue to show that the beach development will still be prone to wave attack with erosion occurring between the +2.9mPD and the +4.0mPD levels with a maximum erosion value of 0.48m. However, the amount of erosion is unlikely to be significant due to the wave heights in this area being relatively small. The other plots use the same wave and water level conditions, but utilise different sediment sizes. As expected and concluded in section 3.3 the beach is more stable with coarser sediment grain sizes and a maximum erosion value of 0.7m. However due to the already insignificant beach responses the savings offered between using different grain size has little impact upon the profile design. In general, there is no significant problem with cross-shore movement under storm conditions.

4. LONG-SHORE MODELLING

4.1 Long-Shore Sediment Transport

The Halcrow Beach Plan Shape Model (BPSM) is a numerical model, which uses recent advances in along-shore beach sediment transport theory to predict the longer term evolution of the beach in response to wave action. The model simulates the development of the plan shape of a single beach contour. The nearshore wave conditions are used in repetitive calculations to give estimates of alongshore sediment drift. The way in which drift rates vary along the coast is then used to compute changes in beach plan shape over time. Iteration between derivation of drift rates and re-aligning the coast provides a realistic response. The Excel sheet version of BPSM is a simplified model which can be used for a given point at the beach using the wind data from the hindcasting wave conditions. This model was used to simulate the effects of wave action based on the wave frequency table. The model provides predictions of the potential long-shore sediment transport. However, in real situation, the beach will be active and will respond to the wave direction on a daily basis. Nevertheless, all numerical models can only simulate the beach responses in a long term, say on a yearly basis. In this way the model takes into account of the seasonal changes of the beach and the final modelling results are based on wave data of the past several years, which will determine the beach orientation.

Calculation of longshore drift rates for given sediment, shoreline and wave data is achieved by application of an empirical formula derived by Kamphuis (1991). Comparisons in the literature have shown the Kamphuis formulation of the alongshore bulk transport formula to give the most accurate prediction, (Schoones and Theon 1996). Recent developments in the theory of coastal processes have included the effects of sediment grain size, beach slope and wave period, among other parameters. A constant sediment size of 200 microns (D_{50}) is assumed, together with a sediment density of 2500 kg/m^3 and a porosity of 0.35. This information is taken from Delft's Report. The beach slope (perpendicular to the coastline) used was 0.067 (i.e. the average of slopes 1 in 12 and 1 in 20), calculated from the planned beach at Lung Mei from the Delft Report.

The long-shore sediment transport modelling determines the beach orientation and the annual long-shore sediment transport rate. The Delft study indicates that the equilibrium orientation of the beach is 130°N, and it concludes that a range of the equilibrium angle between 120° and 150°N seems reasonable. According to the present study, it has been found that the equilibrium angle of the beach is about 138°N. Observation of the present coastline and contours at the Lung Mei from the Admiralty Chart 4128 shows that the orientation of the existing contour is about 150°N to 160°N. Therefore, we suggest that a beach orientation of 140°N to 150°N should be assumed.

The net annual long-shore drift rate can be estimated from the long-shore sediment transport modelling. If the existing beach orientation of 160°N is used as the input data to our model, the annual net drift rate is likely to be 127m^3/yr from the East to the

West. The Delft study shows that the annual net drift rate should be in the range of 10 to 100 m^3/yr. Our long-shore drift calculation therefore indicates that Delft's range of annual net drift rate at 10 to 100 m^3/yr is reasonable.

The calculation of long-shore sediment transport is based on the wave data presented in Table 2.2. Although the dominant wave direction from the Delft Report is different from our dominant wave direction, the resultant long-shore sediment transport rates are in the same order and the net sediment drift directions are the same.

As discussed in Section 3.4 above, we investigated the long shore sediment transportation for a different scenario and had carried out further long-shore sediment modelling using the latest wind and wave data. Table 2.4 shows the wave hindcasting results based on the latest wind data obtained from Tai Mei Tuk station. Those wave data were used as input for the long-shore sediment modelling. The modelling results indicate that the annual net drift rate is likely to be 70m^3/yr from the East to the West, and the equilibrium angle of the beach is about 143°N. Considering the long-shore sediment modelling using both wave data sets as described, it can be concluded that the annual net drift rate is likely to be in the order of 10m^3/yr to 150m^3/yr from the East to the West, and the equilibrium angle of the beach is between 140°N and 150°N.

5. CONCLUSIONS

The modelling work in Delft's Report has been reviewed. Halcrow's in-house models have been used to verify the Delft work independently. The main conclusions are as follows.

- Wave hindcasting results from Delft's Report have been compared with our modelling results using the same wind data set. The maximum wave height of normal wave conditions from the Delft work is 0.24m, which is slightly lower than our result of 0.30m. The maximum wave period of normal wave conditions from the Delft work is 1.75s, which is also slightly lower than our result of 2.15s. The differences in the normal wave conditions calculated by Delft and Halcrow are not significant.

- Using the latest wind data from Tai Mei Tuk station, our wave hindcasting results show that the maximum wave height of normal wave conditions is 0.21m, and the maximum wave period of normal wave conditions is 1.91s. Again the differences between the normal wave conditions calculated by Delft and Halcrow are not significant.

- Using the same extreme wind data set, comparison of the extreme wave conditions indicates that the maximum extreme wave height is from 150° for both Halcrow and Delft results. For a 1 in 100 year return period, the extreme wave height is 1.00m and the wave period is 3.07s according to Delft's results, while our modelling work indicates an extreme wave height of 1.02m and wave period of 3.22s. Based on these results, the extreme wave conditions calculated by Delft and Halcrow are very similar.

- Using extreme wind data from Port Works Design Manual for Waglan Island Station (1975-1999), converted to Plover Cove using the same coefficient in the Delft Report, our modelling work shows an extreme wave height of 1.15m and wave period of 3.36s. Our results are based on the latest wind data. It is therefore concluded that Halcrow's design wave condition of 1 in 100 years return period should be used for groyne design purposes (i.e. extreme wave height of 1.15m and wave period of 3.36s).

- The cross-shore modelling results in the Delft Report (Figure A3.33 in Appendix A) were compared with our cross-shore modelling output (Figure A3.4 in Appendix A) using the same sediment grain size. The wave conditions used in the Delft Report are different from the wave conditions used in this study (which are based on the latest extreme wind data). Considering the wave height in the Delft Report is lower than the wave height in this study, it is expected that Delft's cross-shore modelling profile would show less erosion/accretion than our modelling output. The present modelling study indicates that the planned cross-shore beach is reasonably stable and the conclusion from the Delft report is therefore acceptable.

- The cross-shore modelling was also carried out using different sediment sizes of 0.25mm, 0.3mm and 0.5mm. This has shown that the beach is more stable with coarser sediment grain size. In general, there is no significant problem with cross-shore sediment movement under storm wave conditions.

- The Delft long-shore modelling study indicates that the equilibrium orientation of the beach is 130°N, and it concludes that a range of the equilibrium angle between 120° and 150°N seems reasonable. According to the present study, the equilibrium angle of the beach is about 138°N based on the same wind data that Delft has used, or 143°N based on the latest wind data from Tai Mei Tuk station. Observation of the present coastline and contours at the Lung Mei from the Admiralty Chart 4128 shows that the orientation of the existing contour is about 150°N to 160°N. Therefore we suggest a beach orientation of 140°N to 150°N should be assumed. Therefore, the angle of the beach groynes for this assignment is aligned at an angle of 145°N, similar to that shown on Figure 3.0.

