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Civil Engineering and Development Department

Agreement No. CE 74/2018(CE)

Study of Coastal Hazards under Climate Change and Extreme Weather and Formulation of Improvement Measures – Feasibility Study

Executive Summary

April 2022

Contents

1 Introduction

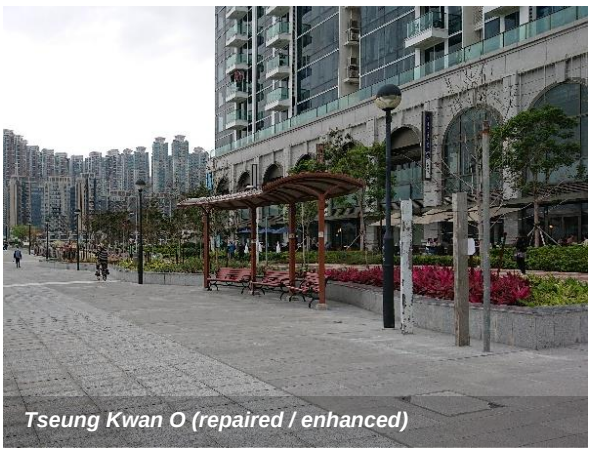
Background of the Study

The geographical position of Hong Kong makes it susceptible to adverse weather-related threats such as tropical cyclones, rainstorms, storm surges[1] and overtopping waves[2]. In particular, some coastal low-lying and windy locations are vulnerable to sea water inundation caused by extreme storm surges and overtopping waves, and have the facilities situated near the seaside damaged as a result.

The Super Typhoons Hato and Mangkhut hit Hong Kong in 2017 and 2018 respectively. Their storm surges and waves caused different extent of damages in some coastal areas of Hong Kong, for instance, some residential areas located in Eastern District of Hong Kong Island, Tseung Kwan O, Lei Yue Mun and Sai Kung. In addition, global warming has led to more frequent and intense extreme weather events around the world.

In April 2019, the Civil Engineering and Development Department (CEDD) commissioned AECOM Asia Company Limited (AECOM) to undertake the "Study of Coastal Hazards under Climate Change and Extreme Weather and Formulation of Improvement Measures – Feasibility Study" ("the Study").

Tseung Kwan O



Tseung Kwan O (repaired / enhanced)

[1] Storm surge is a rise of sea level due to the combined effects of low atmospheric pressure and high wind associated with tropical cyclones

[2] During the passage of tropical cyclones, waves approaching shores may surpass the coping level of seawall forming "overtopping wave"

Objective of the Study

The objective of the Study is to comprehensively review the condition of the coastal low-lying and windy locations in Hong Kong and carry out investigation of storm surges and waves in order to assess the impacts under extreme weather, taking into consideration future climate change projections, at these locations. Where appropriate, enhancement measures are formulated to alleviate these coastal hazards as far as practicable with reference to overseas and local practices and experience in climate adaptation and management.


Chai Wan


Chai Wan (repaired / enhanced)


Siu Sai Wan


Siu Sai Wan (repaired / enhanced)


Sai Kung


Sai Kung (repaired / enhanced)

2 Approach To Deal With Coastal Hazards

Hong Kong Shoreline

Coastal low-lying and windy locations in Hong Kong are vulnerable to attacks by extreme storm surges and overtopping waves. These are naturally occurring coastal processes resulting in coastal flooding and facilities damages along the shorelines that are referred to as coastal hazards as they have the potential impact on public safety and development along the shorelines.

Impacts from coastal hazards may have different degree of significance affected by coastal environment, e.g. geographical locations, coastal topography, bathymetry, coastal defence structures, etc. In assessing the capability of a coastal area to cater for storm surges and overtopping waves under climate changes effects, we need to get hold of the above aspects for adoption in subsequent analytical assessment.

Generally, the south and southeast sides of Hong Kong (e.g. Tseung Kwan O South) are more exposed to overtopping waves caused by more frequent approach directions of typhoons crossing the South China Sea. In comparison, wave generated from wind is relatively insignificant while storm surges plays more important role in Tolo Harbour (e.g. Lam Tsuen River, Tai Po), where the coastal geomorphology amplifies surge levels due to the embayment effect, and the north western New Territories due to the flat low-lying topography.

