CORRIGENDUM No. 1/2022

This corrigendum contains amendments to the Port Works Design Manual, 2002 Edition, and shall be read in conjunction with Corrigendum 1/2018.

Effect on Climate Change

PART 1 – General Design Considerations for Marine Works

(a) CONTENTS

Add the following sections:
Section 2.2.6 Storm Surge Increase due to Climate Change

Section 2.9 Design Allowance with Progressive Adaptive Approach to Enhance Climate Resilience

Section 3.9 Critical Infrastructure

(b) Section 2.2.4 – Extreme Water Levels

Replace the Section with the following:

Updated extreme sea level frequency analysis has been carried out for Chi Ma Wan, Ko Lau Wan, Quarry Bay/North Point, Tai O, Tai Po Kau, Tsim Bei Tsui and Waglan Island. Extreme sea levels for return periods of 2, 5, 10, 20, 50, 100 and 200 years for these seven tide station locations are given in Tables 3 to 9A. The period of records used in each case is given in these tables. At Quarry Bay/North Point and Tai Po Kau, the assessment was carried out on the basis of historic tidal measurement data. At other locations, data imputation with correlation to Quarry Bay/North Point data was made to fill the missing data before the assessment. Generalised Extreme Values (GEV) distribution is generally used to estimate the return values of extreme sea level. The extreme sea levels given in these tables are statistical results of the tides or estimated tides happening since 1954 or 1962, where appropriate. They do not necessarily represent the highest possible sea water levels that may happen at respective locations. The designers shall be responsible for making due allowance in their design for sea level rise having regard to the following factors:

(1) Sensitivity to sea level changes;
(2) Local topography;
(3) Possibility of being hit by tropical cyclones, in particular super typhoons, and the effect of concurrent occurrence of astronomical high tides; and
(4) Climate change effect.

Frequency analysis was also carried out on data reconstructed from numerical simulations or observed by tide poles or tide gauges before 1954, which are non-instrumental in nature, for Quarry Bay/North Point and Tai Po Kau. Higher extreme sea levels are provided in Appendix D for reference. For design of important facilities which are vulnerable and sensitive to sea water level, e.g. E&M installations, designers may consider to take into account the historical storm surge records before 1954 as far as practicable.

Minimum sea levels observed at the 8 tide stations in Figure 2 are shown in Table 10.

(c) Section 2.2 – Tide and Water Levels

Amend the title to read as follows:
Section 2.2 – Tide, Water Levels and Storm Surge

Add the following section:

2.2.6 Storm Surge Increase due to Climate Change
Recent climate research predicts that the intensity of tropical cyclones and associated storm surge and wind waves will increase as a result of climate change. Owing to the nature of differences in topography and bathymetry, the increases in extreme storm surge are anticipated to vary by location. The induced storm surge increase in Hong Kong at tide stations under intermediate greenhouse gas emissions scenario [SSP2-4.5] is given in Table 44.

For design of coastal structures with the most extreme loading condition of having extreme wave condition at the higher return period, to obtain estimates of future extreme water levels for use in design, the storm surge increase at the same return period of the wave should be added to the extreme water levels given in Tables 3 to 9A and sea level rise projections under intermediate greenhouse gas emissions scenario [SSP2-4.5] given in Table 42.

(d) Section 2.4.2 – Extreme Wind Speeds

Replace the Section with the following:
Mean hourly wind speeds for return periods of 5, 10, 20, 50, 100 and 200 years for four of the main stations, namely, Kai Tak Southeast Station, Cheung Chau Station, Waglan Island Station and Hong Kong International Airport Station are given in Tables 12 to 14A. Mean wind speeds for durations of 2, 3, 4, 6 and 10 hours and return periods of 5, 10, 20, 50, 100 and 200 years for Kai Tak Southeast Station, Cheung Chau Station and Waglan Island Station and Hong Kong International Airport Station are also given in Tables 15 to 30F. The assessment was carried out by using GEV or Gumbel distribution, whichever gives greater values, to the annual maximum mean wind speeds for each duration and direction. The period of records used for each station is also given in the tables. The following points about these stations should be noted when applying their mean wind speed data:

- Both the Cheung Chau and Waglan Island Stations are better exposed geographically and not directly affected by urbanization. Their wind data are generally more representative of the wind conditions over Hong Kong.

- The wind data at Kai Tak Southeast Station are subject to the shelter effect of the mountains surrounding the harbor and urban development in the harbor area. Wind data at this station should not be used for locations outside the inner Victoria Harbour area.

- The wind data at Hong Kong International Airport Station are subject to the shelter effect of the mountains on the Lantau Island to the south. Wind data at this station are generally more representative of the wind conditions at the Western Waters of Hong Kong.

The mean wind speeds given in Tables 12 to 30F have been corrected to 60-min average wind speed while a brief history of the heights and locations of the anemometers at the four wind stations is given in Table 30G.

Extreme wind speeds for other wind stations are not shown because of the relatively short period of data collection.

For conversion of the mean hourly wind speeds to mean speeds with durations of less than one hour, the following conversion factors may be cited :

Duration	*Conversion Factor*
1 minute	1.19
5 minutes	1.11
10 minutes	1.09
20 minutes	1.05
1 hour	1.00

Caution should be taken when using the above values, as the conversion factors are greatly affected by the surface roughness and topography around a site of interest.

(e) Section 2.4 – Wind

Amend the section 2.4.4 to read as follows:

2.4.4 Increase in Extreme Wind Speeds due to Climate Change
Tropical cyclone intensity is expected to increase as a result of climate change. Extreme wind speeds for 2050 and 2090 are expected to increase as given in the projections under intermediate greenhouse gas emissions scenario [SSP2-4.5] Table 43.

To obtain estimates of future extreme wind speeds for use in design, the increased wind speed projections should be added to the extreme wind speeds given in Tables 12 to 30F.

The implications of increasing wind speeds on wave generation (height and period) should be considered for design of all marine works in Hong Kong. Changing wave parameters throughout the design life of a structure should be considered to ensure the worst loading cases are identified.

(f)	Section 2.5.5 – Wave Data and Data Sources	**Amend the 1st sentence of the 4th paragraph to read as follows:** A summary of the wave measurement between 1994 and 2020 is given in Tables 32 and 33.
(g)	Section 2.5.6	**Amend the 1st bullet point to read as follows:**

Wind speed at the level of 10 m above mean sea level should generally be used in wave prediction formulae or mathematical wave model. The wind speeds given in Tables 12 to 30F can be used directly for this purpose based on the following considerations:

(a) No correction was needed for the wind data at Kai Tak Southeast Station and Hong Kong International Airport Station as the recording heights are close to the standard height of 10 m.