- From the present study it has been found that the annual net drift rate is likely to be 127m^3/yr from the East to the West based on the same wind data that Delft used, or 70m^3/yr based on the latest wind data from Tai Mei Tuk station. The Delft study shows that the annual net drift rate should be in a range of 10 to 100m^3/yr. Our long-shore drift calculation indicates that the range of annual net drift rate at 10 to 100 m^3/yr presented in Delft Report is reasonable. The actual annual net drift rate is likely to be in a range of 10 to 150 m^3/yr, which is in accordance to this study.

- Both the Delft study and Halcrow study show that the net drift of the sediment is not significant (10 to 100 cubic metres per year), which is mainly due to the wave heights being so small at the Lung Mei beach. Therefore, it is not necessary to consider the mitigation measure in accordance with both studies. If the sediment size D_{50} is increased from 0.2mm to 0.25mm, 0.3mm and 0.5mm, respectively, the orientation of the beach will not be changed according to the model results, but the net drift rate will be lower than 10 to 100 cubic metres per year. The consequence is that the beach should be more stable if coarser sands are used. In other words, the sediment transport and siltation under the influence of environmental forces during the operational phases will be minimal.

- Notwithstanding the above, where we demonstrated that Delft's work in the Feasibility Study was in order. However, due to subsequent discussions with CEDD on December 2006 and the requirement to reduce the reclamation area, further runs were undertaken to develop the design profile further including the latest development footprint. This was done using a 1 in 20 years return period as agreed with CEDD. The 1 in 20 years return period has an Hs=0.8m and a Tp=2.98 and incorporated a water level of +3.8mPD. The models were run for the 0.2mm, 0.25mm, 0.3mm and 0.5mm sediment grain sizes as before but a further run was undertaken investigating a 0.4mm sediment grain size. The conclusions drawn previously have not been significantly affected by changes made to the wave, water level and beach slope conditions. That is, the annual net drift rate is likely to be in the order of $10m^3$/yr to $150m^3$/yr from the East to the West, and the equilibrium angle of the beach is between 140°N and 150°N. As such, the angle of the beach groynes for this assignment is aligned at an angle of 145°N, similar to that shown on Figure 3.0.

6. REFERENCES

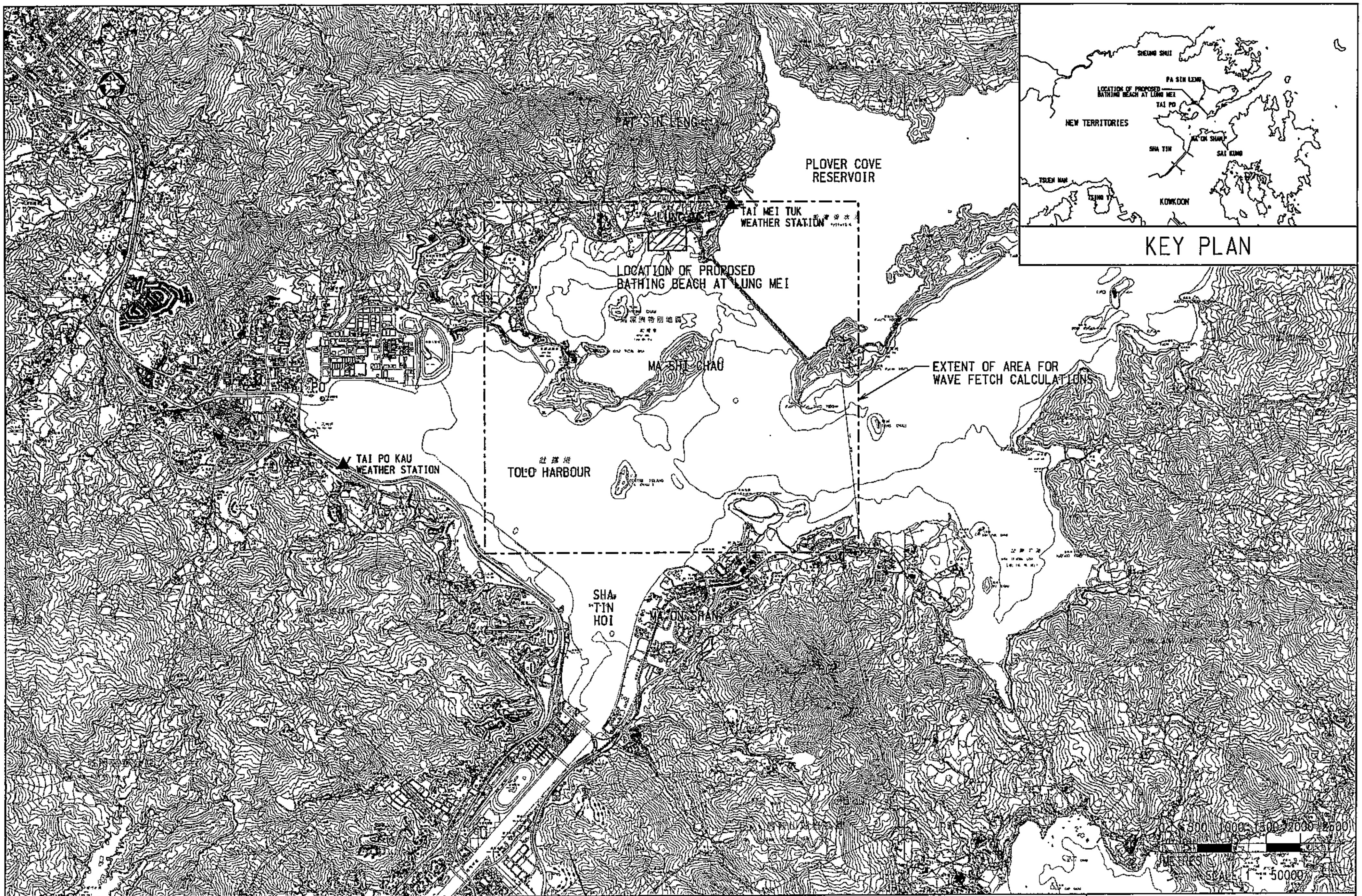
Bttjes J A and Janssen J P F M (1978), Energy Loss and Set-uP due to Breaking of Random Waves, Proc i 6th Int Conf on Coastal Eng, ASCE, Hamburg, pp569-587

Kamphuis, J.W. (1991), “Alongshore sediment transport rate”, Journal of Waterway, Port, Coastal and Ocean Engineering, ASCE, Volume 117, pp 624 – 640.

Nairn R B and Southgate H N (1993), Deterministic Modelling of Nearshore Processes : Part II, Sediment Transport and Beach Profile Development. Coastal Eng., Vol 19.

Schoones and Theon (1996) ‘Improvement of the most accurate alongshore transport formula’, Proc 25th International Conference on Coastal Engineering.