The situation (overtopping waves and flooding) during Super Typhoon Mangkhut in 2018 (Left) and the completed associated improvement measures (Right) were illustrated below:-

Siu Sai Wan (Siu Sai Wan Sports Ground)

Siu Sai Wan (Siu Sai Wan Sports Ground)
(New Flood Wall completed)

Tseung Kwan O (Tseung Kwan O Waterfront Park)

Tseung Kwan O (Tseung Kwan O Waterfront Park)
(New Wave Wall completed)

Tai Po (Nam Wan Road)

Tai Po (Nam Wan Road)
(New Demountable Flood Barrier completed)

Overseas Coastal Resilience Practices

Some overseas countries, such as United States, United Kingdom etc., have been historically hit by severe cyclones and caused severe coastal hazards. In response to their lessons learnt, these places have developed disaster management and adaptation measures. They have formulated guidelines to cope with coastal hazards. The key steps are to identify coastal areas exposed to coastal hazards; to identify key assets potentially impacted and the associated risks; and to identify practical and feasible options for enhancement.

The Study has made reference to their practices in coastal protection, climate vulnerability assessment [3] and management to recommend enhancement plans suitable for Hong Kong.

[3] The tolerance of potential impacts of wave attack and associated consequence in coastal areas

Climate Change Projection

The Earth's climate has been changing due to variation in sunlight, Earth's orbital changes, volcanic activity, etc. However, their effects have been overshadowed by that of the increasing atmospheric concentration of greenhouse gases (GHG) since the Industrial Revolution. Human-caused climate change has become one of major challenges of mankind.

Climate change is one of the factors influencing the above-mentioned coastal processes. Sea level rise (SLR) and intensification of wave and extreme storms exacerbate the effect of the coastal hazards. Increase in GHG concentration causes a reduction in the outgoing infrared radiation, allowing heat energy to accumulate on the Earth and leading to warming of the climate system.

Global climate may continue to change in future. The Intergovernmental Panel on Climate Change (IPCC) is the United Nations body which will provide scientific assessments on climate change, its implications and potential future risks, as well as adaptation and mitigation options.

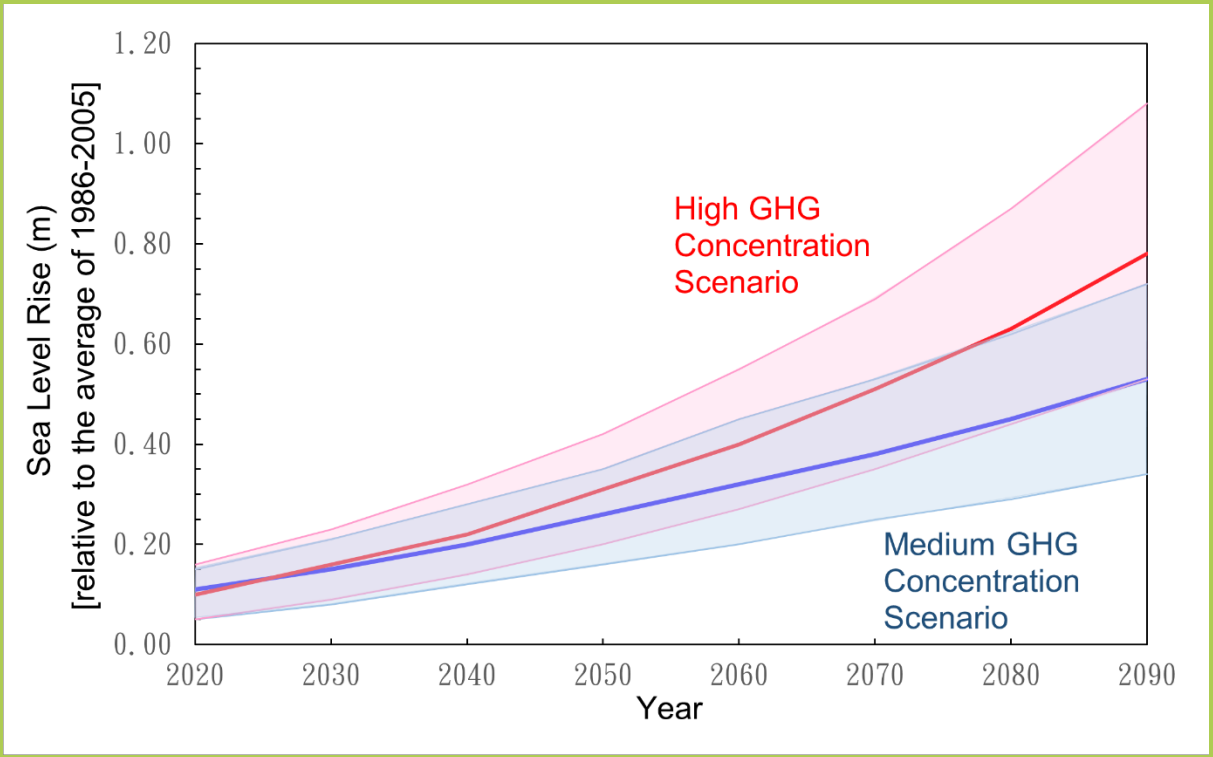
Climate change projections are developed based on a range of emissions scenarios. The IPCC Fifth Assessment Report (AR5) has considered four different pathways (RCP2.6, RCP4.5, RCP6.0 and RCP8.5) which referred to as Representative Concentration Pathways (RCPs) and these pathways are represented to low, [medium low, medium high] (medium) and high GHG concentration scenarios respectively.