(b) It should be noted that the normal wind-height adjustment formulae, including the one-seventh power law and the Hellman formula, are not recommended for use in Hong Kong conditions. Hence, it is considered more conservative to use wind data at Waglan Island and Cheung Chau wind stations which have recording heights of 83 m and 98 m above mean sea level respectively.

Amend the last sentence of the 2nd bullet point to read as follows:
For duration greater than one hour, the respective wind speed information is given in Tables 15 to 30F.

(h) Section 2.9 – Design Allowance with Progressive Adaptive Approach to Enhance Climate Resilience

Add the following section:

2.9 Design Allowance with Progressive Adaptive Approach to Enhance Climate Resilience

While climate change has been established among the scientific community to be occurring and the trends are upward, there is significant uncertainty about the magnitude of future climate change impacts particularly towards the end of century and beyond due to uncertain future greenhouse gas emissions. Depending on climate actions taken by global countries to reduce greenhouse gas emissions, development of climate change effects may follow different possible pathways in long-term future.

Considering the uncertainties in the range of possible future climate change development and global actions among nations on reducing carbon emissions, the progressive adaptive approach shall be adopted to formulate climate adaptation measures for marine works. This approach is to be flexible and adaptive enough that they can be changed or updated as conditions change or if impacts due to climate change are different from that anticipated.

Under the progressive adaptive approach, with a view to further enhancing the resilience against climate change for new coastal structures, against possible higher greenhouse gas emissions scenarios, the design allowance in design of adaptation measures, including the possible projection differences between very high greenhouse gas emissions scenario [SSP5-8.5] and intermediate greenhouse gas emissions scenario [SSP2-4.5] in sea level rise ($\Delta_{\text{sea level rise}}$), storm surge increase ($\Delta_{\text{storm surge increase}}$) and wave effect ($\Delta_{\text{wave effect}}$) is required. With these design sea level and design wave height under higher greenhouse gas emissions scenario, the wave overtopping will become larger. The crest elevation of seawall cope level must be raised to offset the increase in wave overtopping rates. The required raise of the crest elevation is the design allowance.

Design allowance given in Table 45 should be added to the design cope level of new coastal structures such as seawalls, breakwaters, piers and wave walls in Hong Kong, e.t.c. to enhance climate resilience.

With due consideration of other factors with care and supporting evidence, e.g. social impacts, operation requirements, technical/site constraints and feasibility of upgrading the structures, the designer can either adopt the design allowance in one-go or adopt in stages through the progressive adaptive approach.

The design allowance given in Table 45 is for the design of new coastal structures with paved land behind. For the design of new coastal structures with unpaved land behind, which is not common in nature, designers are advised to add the figures of 0.01m and 0.05m for 2050 and 2090, respectively, to the design allowance given in Table 45.

For extreme environmental conditions, the operations such as pedestrian and vehicle movements commonly cease at a marine structure. However, for the exceptional case when there is personnel or vehicle congregating at or near the marine structure under extreme environmental conditions, designers should determine the design allowance by considering the permissible overtopping rates for personnel and vehicles as stipulated in Section 5.3.2 of the Port Works Design Manual : Part 4 – Guide to Design of Seawalls and Breakwaters.

(i) Section 3.9 – Critical Infrastructure

Add the following section:

3.9 Critical Infrastructure

To improve the resilience of Critical Infrastructure (CI) in general, the marine CI such as piers and breakwaters and coastal protection works of CI are required to be designed for extreme environmental events with return periods of about 200 years. A CI is classified based on the three key principles as follows:

- Long recovery time upon hazard impact means the operation of infrastructures could not be resumed in short to medium term after the impact of climate-related hazards, or

- Non-substitutability is the reliance on the infrastructure to serve its function for the community. Some CI will be more critical if they are not easily substituted or replaced. The function(s) of CI could not be met by alternative means, or

- Disruption to territorial/regional wide service/daily life or economic impact is a "socio-economic" factor and thus it reflects the criticality of infrastructure to people and economic activities. People movements or economic activities can be considered in multiple hierarchies in the increasing sequence from local, district, regional to territorial.

(j) Section 5.10.2 – Wave Conditions

Amend the 1st paragraph to read as follows:

The wave conditions that should be assessed in design should be jointly described with the water levels as these two variables are correlated (HKPU, 2000). Under the effect of climate change, the storm surge increase, with the same return period as the return period of the wave conditions shall also be taken into account. For typical marine works with a design life of 50 years, the following wave conditions, surge storm increases and water levels should normally be considered :

Loading Conditions	*Waves, Storm Surge Increases and Water Levels*
• Extreme	• Extreme wave condition and storm surge increase at 100-year return period and extreme water level at 10-year return period.
	• Extreme wave condition and storm surge increase at 10-year return period and extreme water level at 100-year return period.
	• Extreme wave condition and storm surge increase at 50-year return period and extreme water level at 50-year return period.
	• Extreme wave condition and storm surge increase at 100-year return period and mean lower low water level.
• Normal	• Wave condition at tropical cyclone warning signal no. 3 or within the first few hours of the issuance of tropical cyclone signal no. 8 and maximum water level at 2-year return period.

	• Wave condition at tropical cyclone warning signal no. 3 or within the first few hours of the issuance of tropical cyclone warning signal no. 8 and mean lower low water level.
• Accident	• Same as normal loading condition.
• Temporary	• Wave condition to be assessed by designers for each individual case.

The extreme waves, storm surge increases and water level conditions given above for typical marine works refers to extreme environmental events with return periods of about 100 years.

For design of Critical Infrastructure, the following wave conditions, storm surge increase and water levels for the extreme loading condition should normally be considered :

Loading Conditions	*Waves, Storm Surge Increases and Water Levels*
• Extreme	• Extreme wave condition and Storm Surge Increase at 200-year return period and extreme water level at 10-year return period.
	• Extreme wave condition and Storm Surge Increase at 10-year return period and extreme water level at 200-year return period.
	• Extreme wave condition and Storm Surge Increase at 100-year return period and extreme water level at 100-year return period.
	• Extreme wave condition and Storm Surge Increase at 200-year return period and mean lower low water level.

The extreme waves, storm surge increases and water level conditions given above for Critical Infrastructure refers to extreme environmental events with return periods of about 200 years.