Figures



CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer: Halcrow, Halcrow China Ltd. / ERM Environment Resources Management as sub-consultant	Agreement No.: CE 59/2005 (EP)	WORKING PAPER 2.5 - WAVE AND SEDIMENT MODELLING REPORT
		Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	Figure Title: LOCATION PLAN OF STUDY AREA

FIGURE 1.1

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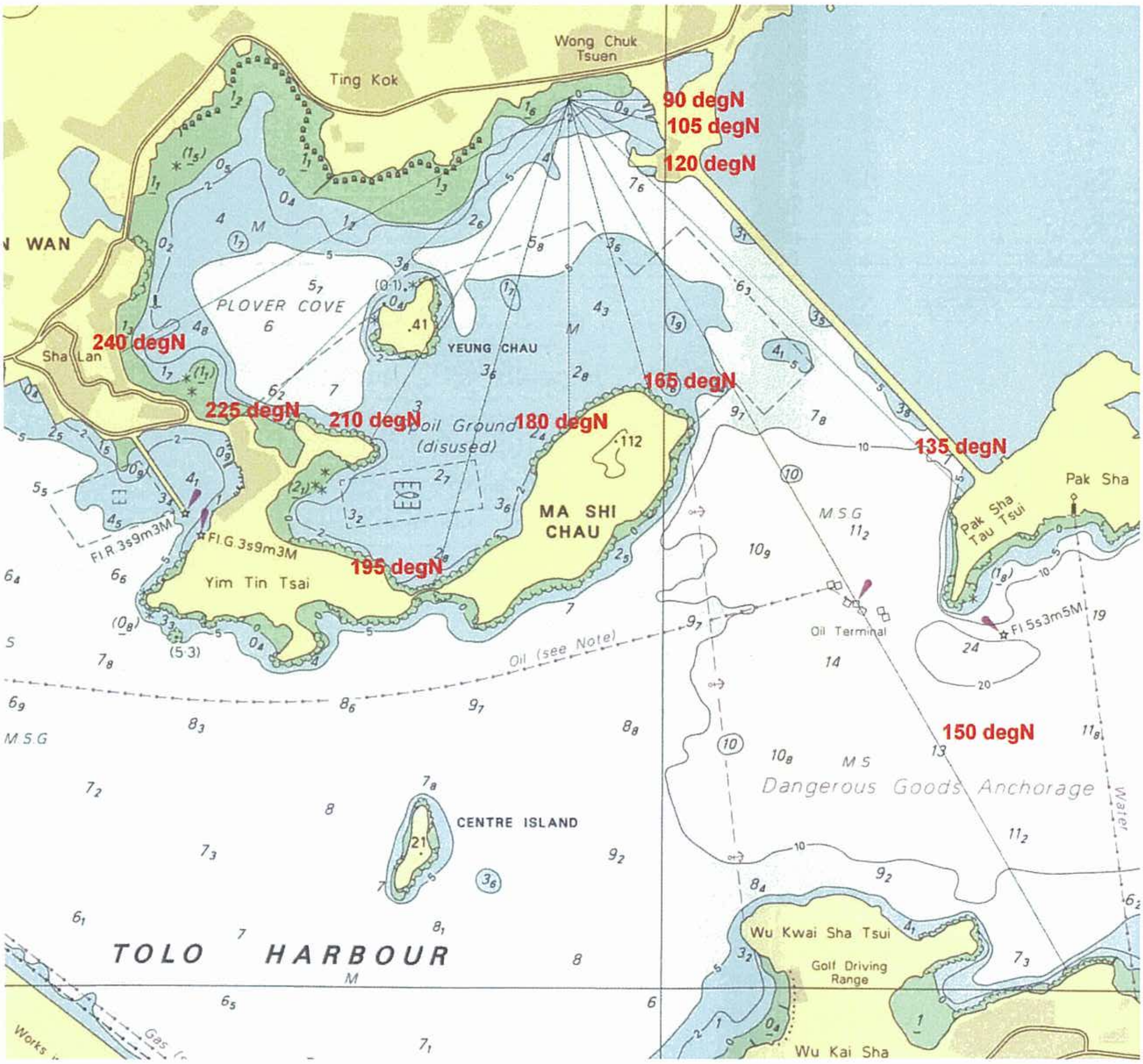


Figure 1.2: Extent of area for wave fetch length calculations; fetch lengths given at 15° increments (from Admiralty Chart 4128, Mirs Bay, Hong Kong).

Agreement No.: CE 59/2005(EP)	DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	**FIGURE 1.2**
Client: CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer: Halcrow, Halcrow China Ltd.; ERM Environmental Resources Management as sub-consultant	WORKING PAPER 2.5 - WAVE AND SEDIMENT MODELLING REPORT