Uncertainty of Climate Change

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 particularly towards the end of century and beyond. Depending on climate actions taken by global countries to reduce GHG emissions, development of climate change effects may follow different possible pathways in long-term future.

Nations have committed to take actions to reduce carbon emissions and implement climate mitigation as pledged under the Paris Agreement. In April 2021, the United States and China committed to cooperating with each other to tackle the climate crisis and to take further concrete actions to reduce emissions aimed at keeping the Paris Agreement-aligned temperature limit within reach. Subsequently, most nations (including the world's two biggest CO_2 emitters) have pledged to act in a joint declaration to take actions to reduce the GHG emissions in the 26th UN Climate Change Conference of the Parties (COP26) meeting in United Kingdom.

With reference to AR5 published by the IPCC[4], there is insignificant difference in SLR projection under medium GHG and high GHG concentration scenarios in mid-century whereas the difference is increasing significantly as time towards the end of century.



Reference: The Fifth Assessment Report of the Intergovernmental Panel on Climate Change

[4] IPCC has released global mean SLR projection in the Sixth Assessment Report (AR6) in August 2021. The global mean SLR at mid-century under the intermediate GHG emissions scenario in AR6 are comparable with the projections under medium GHG concentration scenario in AR5

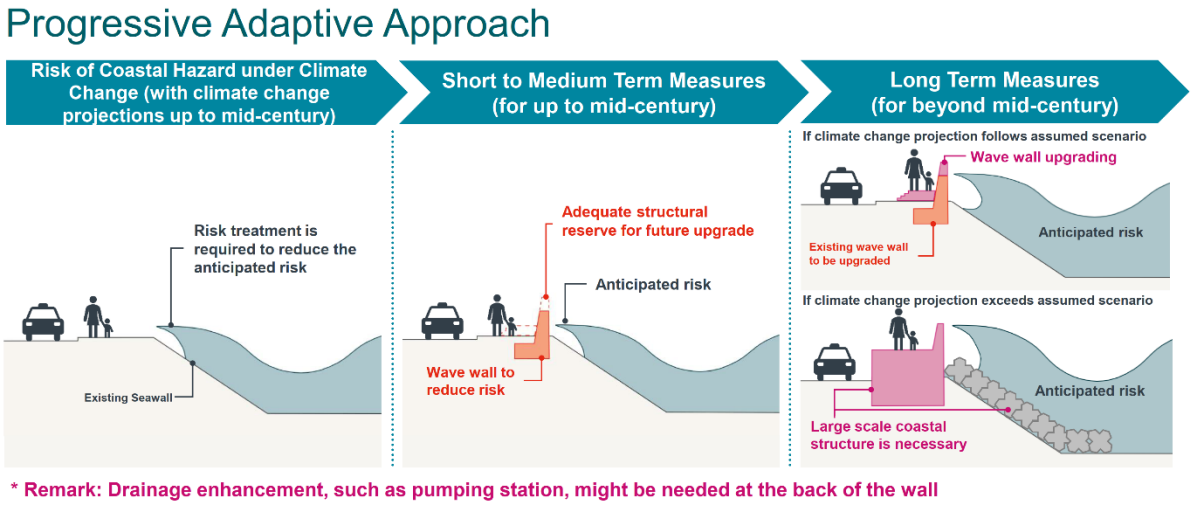
Strategy for Adapting to Coastal Risks

To combat climate change effectively, apart from materializing measures to reduce emission of GHG, we need to formulate strategy on climate change adaptation taking into account the coastal risks with a view to reducing the impacts on coastal and low-lying areas from extreme weather and strengthen the resilience of the community.