(k) TABLES **Tables 2 – 30G, 32 – 33, 42 – 45 are updated/added as follows:**

Table 2 Mean Sea Levels, Mean Higher High Water Levels and Mean Lower Low Water Levels

Location	Period of Data	Mean Sea Level (mPD)	Mean Higher High Water Level (mPD)	Mean Lower Low Water Level (mPD)
Ko Lau Wan[1]	1983-2019	1.26	2.00	0.51
Quarry Bay/North Point	1954- 2019	1.26	2.01	0.47
Tai O[2]	1985-2019	1.27	2.13	0.31
Tai Po Kau	1963-2019	1.26	2.02	0.48
Tsim Bei Tsui	1974- 2019	1.31	2.32	0.26
Waglan Island[3]	1976- 2018	1.40	2.08	0.66

Notes:
1. Ko Lau Wan tide station temporarily closed between 1996 and 2000 inclusive and there were no data records during the period.
2. Data period for analysis at Tai O tide station does not cover 1998-2010 inclusive.
3. Waglan Island tide station was damaged by Super Typhoon Mangkhut in 2018, the measurement of sea level at the station has been temporarily suspended since 16 September 2018.

Table 3 Extreme Sea Levels at Ko Lau Wan (1954-2019)

Return Period (years)	Sea Level (mPD)
2	2.79
5	2.99
10	3.11
20	3.24
50	3.43
100	3.58
200	3.72

Note The data are relative to the AR6 base year (1995-2014). The extreme sea levels at Ko Lau Wan were based on frequency analysis of instrumental data and correlated data of North Point/ Quarry Bay with an extended data set of 66 years (from 1954 to 2019).

Table 4 Extreme Sea Levels at Quarry Bay/North Point (1954-2019)

Return Period (years)	Sea Level (mPD)
2	2.82
5	3.03
10	3.20
20	3.38
50	3.66
100	3.91
200	4.19

Note The extreme sea levels at Quarry Bay / North Point were based on frequency analysis of instrumental data from 1954 to 2019 (66 years) and adjusted by +0.07m to AR6 base year (1995-2014).

Table 5 Extreme Sea Levels at Tai Po Kau (1962-2019)

Return Period (years)	Sea Level (mPD)
2	2.97
5	3.27
10	3.54
20	3.86
50	4.41
100	4.93
200	5.59

Note The extreme sea levels at Tai Po Kau were based on frequency analysis of instrumental data from 1962 to 2019 (58 years) and adjusted by +0.04m to AR6 base year (1995-2014).

Table 6 Extreme Sea Levels at Tsim Bei Tsui (1954-2019)

Return Period (years)	Sea Level (mPD)
2	3.07
5	3.31
10	3.52
20	3.74
50	4.09
100	4.41
200	4.78

Note The data are relative to the AR6 base year (1995-2014). The extreme sea levels at Tsim Bei Tsui were based on frequency analysis of instrumental data and correlated data of North Point/ Quarry Bay with an extended data set of 66 years (from 1954 to 2019).

Table 7 Extreme Sea Levels at Waglan Island (1954-2019)

Return Period (years)	Sea Level (mPD)
2	2.79
5	2.95
10	3.09
20	3.24
50	3.45
100	3.62
200	3.81

Note The data are relative to the AR6 base year (1995-2014). The extreme sea levels at Waglan Island were based on frequency analysis of instrumental data and correlated data of North Point/ Quarry Bay with an extended data set of 66 years (from 1954 to 2019).

Table 8 Extreme Sea Levels at Chi Ma Wan (1954-2019)

Return Period (years)	Sea Level (mPD)
2	2.86
5	3.07
10	3.23
20	3.41
50	3.65
100	3.85
200	4.08

Note The data are relative to the AR6 base year (1995-2014). The extreme sea levels at Chi Ma Wan were based on frequency analysis of instrumental data and correlated data of North Point/ Quarry Bay with an extended data set of 66 years (from 1954 to 2019).

Table 9A Extreme Sea Levels at Tai O (1954-2019)

Return Period (years)	Sea Level (mPD)
2	2.87
5	3.16
10	3.36
20	3.57
50	3.84
100	4.06
200	4.28

Note The data are relative to the AR6 base year (1995-2014). The extreme sea levels at Tai O were based on frequency analysis of instrumental data and correlated data of North Point/ Quarry Bay with an extended data set of 66 years (from 1954 to 2019).

Table 10 Observed Minimum Sea Levels

Location	Period of Data	Minimum Sea Levels (mPD)
Ko Lau Wan	1974-2019	-0.28
Quarry Bay	1954- 2019	-0.30
Tai O	1985-2019	-0.67
Tai Po Kau	1963- 2019	-0.48
Tsim Bei Tsui	1974- 2019	-0.36
Waglan Island	1976- 2018	-0.32

Notes:

1. Ko Lau Wan tide station temporarily closed between 1996 and 2000 inclusive and there were no data records during the period.
2. Data period for analysis at Tai O tide station does not cover 1998-2010 inclusive.
3. Waglan Island tide station was damaged by Super Typhoon Mangkhut in 2018, the measurement of sea level at the station has been temporarily suspended since 16 September 2018.

Table 12 Mean Hourly Wind Speeds (m/s) – Kai Tak Southeast Station (1968-2020)

Return Period (Years)	N	NE	E	SE	S	SW	W	NW
5	13	14	17	16	13	14	13	12
10	15	16	20	19	16	16	16	14
20	17	18	23	21	18	19	18	16
50	20	21	27	25	21	23	21	18
100	22	23	30	27	23	27	23	20
200	24	25	34	30	26	29	25	21

Table 13 Mean Hourly Wind Speeds (m/s) – Cheung Chau Station (1953- 2020)

Return Period (Years)	N	NE	E	SE	S	SW	W	NW
5	19	21	25	24	20	18	17	18
10	22	24	29	29	23	21	20	21
20	24	27	33	33	27	24	22	25
50	27	31	37	38	32	29	26	29
100	30	35	41	42	37	33	29	31
200	32	38	44	46	41	36	31	34

Table 14 Mean Hourly Wind Speeds (m/s) – Waglan Island Station (1953-2020)

Return Period (Years)	N	NE	E	SE	S	SW	W	NW
5	22	26	28	25	23	23	20	17
10	24	30	32	29	27	26	23	20
20	26	34	35	33	31	29	26	24
50	29	39	40	39	36	33	30	28
100	31	44	44	43	39	36	34	32
200	33	48	47	47	43	40	37	37

Table 14A Mean Hourly Wind Speeds (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	N	NE	E	SE	S	SW	W	NW
5	15	15	21	17	14	18	16	17
10	17	17	23	20	16	21	19	19
20	19	20	26	22	18	25	23	21
50	21	22	29	25	21	31	28	24
100	23	25	31	27	23	36	32	26
200	24	27	34	29	25	42	36	28

Table 15 Mean Wind Speeds East Direction (m/s) – Kai Tak Southeast Station (1968-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	17	17	17	16	16	15
10	20	20	19	19	18	17
20	23	23	22	22	21	19
50	27	27	26	26	24	22
100	30	30	29	29	27	24
200	34	34	33	32	31	26