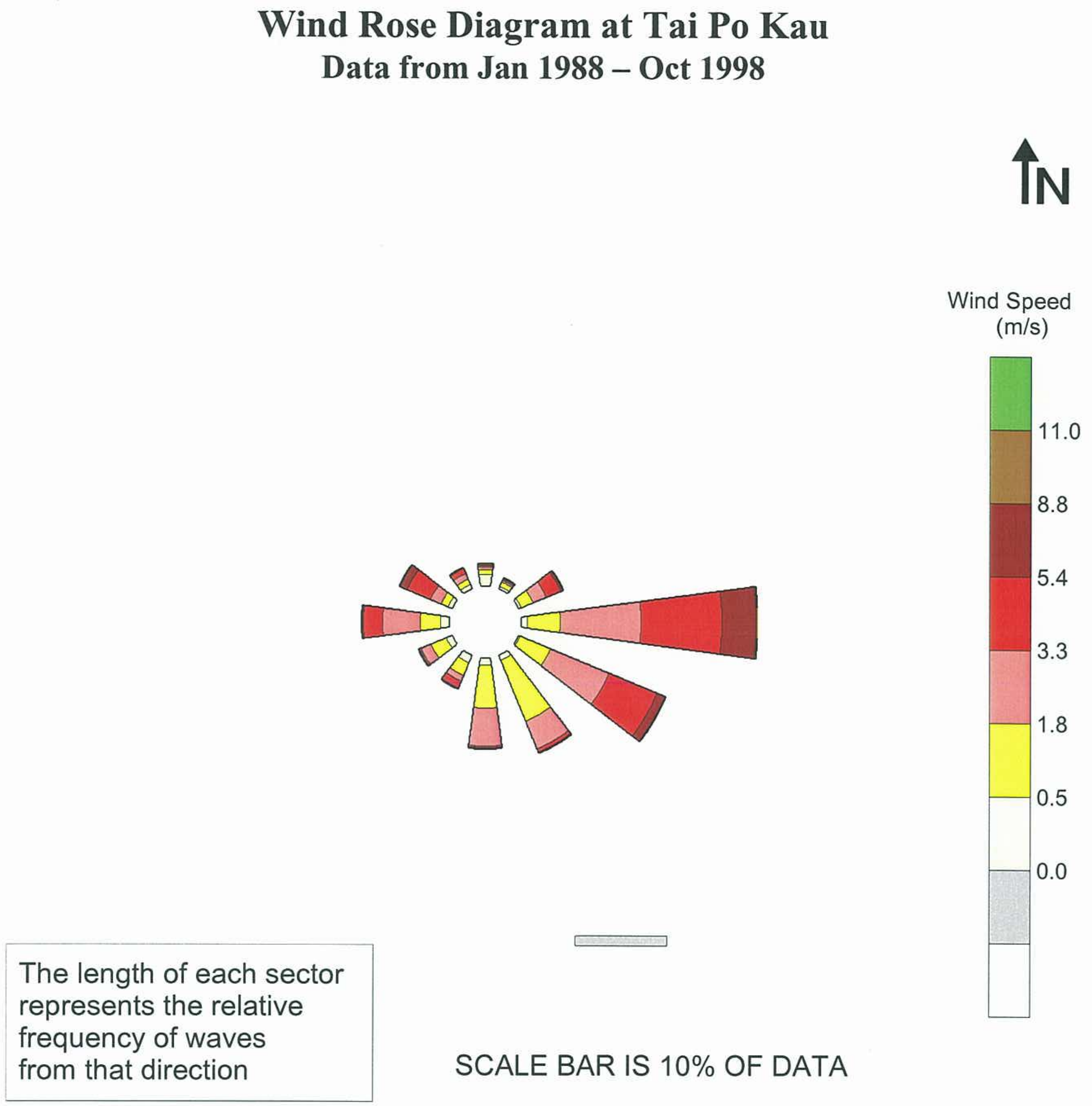


Figure 2.1: Wind Rose Diagram at Tai Po Kau.

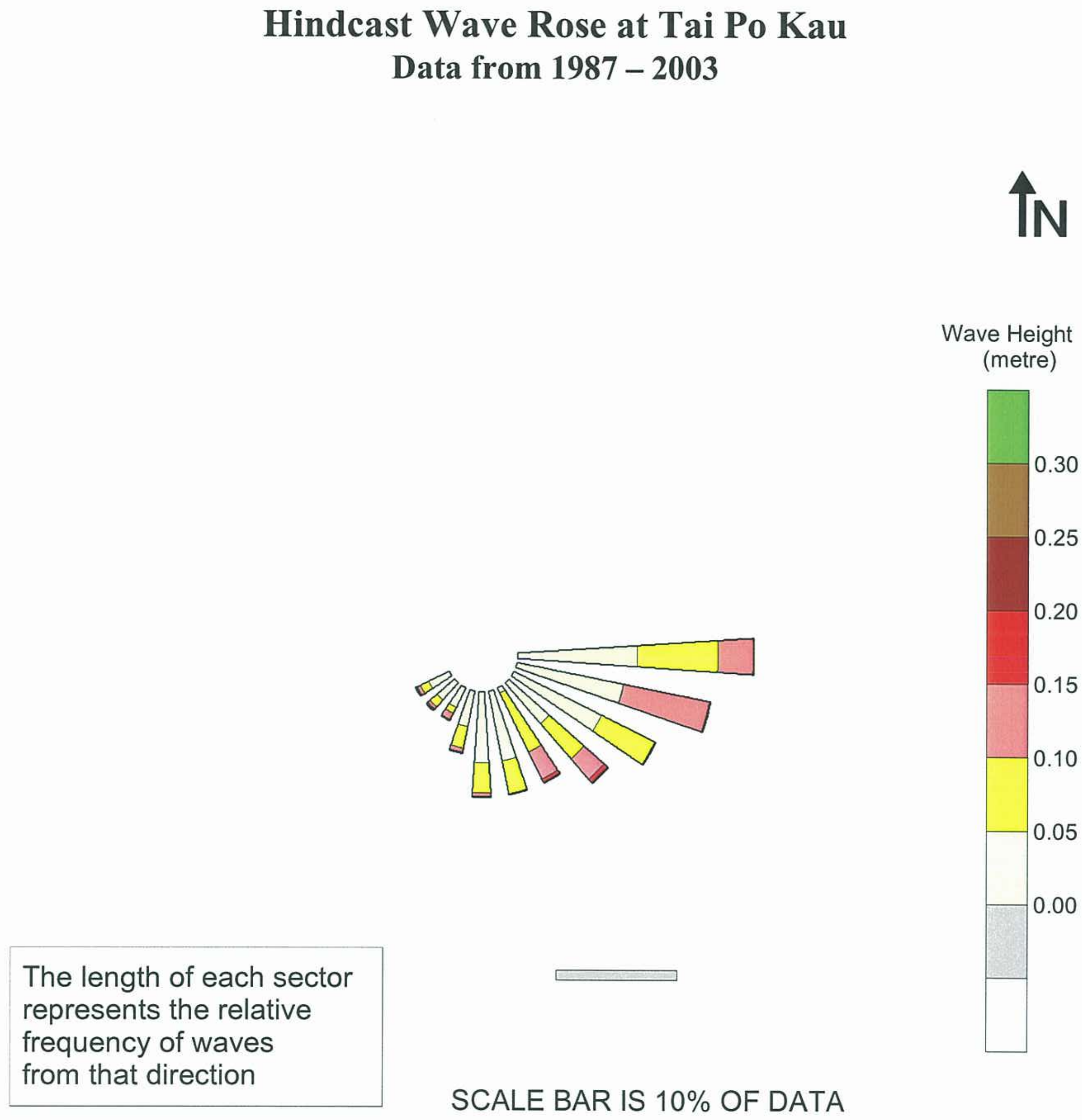


Figure 2.2: Wave Rose Diagram at Tai Po Kau.