Progressive Adaptive Approach

Considering the uncertainties in the range of possible future climate change development and global actions among nations on reducing carbon emissions, this Study recommends to adopt a **progressive adaptive approach** to formulate climate adaptation measures for coastal low-lying and windy locations. 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, this Study recommends to adopt medium GHG concentration scenario (assumed scenario) established in IPCC to focus on devising enhancement measures up to mid-century (2050), and closely monitor long-term climate change projection. Planning and management of the implications of climate change on coastal hazards should therefore be carefully considered to appropriately account for the uncertainty.



According to the Port Works Design Manual, extreme events with return periods of 100 years should be considered in the design of typical coastal structures. In general, other places including United Kingdom, New York, United States and Mainland commonly adopt 100-year return period extreme events for design of coastal structures. Taking into account site constraints and environmental and social impacts, the Study recommends to adopt 100-year return period extreme event, as far as practicable, in designing the enhancement for existing marine structures in Hong Kong.

Where practical, this Study recommends to apply "**design allowance**" [5] in design of adaptation measures for coastal structures, with a view to further enhancing their resilience against climate change, including the possible differences in SLR predictions, increase in storm surge and wave height due to increase in wind intensity.

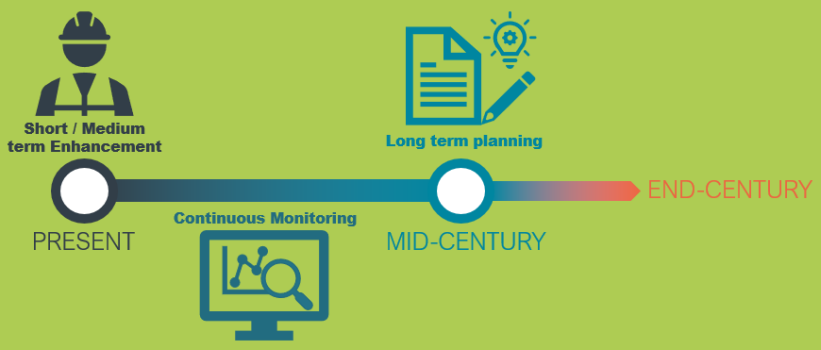
As part of progressive adaptive approach, this Study recommends to **continuously monitor the climate change and review the measures** to cope with coastal risks **in a timely manner**.

For **enhancement of existing coastal structures**, even if the climate change projection is more severe than the assumed scenario in **mid-century** (i.e. towards high GHG concentration scenario), the design allowance to be adopted by the Government could enhance the resilience of existing coastal structures.

If the long-term climate change to be predicted near mid-century follows the assumed scenario, modification (by means of heightening or strengthening) of the concerned coastal structures in a timely manner could generally enable them to cope with the extreme weather in **end of century**. If the long-term climate change to be predicted near mid-century is more severe than the assumed scenario, the Government should consider planning for larger-scale coastal protection measures to cater for the coastal risks in end of century. This approach could avoid implementation of large-scale mitigation measures prematurely at unnecessary construction and operation cost.

For **new coastal structures**, this Study recommends to reserve design allowance in design taking into account the design life of marine structures to enhance their resilience against possible higher GHG concentration scenario.

Making reference to overseas experience, this Study recommends to providing guidelines on planning and land use as well as formulating the related long-term strategies and defensive measures to enhance the Government and relevant stakeholders' ability to cope with climate change in Hong Kong.

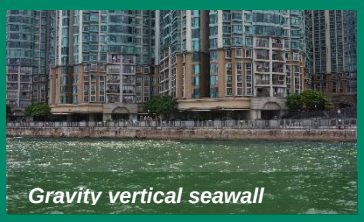


[5] Design Allowance: It reserves as an allowance for modification of design in future, e.g. designing sufficient foundation capacity for further raising height of wave wall, etc., if necessary.

3 Identification Of Coastal Areas To Be Enhanced

Review of Hong Kong Shoreline


Rubble mound sloping seawall


Gravity vertical seawall


Stilt houses along coastline


Riverside


Natural shoreline


Low-lying wetland

With its longer than 1,000km shore, including man-made coastlines, low-lying coastlines, beaches, riversides, natural shorelines, coastal high grounds, undeveloped shorelines, etc., Hong Kong is one of the major cities in Southeast Asia having longest coastlines. Though many coastal areas in Hong Kong are protected by coastal structures, they are experiencing risks caused by continuous climate change.