Table 16 Mean Wind Speeds Southeast Direction (m/s) – Kai Tak Southeast Station (1968-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	16	15	14	14	13	12
10	19	17	16	16	15	14
20	21	20	19	18	17	16
50	25	22	21	21	19	18
100	27	25	23	23	21	20
200	30	27	25	24	23	21

Table 17 Mean Wind Speeds West Direction (m/s) – Kai Tak Southeast Station (1968- 2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	13	13	12	12	11	10
10	16	15	14	14	13	12
20	18	17	16	15	14	13
50	21	19	18	18	16	15
100	23	21	20	19	18	16
200	25	22	22	21	19	17

Table 18 Mean Wind Speeds North Direction (m/s) – Cheung Chau Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	19	19	18	18	17	16
10	22	21	20	20	19	18
20	24	23	23	22	21	20
50	27	26	26	25	24	22
100	30	29	28	27	26	24
200	32	31	31	30	27	25

Table 19 Mean Wind Speeds Northeast Direction (m/s) – Cheung Chau Station (1953- 2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	21	19	19	18	17	16
10	24	22	21	21	19	18
20	27	25	24	23	22	20
50	31	29	28	27	25	22
100	35	32	30	29	27	24
200	38	35	33	32	30	26

Table 20 Mean Wind Speeds East Direction (m/s) – Cheung Chau Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	25	24	23	23	21	20
10	29	28	27	26	25	23
20	33	31	30	29	28	26
50	37	36	35	34	32	29
100	41	39	38	37	35	32
200	44	43	41	40	38	35

Table 21 Mean Wind Speeds Southeast Direction (m/s) – Cheung Chau Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	24	23	22	22	21	19
10	29	28	26	26	25	23
20	33	32	30	29	28	26
50	38	37	35	34	33	30
100	42	41	39	38	36	33
200	46	45	43	42	39	36

Table 22 Mean Wind Speeds South Direction (m/s) – Cheung Chau Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	20	19	18	18	17	15
10	23	22	22	21	20	18
20	27	26	25	24	23	20
50	32	31	30	29	27	24
100	37	36	34	32	30	26
200	41	40	38	36	33	29

Table 23 Mean Wind Speeds Southwest Direction (m/s) – Cheung Chau Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	18	17	16	16	15	14
10	21	20	19	19	18	16
20	24	23	22	22	21	19
50	29	27	27	26	25	22
100	33	31	30	29	28	25
200	36	35	34	33	32	28

Table 24 Mean Wind Speeds North Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	22	22	21	21	20	19
10	24	24	23	23	22	21
20	26	26	25	25	24	22
50	29	29	28	27	26	24
100	31	31	30	29	28	26
200	33	33	32	31	29	27

Table 25 Mean Wind Speeds Northeast Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	26	25	25	24	23	21
10	30	29	28	27	26	24
20	34	33	32	30	29	27
50	39	38	36	35	33	31
100	44	42	40	38	36	34
200	48	46	43	42	40	36

Table 26 Mean Wind Speeds East Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	28	28	27	26	26	24
10	32	31	30	30	28	26
20	35	34	34	33	31	29
50	40	39	38	37	35	32
100	44	42	41	40	38	34
200	47	46	44	43	41	37

Table 27 Mean Wind Speeds Southeast Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	25	24	23	22	21	20
10	29	28	27	26	25	23
20	33	32	31	30	28	26
50	39	37	36	35	33	30
100	43	41	40	39	37	34
200	47	45	44	43	41	37

Table 28 Mean Wind Speeds South Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	23	22	21	20	19	18
10	27	26	25	24	23	21
20	31	29	28	27	26	24
50	36	34	33	32	30	28
100	39	38	37	36	34	31
200	43	42	40	39	37	34

Table 29 Mean Wind Speeds Southwest Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	23	22	21	20	19	18
10	26	25	24	24	22	20
20	29	28	27	26	25	22
50	33	32	31	30	28	25
100	36	35	34	33	31	27
200	40	38	37	36	33	29

Table 30 Mean Wind Speeds West Direction (m/s) - Waglan Island Station (1953-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	20	19	18	18	17	16
10	23	22	21	20	19	18
20	26	25	24	23	22	20
50	30	29	27	26	25	23
100	34	32	30	28	27	25
200	37	35	33	31	29	27

Table 30A Mean Wind Speeds North Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	15	14	14	14	13	12
10	17	16	16	15	15	13
20	19	18	18	17	17	15
50	21	20	20	20	19	17
100	23	22	22	22	21	19
200	24	24	24	24	23	21

Table 30B Mean Wind Speeds Northeast Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	15	15	14	13	12	11
10	17	17	16	15	14	13
20	20	19	18	17	15	14
50	22	21	20	19	17	15
100	25	23	22	21	19	17
200	27	25	24	22	20	18

Table 30C Mean Wind Speeds Southeast Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	17	16	16	15	14	13
10	20	18	18	17	16	15
20	22	20	19	19	18	17
50	25	23	22	21	20	19
100	27	25	24	22	21	20
200	29	27	25	24	23	22

Table 30D Mean Wind Speeds Southwest Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	18	16	16	15	14	13
10	21	20	19	18	16	14
20	25	23	22	20	18	16
50	31	28	26	24	21	17
100	36	33	30	27	23	19
200	42	38	35	31	25	20

Table 30E Mean Wind Speeds West Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	16	15	14	14	12	11
10	19	18	17	16	15	13
20	23	21	20	19	17	15
50	28	26	24	22	20	17
100	32	29	27	25	22	19
200	36	32	30	27	24	21

Table 30F Mean Wind Speeds Northwest Direction (m/s) – Hong Kong International Airport Station (1979-1983, 1997-2020)

Return Period (Years)	Duration (hr)					
	1	2	3	4	6	10
5	17	16	15	15	14	13
10	19	18	17	17	16	14
20	21	20	19	18	17	15
50	24	23	22	21	19	17
100	26	24	23	22	21	19
200	28	26	25	24	22	20

Table 30G Brief History of the Anemometers at the Four Wind Stations

Wind Station	Time Period	Anemometer height (above MSL) to the nearest meter	Location
Waglan Island	1952-1964	70	Only small distance relocation within buildings on the island
	1964-1966	67	
	1966-1989	75	
	1989-now	83	
Cheung Chau	1953-1971	48	Old site near Cheung Chau Sports Ground
	1971-1992	92	At Cheung Chau Aeronautical Meteorological Station
	1992-now	98	
Kai Tak Southeast	1948-1962	16	At old Kai Tak Meteorological Station
	1962-1974	10	Near south-eastern end of the runway
	1974-now	16	Near south-eastern end of the extended runway
Hong Kong International Airport	1979-1983	65	On Chek Lap Kok Island
	1997-now	14	At central part of the Center Runway* of HKIA