Wind Rose Diagram at Tai Mei Tuk
Data from Jan 2000 – May 2006

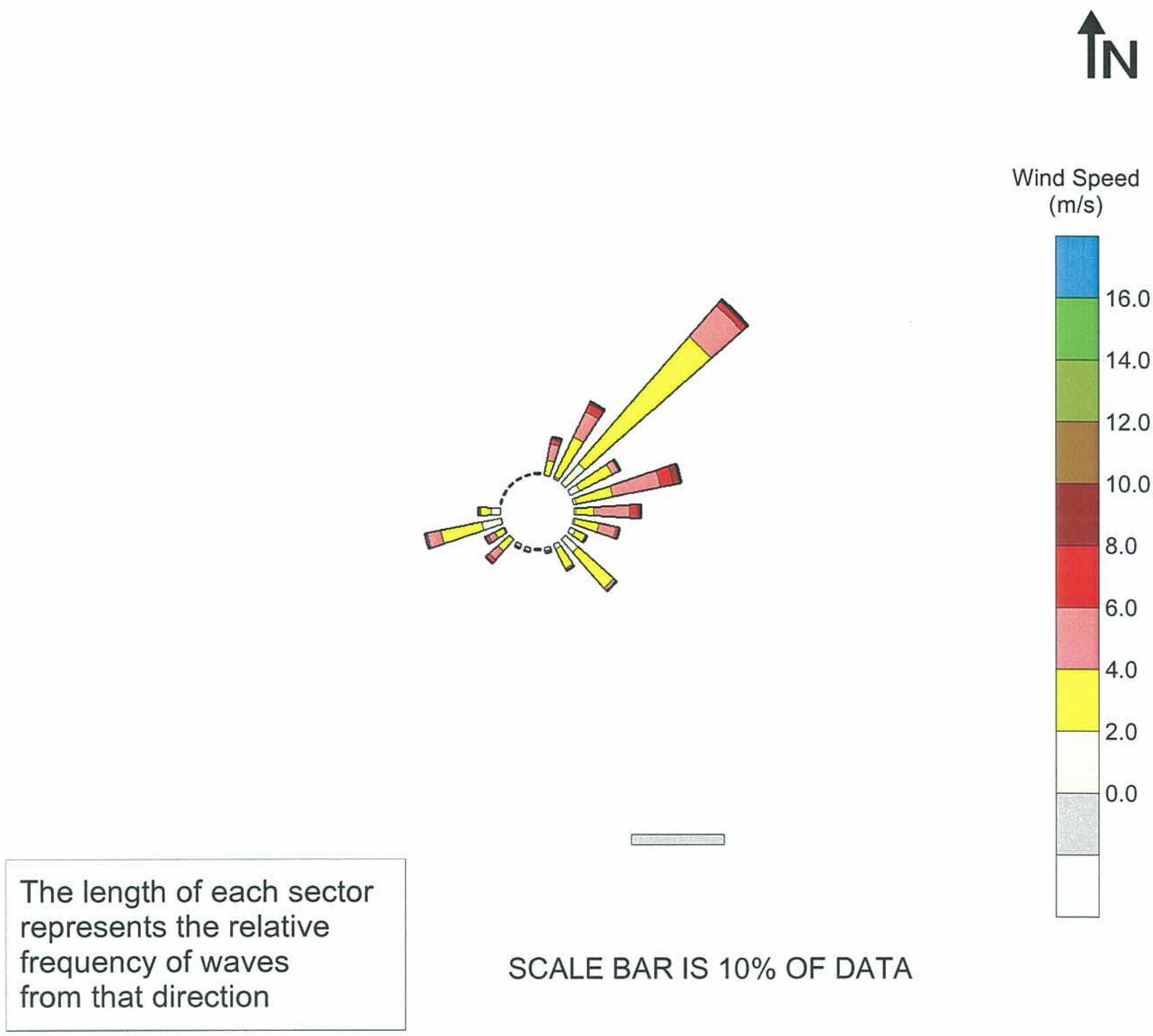


Figure 2.3: Wind Rose Diagram at Tai Mei Tuk.

Agreement No.: CE 59/2005(EP)	DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	**FIGURE 2.3**
Client: CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer: Halcrow, Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	WORKING PAPER 2.5 - WAVE AND SEDIMENT MODELLING REPORT

Hindcast Wave Rose at Tai Mei Tuk
Data from Jan 2000 – May 2006

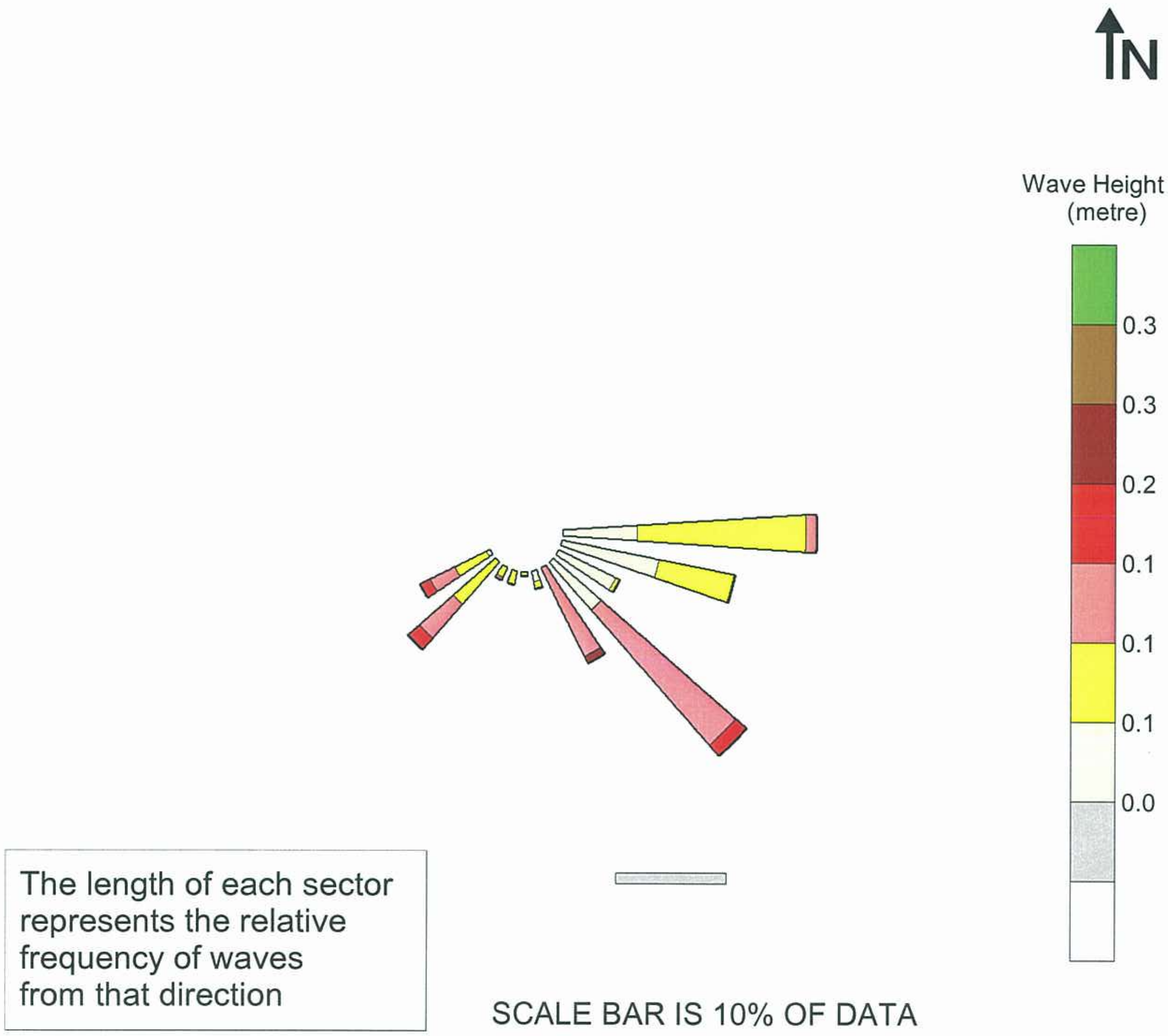
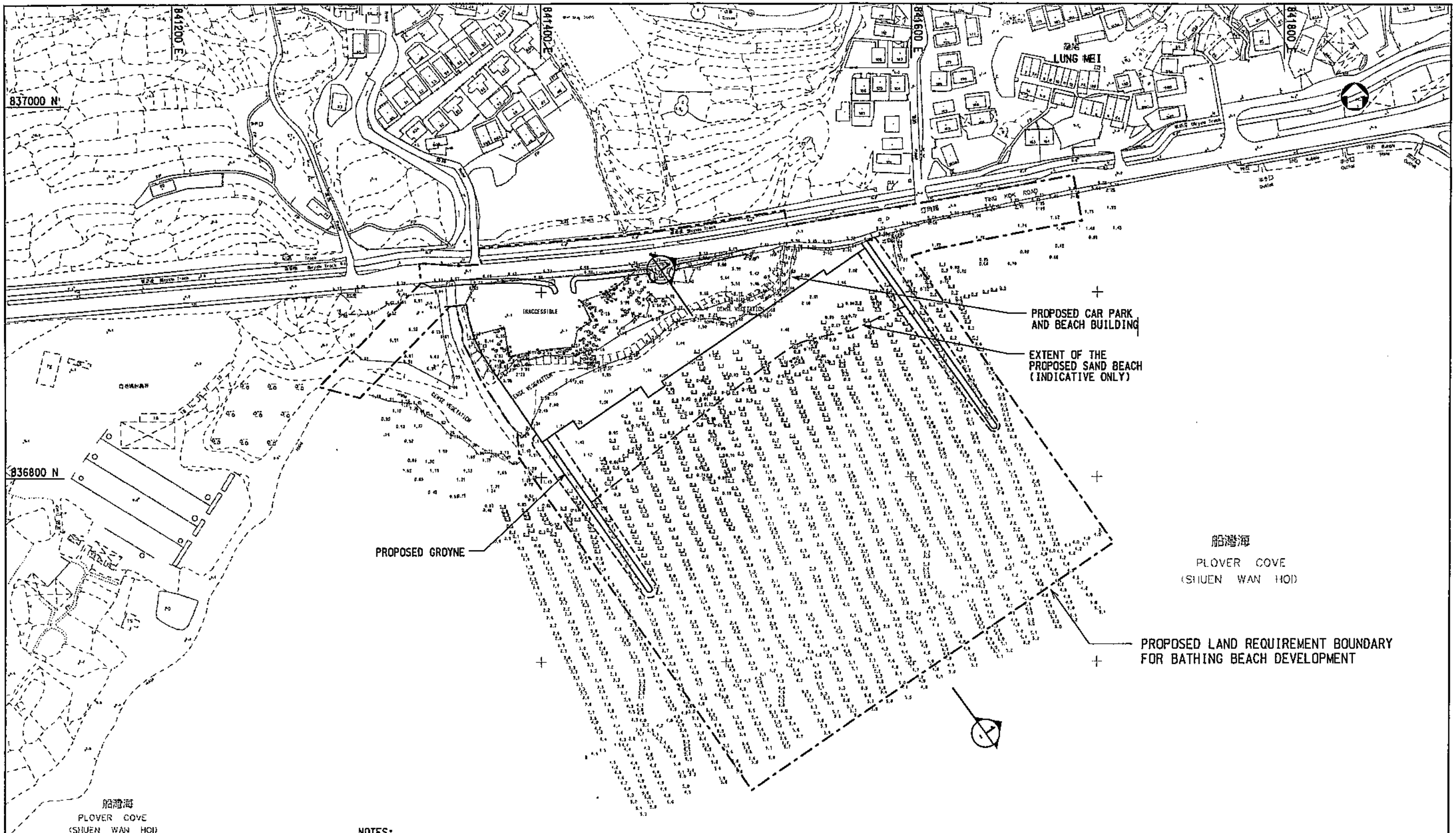