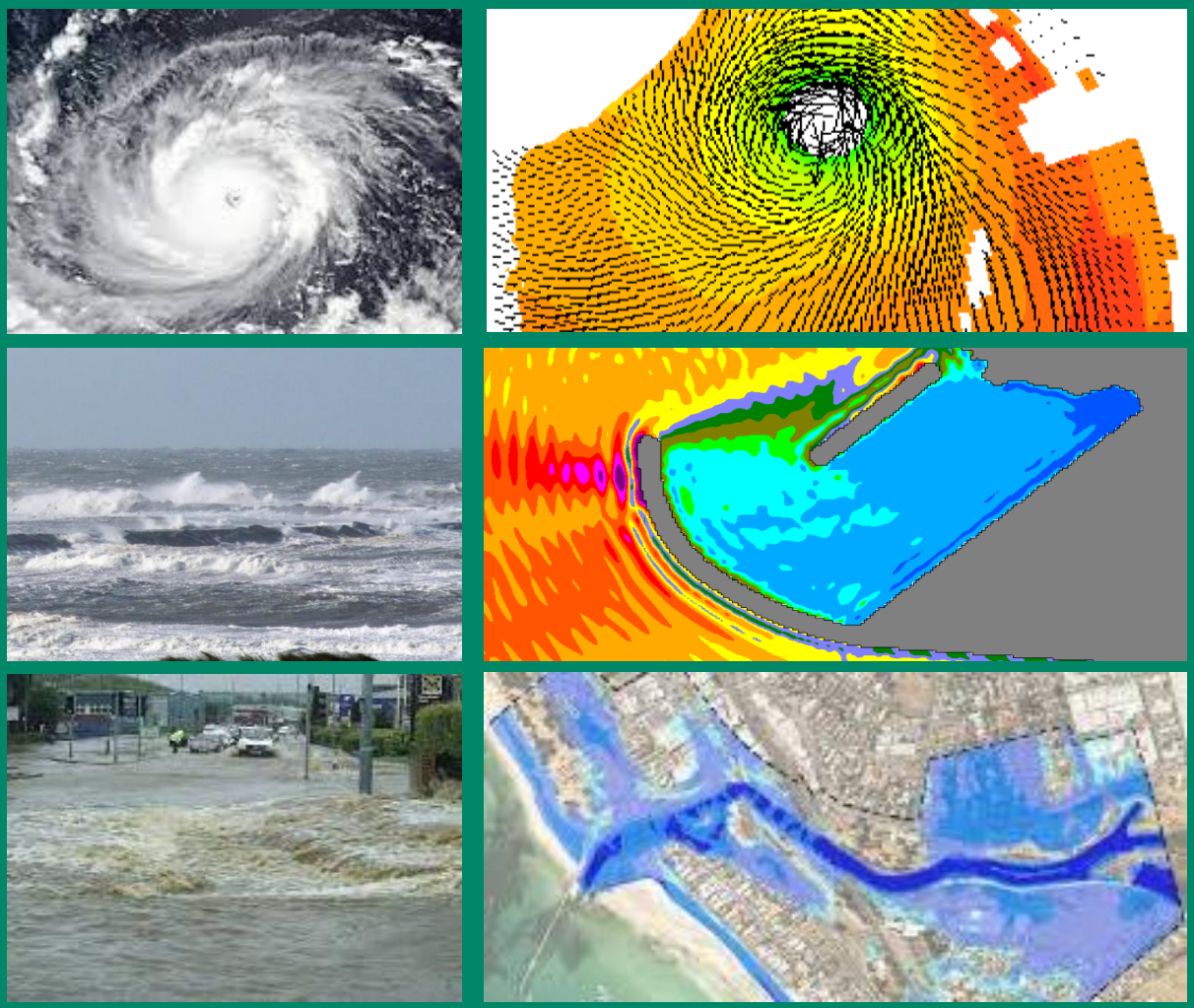
Hong Kong's existing shoreline comprises a variety of different coastline settings. Considering Hong Kong's geographic position, different topography, bathymetry and relevant coastal defence structures, etc. Some coastal areas are exposed to coastal hazards in different extent under extreme weather and climate change. Identifying those coastal areas susceptible to higher risks is primarily based on likelihood of coastal hazards and severity of consequence. During the analytical process, this Study has made reference to the records of damage posed by coastal flooding in past super typhoon attacks.