* Known as “North Runway” before 8:00 HKT on 2 December 2021

Table 32 Wave Measurement at Kau Yi Chau Station (1994-2020)

Year	Percentage of Time in Service	Calm Period (H_{m0}<0.3m)	Average H_{m0} (m)	Average Peak Period T_p (s)	Maximum H_{m0} (m) [Tp (s)]	Maximum Recorded Wave Height H_{max} (m)
1994	78%	63%	0.31	6.74	1.46 [9.14]	2.45
1995	87%	77%	0.26	6.47	1.51 [11.63]	2.68
1996	60%	75%	0.27	6.33	1.57 [11.63]	2.38
1997	95%	79%	0.26	6.65	1.61 [11.63]	2.68
1998	97%	81%	0.24	6.38	1.40 [9.14]	2.92
1999	93%	75%	0.25	6.15	2.37 [9.85]	3.75
2000	100%	73%	0.27	6.38	1.70 [9.14]	2.33
2001	73%	70%	0.29	6.29	2.68 [10.67]	3.87
2002	96%	79%	0.26	6.12	2.46 [11.64]	3.42
2003	85%	78%	0.27	6.30	2.68 [12.8]	3.44
2004	86%	69%	0.28	5.63	1.33 [6.67&9.53]	2.13
2005	84%	58%	0.31	5.62	1.73 [13.21]	2.65
2006	72%	58%	0.32	6.04	2.47 [11.7]	3.83
2007	51%	40%	0.35	5.26	1.75 [3.95]	2.83
2008	67%	39%	0.41	5.32	3.31 [12.26]	5.31
2009	79%	39%	0.52	5.11	3.34 [12.26]	5.45
2010	80%	60%	0.37	5.05	2.89 [3.64]	4.82
2011	94%	78%	0.17	4.90	2.29 [10.72]	3.52
2012	86%	77%	0.18	5.08	2.59 [10.5]	4.14
2013	76%	81%	0.15	4.99	1.72 [11.98]	2.70
2014	58%	61%	0.31	5.42	2.07 [3.66]	3.35
2015	75%	11%	0.47	4.50	1.86 [10.95]	2.96
2016	55%	70%	0.16	4.56	0.97 [8.57]	1.55
2017	54%	65%	0.23	5.55	1.36 [10.95]	2.13
2018	66%	54%	0.30	6.16	4.32 [14.32]	6.80
2019	81%	63%	0.29	6.06	1.35 [10.5]	2.11
2020	59%	26%	0.38	5.83	1.65 [7.56]	2.47

Note 1. The percentage of time in service refers to the time at which the recorder is operational.
2. For the maximum H_{m0}, the corresponding peak period T_p is shown in brackets.
3. For data beyond 2020, CEDD website https://www.cedd.gov.hk/ should be referred.

Table 33 Wave Measurement at West Lamma Channel Station (1994-2020)

Year	Percentage of Time in Service	Calm Period (H_{m0}<0.3m)	Average H_{m0} (m)	Average Peak Period T_p (s)	Maximum H_{m0} (m) [Tp (s)]	Maximum Recorded Wave Height H_{max} (m)
1994	84%	55%	0.33	7.51	1.68 [9.14]	2.42
1995	53%	46%	0.36	7.29	1.45 [3.88]	2.47
1996	41%	56%	0.32	7.08	1.71 [11.63]	2.83
1997	71%	60%	0.28	6.66	2.52 [5.82]	3.99
1998	34%	51%	0.32	7.99	1.08 [12.8]	1.93
1999	51%	50%	0.33	7.34	3.28 [9.85]	4.68
2000	72%	38%	0.38	6.49	1.95 [9.85]	3.01
2001	77%	45%	0.35	6.60	3.03 [10.67]	4.01
2002	27%	52%	0.33	7.40	2.29 [10.67]	3.41
2003	78%	45%	0.36	6.64	3.38 [12.8]	5.45
2004	75%	32%	0.37	6.36	1.59 [10.29]	2.57
2005	89%	43%	0.35	6.89	2.01 [11.98]	3.11
2006	77%	41%	0.37	7.29	2.99 [10.95]	4.64
2007	82%	47%	0.34	6.95	2.29 [5.97&7.79]	3.69
2008	95%	41%	0.36	7.24	3.49 [13.93]	5.46
2009	97%	34%	0.36	7.19	2.81 [11.19]	4.47
2010	99%	39%	0.33	6.87	1.33 [10.10]	2.24
2011	72%	54%	0.29	6.07	2.81 [13.56]	4.34
2012	88%	60%	0.22	5.94	0.72 [5.97]	1.18
2013	99%	75%	0.15	5.45	1.79 [11.19]	2.84
2014	99%	51%	0.28	6.41	2.47 [11.7]	3.89
2015	75%	52%	0.27	6.57	1.76 [10.09]	2.77
2016	90%	39%	0.36	6.73	2.08 [5.83]	3.40
2017	67%	29%	0.39	6.58	1.65 [10.72]	2.61
2018	71%	48%	0.31	6.16	4.37 [14.73]	6.81
2019	81%	34%	0.35	6.55	0.94 [7.67]	1.49
2020	43%	16%	0.43	6.56	1.43 [12.02]	2.39

Note 1. The percentage of time in service refers to the time at which the recorder is operational.
2. For the maximum H_{m0}, the corresponding peak period T_p is shown in brackets.
3. For data beyond 2020, CEDD website https://www.cedd.gov.hk/ should be referred.

Table 42 Rise in Mean Sea Levels Due to Climate Change

Years	Sea Level Rise (m)
2030	0.09
2040	0.14
2050	0.20
2060	0.26
2070	0.32
2080	0.39
2090	0.47
2100	0.56

Note The mean sea level rise is relative to the average of 1995-2014.
Median projection values are adopted in the table.