Figure 2.4: Wave Rose Diagram at Tai Mei Tuk.



LEGEND :

1 — 1 TYPICAL PROFILE OF EXISTING LUNG MEI BEACH

NOTES:

1. LEVEL/DEPTHS ARE IN METRES AS BELOW:-
   SOUNDINGS: BELOW CD: 2.3, ABOVE CD: 1.2
   SPOT LEVELS: ABOVE CD: 2.34, BELOW CD: -1.23
2. FOR MODEL ANALYSES AT THE TYPICAL PROFILE, REFER TO FIGURES 3.41 TO 3.50

0 20 40 60 80 100
METRES
SCALE 1 : 2000

CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer: Halcrow, Halcrow China Ltd. ERM Environment Resources Management as sub-consultant	Agreement No.: CE 59/2005 (EP)	WORKING PAPER 2.5 - WAVE AND SEDIMENT MODELLING REPORT
		Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	Figure Title: PLAN OF EXISTING LUNG MEI BEACH

FIGURE 3.0		
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02/03/2007

Figure 3.41: Cross-shore modelling results using COSMOS model for further developed design profile as constructed (0.2mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.41		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

Figure 3.42: Cross-shore modelling results using COSMOS model for further developed design profile in equilibrium (0.2mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.42		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

Lung Mei - Cross-shore model - Developed profile (For Construction)

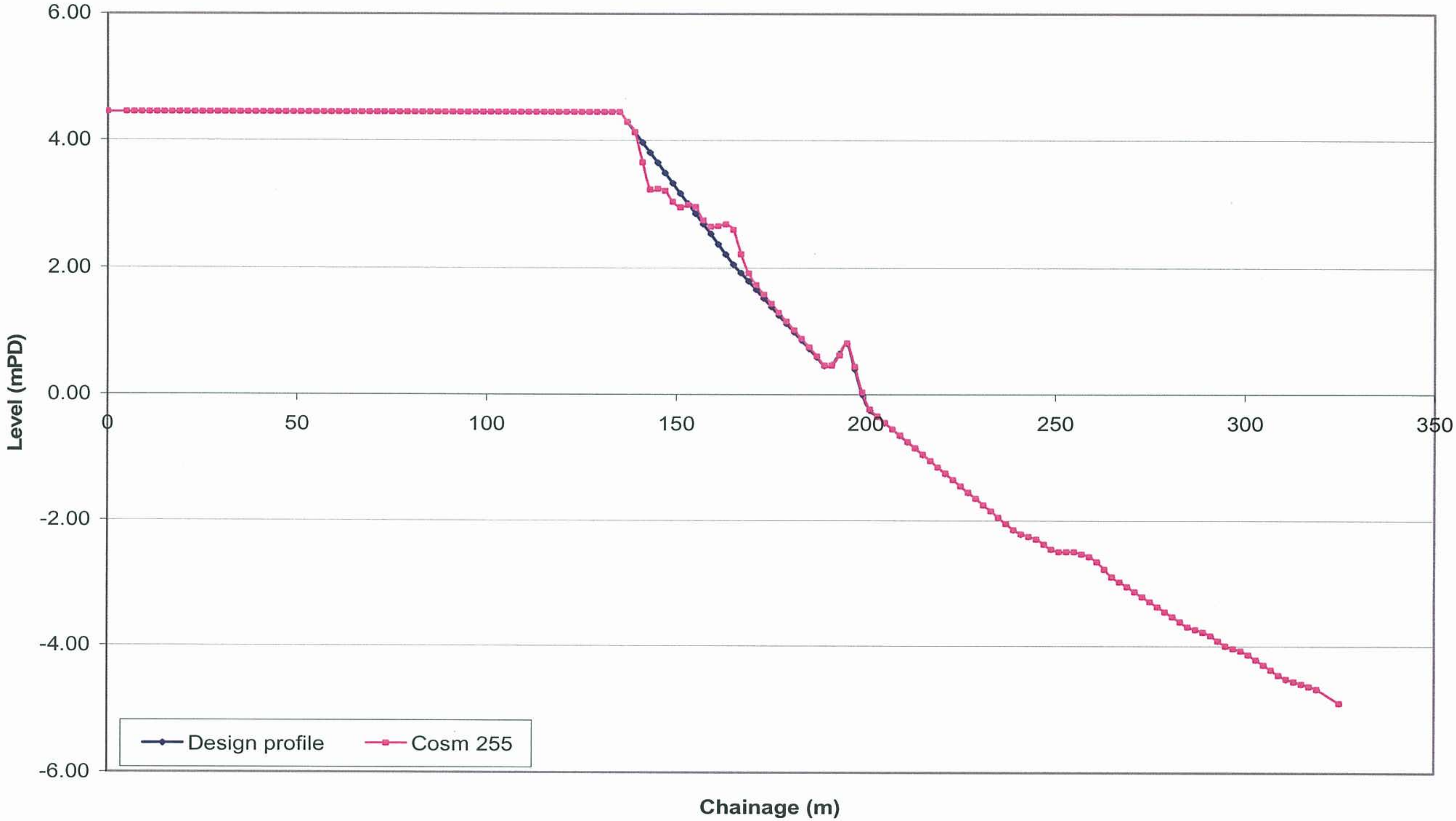

Figure 3.43: Cross-shore modelling results using COSMOS model for further developed design profile as constructed (0.25mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.43		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