Analytical Assessment

We have applied computer models to simulate the sea water level and wave height with 100-year return period extreme events taking into consideration climate change projections up to 2050 under medium GHG concentration scenario.

We have collected data and information, e.g. coastal topography and bathymetry data, coastal defence structures, wind speeds, storm surge data, as-built records of marine structures, survey record plans, past coastal flood damage record etc., from the relevant government departments and organizations. We have also verified the information by means of site reconnaissance.

Considering the above data and information, we have conducted stability analysis of existing coastal structures, wave overtopping and coastal flood inundation analysis by means of computer modelling. This facilitates assessment of the potential impact and severity of consequences for coastal areas exposed to the coastal hazards.



Computer Simulation of Typhoon, Wave and Coastal Flooding

We have reviewed the existing seawalls susceptible to coastal risks. They could generally be able to withstand 100-year return period extreme weather taking into account climate change projections up to 2050.

According to our wave overtopping and coastal flood inundation analysis, the potential coastal risks at coastal areas of Hong Kong under extreme weather up to 2050 are identified as follows:

- Coastal flooding due to spreading of water from overtopping waves
- Damage of waterfront pavement due to overtopping waves
- Sea water inundation at low-lying areas

Coastal flooding due to spreading of water from overtopping waves

Damage of waterfront pavement due to overtopping waves

Sea water inundation at low-lying areas

Identified Areas Vulnerable to Coastal Risks

Under normal weather conditions, existing coastal structures along the shoreline of Hong Kong are generally adequate to safeguard coastal areas from coastal flooding at least up to 2050.

Following risk management approach, we first deal with those locations susceptible to higher risk with greater consequence. Most people will stay at home when typhoon strikes. To address the prime concern of human safety, coastal areas with residential developments vulnerable to potential coastal risks are identified, where priority should be accorded to formulate enhancement measures to alleviate the implications of extreme weather to the public and to enhance the resilience of the community.

This Study has identified 26 coastal low-lying and windy residential areas more vulnerable to higher potential risks during extreme weather with climate change projection up to 2050, which are shown in the diagram below:

4 Enhancement Plans

Major Considerations for Enhancement Options

We have taken into account the following 9 major considerations, such as limitation of space for construction works, irregularity of coastline with different levels, coastal enhancement works under construction and planning, such as Yuen Long barrage scheme, etc. in recommending enhancement plans for the coastal areas concerned.

Pragmatic Enhancement Measures

In view of the transient and high consequential nature of extreme weather, the Study has proposed to adopt a pragmatic approach in formulation of cost-effective enhancement plans that strike a right balance between potential coastal risks and practical mitigation solutions.

We need to consider practical and feasible situations to protect or reduce the coastal risks at the coastal areas in priority manner. However, not all coastal areas could be fully protected by engineering approaches of infrastructure enhancement ("Hardware") due to factors including site constraints, consideration of cost-effectiveness, and impact on marine traffic, social activities as well as environment. It is equally important to identify appropriate management measures ("Software"), including early alert system, emergency response, etc. to enhance the level of preparedness, response and resilience of the community to cope with the residual risks after the Hardware is in place.

Making reference to overseas and local experience and approaches, this Study recommends to adopt multi-layered enhancement measures to cope with extreme weather, which take the following advantages:

- More cost-effective and environmental friendly as compared with construction of mega infrastructure;
- Minimizing social impact;
- Making use of space near seafront, if available, as buffer areas; and
- Allowing flexibility for raising of wave walls later, if necessary.