Table 43 Increase in Extreme Wind Speeds Due to Climate Change

	Type	Year 2050	Year 2090
Wind Speed Increase (%)	Typical Marine Structure	3.3	6.7
	Critical Infrastructure	3.6	6.9

Add Table 44 as follows:

Table 44 Storm Surge Increase Due to Climate Change

Return Period (years)	Location	Storm Surge Increase (m)	
		Year 2050	Year 2090
2	Quarry Bay/North Point	0.04	0.06
	Tai Po Kau	0.05	0.09
	Tsim Bei Tsui	0.05	0.09
	Tai O	0.03	0.06
	Waglan Island	0.03	0.06
	Ko Lau Wan	0.04	0.07
	Chi Ma Wan	0.04	0.08
5	Quarry Bay/North Point	0.05	0.09
	Tai Po Kau	0.07	0.14
	Tsim Bei Tsui	0.06	0.12
	Tai O	0.05	0.09
	Waglan Island	0.05	0.08
	Ko Lau Wan	0.06	0.10
	Chi Ma Wan	0.06	0.11

Table 44 Storm Surge Increase Due to Climate Change (Con't)

Return Period (years)	Location	Storm Surge Increase (m)	
		Year 2050	Year 2090
10	Quarry Bay/North Point	0.06	0.10
	Tai Po Kau	0.08	0.17
	Tsim Bei Tsui	0.08	0.15
	Tai O	0.05	0.10
	Waglan Island	0.05	0.09
	Ko Lau Wan	0.07	0.11
	Chi Ma Wan	0.07	0.13
20	Quarry Bay/North Point	0.07	0.12
	Tai Po Kau	0.10	0.20
	Tsim Bei Tsui	0.09	0.17
	Tai O	0.06	0.12
	Waglan Island	0.06	0.11
	Ko Lau Wan	0.07	0.13
	Chi Ma Wan	0.08	0.15
50	Quarry Bay/North Point	0.08	0.14
	Tai Po Kau	0.13	0.25
	Tsim Bei Tsui	0.11	0.20
	Tai O	0.08	0.14
	Waglan Island	0.07	0.12
	Ko Lau Wan	0.09	0.15
	Chi Ma Wan	0.09	0.18
100	Quarry Bay/North Point	0.09	0.16
	Tai Po Kau	0.15	0.29
	Tsim Bei Tsui	0.12	0.23
	Tai O	0.09	0.16
	Waglan Island	0.08	0.13
	Ko Lau Wan	0.10	0.17
	Chi Ma Wan	0.10	0.20
200	Quarry Bay/North Point	0.10	0.18
	Tai Po Kau	0.17	0.34
	Tsim Bei Tsui	0.13	0.26
	Tai O	0.10	0.18
	Waglan Island	0.08	0.14
	Ko Lau Wan	0.11	0.19
	Chi Ma Wan	0.11	0.22

Add Table 45 as follows:

Table 45 Design Allowance to Enhance Climate Resilience

Return Period (years)	Location	Design Allowance (m)			
		Year 2050		Year 2090	
		$\Delta_{\text{sea level rise}} + \Delta_{\text{storm surge increase}}$	$\Delta_{\text{wave effect}}$	$\Delta_{\text{sea level rise}} + \Delta_{\text{storm surge increase}}$	$\Delta_{\text{wave effect}}$
100	Quarry Bay / North Point	0.05	0.06	0.24	0.18
	Tai Po Kau	0.09	0.03	0.31	0.08
	Tsim Bei Tsui	0.07	0.04	0.26	0.07
	Tai O	0.06	0.05	0.23	0.18
	Waglan Island	0.05	0.02	0.21	0.10
	Ko Lau Wan	0.05	0.04	0.24	0.10
	Chi Ma Wan	0.07	0.02	0.25	0.09
200	Quarry Bay / North Point	0.05	0.07	0.25	0.22
	Tai Po Kau	0.10	0.04	0.34	0.16
	Tsim Bei Tsui	0.07	0.04	0.27	0.11
	Tai O	0.06	0.08	0.24	0.26
	Waglan Island	0.05	0.04	0.21	0.14
	Ko Lau Wan	0.06	0.04	0.25	0.22
	Chi Ma Wan	0.08	0.08	0.25	0.23

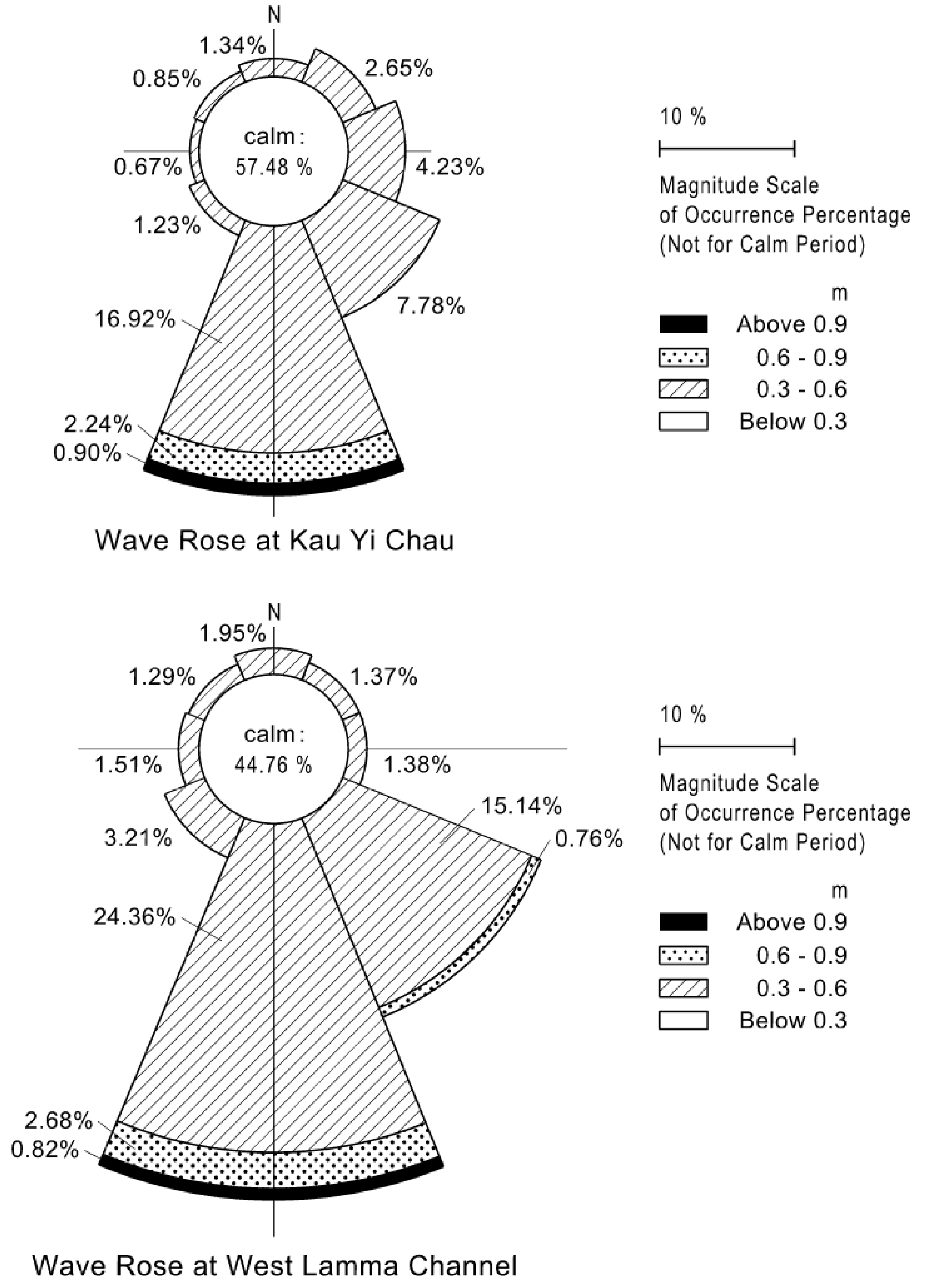
Note The design allowance values for the 100 year return period above are calculated by considering the envelop of the (i) extreme wave condition and storm surge increase at 100-year return period and extreme water level at 10-year return period, (ii) extreme wave condition and storm surge increase at 10-year return period and extreme water level at 100-year return period, and (iii) extreme wave condition and storm surge increase at 50-year return period and extreme water level at 50-year return period.