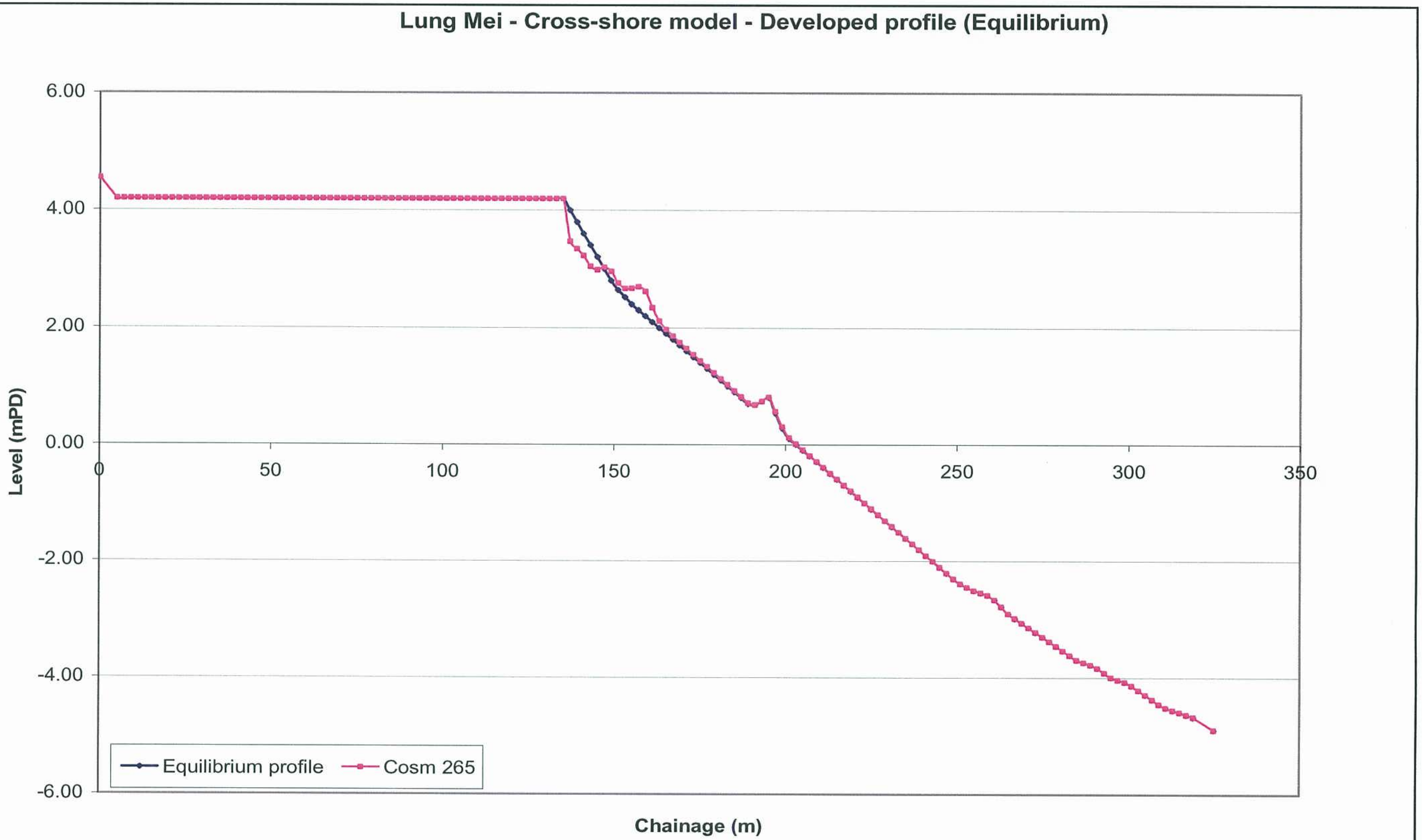

Figure 3.44: Cross-shore modelling results using COSMOS model for further developed design profile in equilibrium (0.25mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.44		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

Figure 3.45: Cross-shore modelling results using COSMOS model for further developed design profile as constructed (0.3mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.45		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow China Ltd. / ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