The design allowance values for the 200 year return period above are calculated by considering the envelop of the (i) extreme wave condition and storm surge increase at 200-year return period and extreme water level at 10-year return period, (ii) extreme wave condition and storm surge increase at 10-year return period and extreme water level at 200-year return period, and (iii) extreme wave condition and storm surge increase at 100-year return period and extreme water level at 100-year return period.

The design allowance given above is for the design of new coastal structures with paved land behind. For the design of new coastal structures with unpaved land behind, which is not common in nature, designers are advised to add the figures of 0.01m and 0.05m for 2050 and 2090, respectively, to the design allowance given above.

Median projection values are adopted in the table.

(l) FIGURES **Figure 7 is updated as follows:**



Notes:

1. Data Collection Period 2004 - 2020.
2. Wave heights with occurrence percentage less than 0.5% are not shown.
3. Wave data for 1994 - 2003 are not included because of the data inadequacy in wave direction.
4. Wave heights of calm period in wave roses are regardless of direction.

Figure 7 – Wave Rose at Kau Yi Chau and West Lamma Channel Wave Stations

(m) Appendix C – WORKED EXAMPLES	**Add the 2 examples to the Appendix after the example C.7 in following pages:**

C.8 CALCULATION OF DESIGN WATER LEVEL

Reference Sections 2.2.4, 2.2.5 and 2.2.6.

Given

A seawall located in the Inner Victoria Harbour is designed for use up to 2090.

Find

The 100-year and 10-year design water levels for checking seawall stability or overtopping under the combination of hydraulic conditions for an extreme event of about 100 years.

Solution

For a conservative design, return period of storm surge increase shall follow the return period of wave.

100-year design water level

100-year design water level = 100-year extreme sea level + sea level rise + 10-year storm surge increase

From Table 4, the 100-year extreme sea level at Quarry Bay / North Point is 3.91mPD.
From Table 42, the rise in sea level due to climate change for 2090 is 0.47m.
From Table 44, the 10-year storm surge increase at Quarry Bay / North Point for 2090 is 0.10m.

The 100-year design water level = 3.91mPD + 0.47m + 0.10m = 4.48 mPD

10-year design water level

10-year design water level = 10-year extreme sea level + sea level rise + 100-year storm surge increase

From Table 4, the 10-year extreme sea level at Quarry Bay / North Point is 3.20mPD.
From Table 42, the rise in sea level due to climate change for 2090 is 0.47m.
From Table 44, the 100-year storm surge increase for 2090 is 0.16m.

The 10-year design water level = 3.20mPD + 0.47m + 0.16m = 3.83 mPD

C.9 CALCULATION OF SEAWALL COPE LEVEL WITH CLIMATE RESILIENCE

Reference Section 2.9

Given

A vertical seawall located in the Inner Victoria Harbour has been designed to cater for wave, sea level and storm surge increase conditions with climate change effect up to 2090, after taking into account the relevant parameters given in Tables 3 to 30F and Tables 42 to 44. The minimum cope level is calculated to be +5.5mPD with paved land behind.

Find

If the land behind is unpaved in nature, the required design cope level of the seawall with climate resilience.

Solution

From Section 2.9, to further enhance the resilience against climate change for new coastal structures against possible higher Greenhouse Gas emissions scenarios, the design allowance shall be added to the design of marine works, unless infeasible.

From Table 45, a design allowance value can be chosen based on location and time horizon. Quarry Bay / North Point location provides the most representative conditions of Inner Victoria Harbour.

From Table 45, the design allowance at Quarry Bay / North Point in 2090 for 100-year return period event for paved land behind the structure = 0.24m + 0.18m = 0.42m.

Since the land behind is unpaved in nature, an additional figure of 0.05m is required to be added so the design allowance = 0.42m + 0.05m = 0.47m.

The design cope level for the seawall is +5.5mPD + 0.47m = +5.97 mPD.

(n) Appendix D - REFERENCE EXTREME SEA LEVELS AT QUARRY BAY/NORTH POINT AND TAI PO KAU	**Add Appendix D in the following page:**

APPENDIX D

REFERENCE EXTREME SEA LEVELS
AT QUARRY BAY/NORTH POINT AND TAI PO KAU

D.1 GENERAL

For design of important facilities which are vulnerable and sensitive to sea water level, e.g. E&M installations, designers may take into account the historical storm surge records before 1954 as far as practicable.

This Appendix provides the extreme sea levels at North Point/ Quarry Bay and Tai Po Kau derived from frequency analysis of extreme sea levels with longer data periods including pre-1954 records in tabular form and graphical form with 95% confidence interval curves as follows:

Table D1 Extreme Sea Levels at Quarry Bay / North Point with pre-1954 records (1874-2019)

Return Periods (years)	Sea Level (mPD)
2	2.81
5	3.03
10	3.20
20	3.41
50	3.74
100	4.05
200	4.42

Note: Tide gauge data period is (1954-2019). Historical records for significant storm surge events in 1874, 1923, 1936, 1937, 1949 and 1951 are included for analysis. Missing data are imputed by bootstrapping tide gauge tide below 3.15 mPD. The extreme sea levels at Quarry Bay/North Point were based on frequency analysis of non-instrumental data and instrumental data from 1874 to 2019 and adjusted by +0.07m to AR6 base year (1995-2014).

Table D2 Extreme Sea Levels at Tai Po Kau with pre-1954 records (1874-2019)

Return Periods (years)	Sea Level (mPD)
2	2.96
5	3.26
10	3.55
20	3.93
50	4.62
100	5.34
200	6.30

Note: Tide gauge data period is (1962-2019). Historical records for significant storm surge events in 1874, 1923, 1936 and 1937 are included for analysis. Missing data are imputed by bootstrapping below 3.55 mPD. The extreme sea levels at Tai Po Kau were based on frequency analysis of non-instrumental data and instrumental data from 1874 to 2019 and adjusted by +0.04m to AR6 base year (1995-2014).

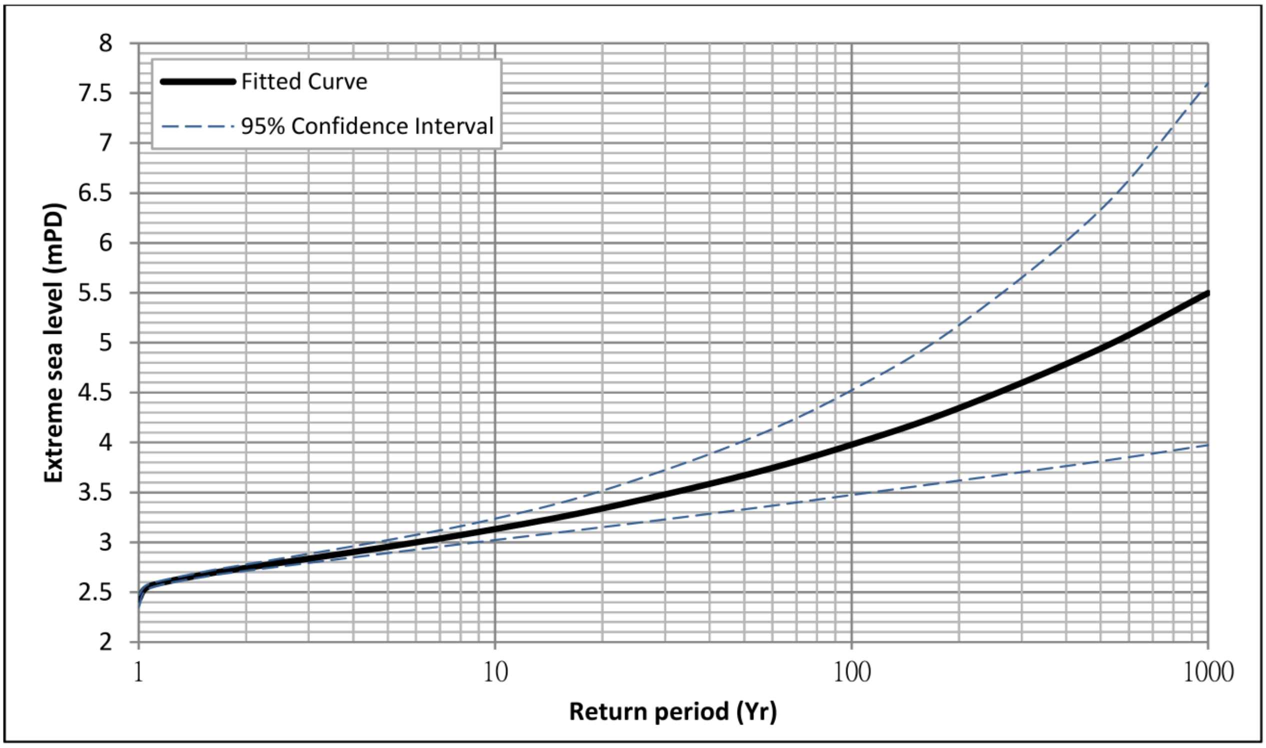


Figure D1 Extreme Sea Levels at Quarry Bay / North Point with pre-1954 records (1874-2019)

Note: For adopting the data of this figure, the user shall make adjustment to AR6 base year (1995-2014) by adding +0.07m of the data read in this figure.

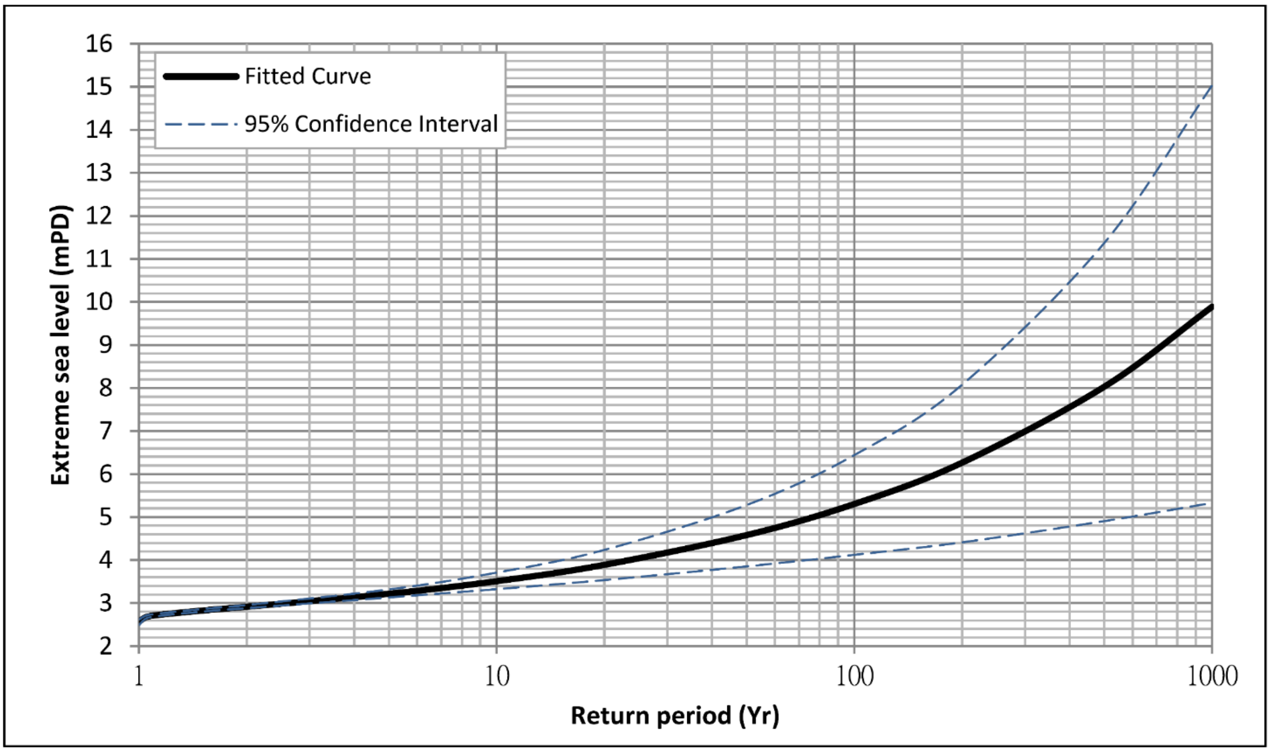


Figure D2 Extreme Sea Levels at Tai Po Kau with pre-1954 records (1874-2019)

Note: For adopting the data of this figure, the user shall make adjustment to AR6 base year (1995-2014) by adding +0.04m of the data read in this figure.