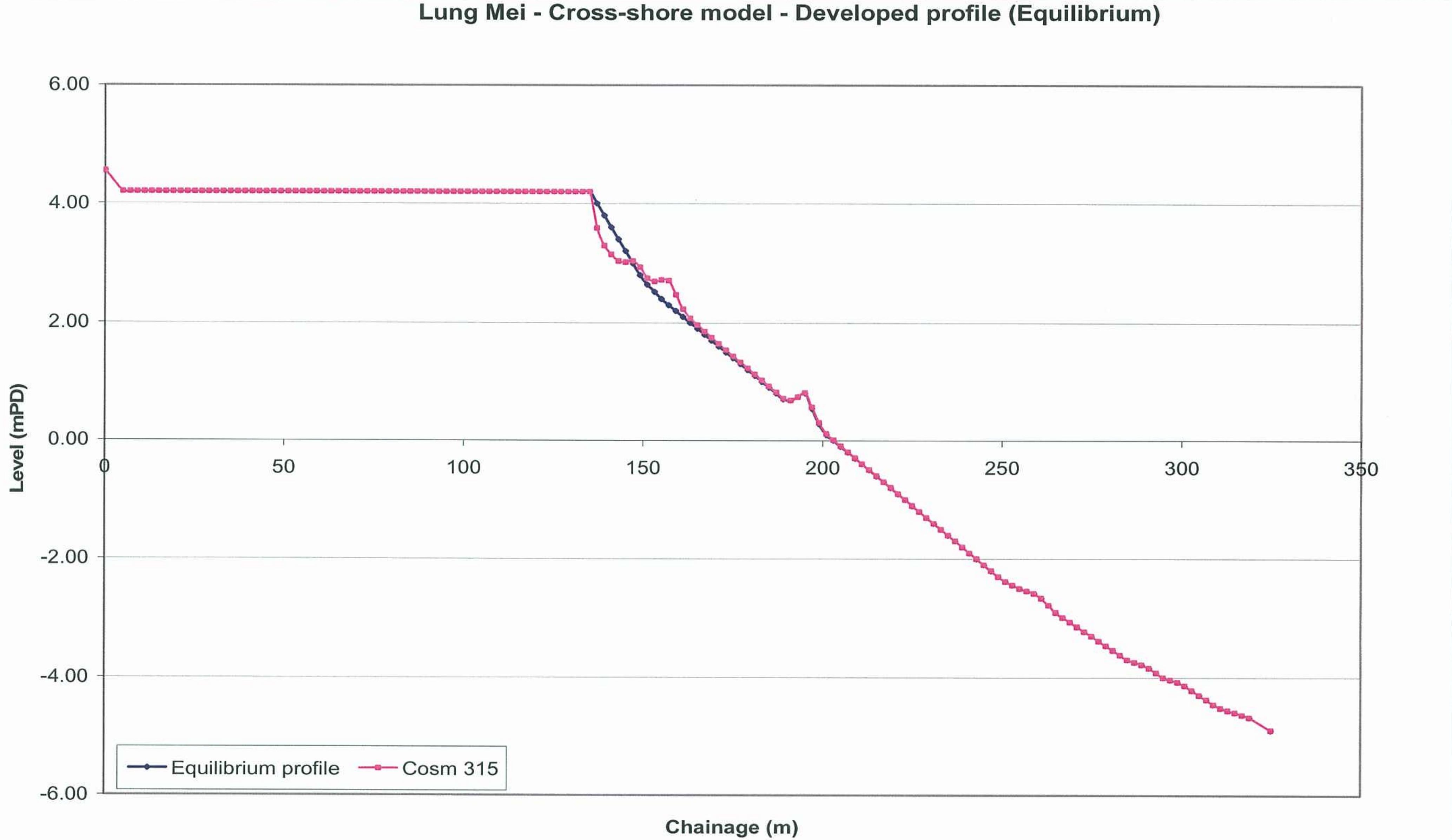

Figure 3.46: Cross-shore modelling results using COSMOS model for further developed design profile in equilibrium (0.3mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.46		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

Figure 3.47: Cross-shore modelling results using COSMOS model for further developed design profile as constructed (0.4mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.47		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

Figure 3.48: Cross-shore modelling results using COSMOS model for further developed design profile in equilibrium (0.4mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Agreement No.: CE 59/2005(EP) Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	**Figure 3.48** Checked: PS / Scale: - / Rev.: 1 Designed: TF / Drawn: - / Date: 04/09/2006

Figure 3.49: Cross-shore modelling results using COSMOS model for further developed design profile as constructed (0.5mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client	Consulting Engineer	Agreement No.: CE 59/2005(EP)		Figure 3.49		
CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Halcrow Halcrow China Ltd. ERM Environmental Resources Management as sub-consultant	Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Checked PS	Scale -	Rev. 1
				Designed TF	Drawn -	Date 04/09/2006

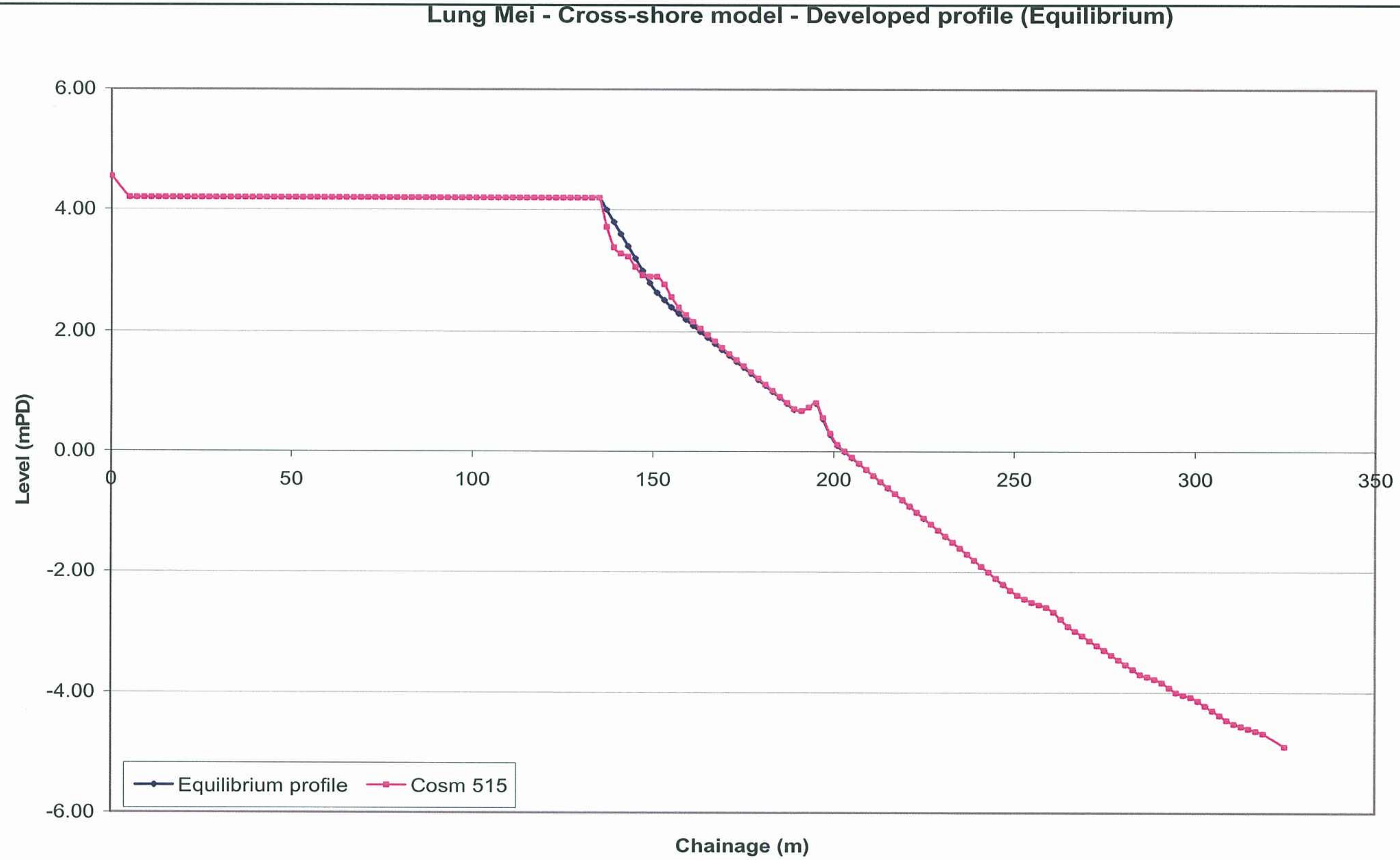

Figure 3.50: Cross-shore modelling results using COSMOS model for further developed design profile in equilibrium (0.5mm)

Note: At a typical profile of the existing Lung Mei Beach as shown on Figure 3.0

Client: CEDD CIVIL ENGINEERING AND DEVELOPMENT DEPARTMENT	Consulting Engineer: Halcrow, Halcrow China Ltd.; ERM Environmental Resources Management as sub-consultant	Agreement No.: CE 59/2005(EP) Project Title: DEVELOPMENT OF A BATHING BEACH AT LUNG MEI, TAI PO	WORKING PAPER 2.5 WAVE AND SEDIMENT MODELLING REPORT	Figure 3.50 Checked: PS; Scale: -; Rev.: 1 Designed: TF; Drawn: -; Date: 04/09/2006