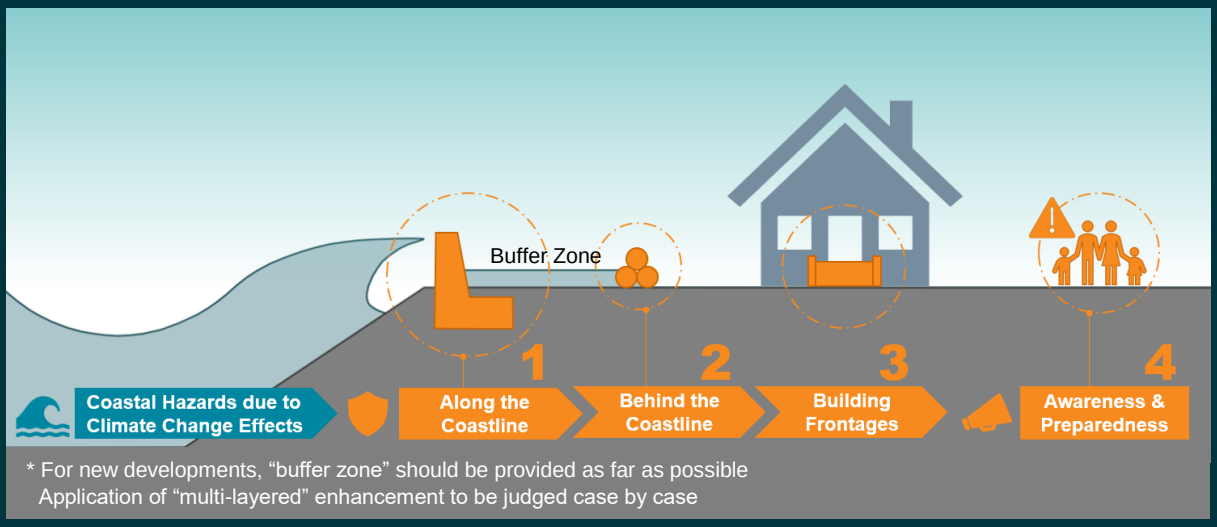
The **multi-layered** enhancement comprises:

(1) Constructing or raising wave walls along the coastline to reduce coastal hazards; and/or

(2) Installing fixed and/or demountable flood barriers at suitable places behind the coastline to cut off water pathway towards inland; and/or

(3) Installing demountable flood barriers or providing sandbags at building frontages.

(4) Adopt management measures to work with (2) and/or (3) above to enhance the awareness and preparedness of the public against extreme storm events, e.g. formulation of action plans on early alert system and emergency preparedness, provision of staff gauge, placement of water pump and warning signs.




(1) Construct/raise the wave wall


(2) Fixed / demountable flood barrier


(3) Demountable flood barrier

Coastal flooding problem cannot be solely resolved by layers (1) and (2) above in some coastal areas, in particular at low-lying areas. Residential units scattered along irregular low-lying coastline or riverside at different levels, or stilt houses abutting sea render construction of wave wall or installation of demountable flood barriers along the coastline (layers (1) and (2) above) not cost-effective nor practically feasible, or posing impact on public's activities. It is more practical to provide demountable flood barriers for self-protection of building frontages (layer (3) above) to alleviate the risk to public safety and their property loss against coastal flooding. Relevant stakeholders should also consider to improve drainage system (e.g. pumping facilities, backflow preventers, etc.) at suitable locations. This Study also recommends to continuously monitor and review the development of climate change and conduct further studies for enhancement measures in a timely manner.


Irregular coastline and scattered houses along coastline


Stilt houses abutting Sea

Summary of Recommended Enhancement Measures for Identified Existing Residential Areas

Identified Areas		Adaptation Measures			Management Measures
		Construct or raise the wave wall	Install flood barriers behind the coastline	Install flood barrier at building frontages	
1	Kennedy Town, Sai Ying Pun and Sheung Wan	✓	✓	-	✓
2	Heng Fa Chuen	✓	✓	-	✓
3	Shek O Village	-	✓	✓	✓
4	Pak Kan, Stanley	✓	-	-	-
5	South Horizons	-	-	-	✓
6	Tung Chung Bay (Ma Wan Chung Village, Sha Tsui Tau, Sha Lo Wan)	-	-	✓	✓
7	Tai O	✓	✓	✓	✓
8	Shap Long and Cheung Sha Lower Village, Lantau Island	✓	-	-	-
9	Ma Po Tsuen and Chung Hau, Mui Wo	✓	✓	✓	✓
10	Peng Chau West Areas (Nam Wan San Tsuen)	✓	✓	-	✓
11	Cheung Chau West Areas	✓	-	-	-
12	Yung Shue Wan, Lamma Island	✓	✓	-	-
13	Lei Yue Mun (Ma Wan Tsuen, Sam Ka Tsuen)	✓	✓	✓	✓
14	Sha Tau Kok Town (Chung Ying Street, Kong Ha)	-	✓	✓	✓
15	Kat O West Low-lying Areas (Kat O Fisherman Village)	-	-	✓	✓
16	Sam Mun Tsai New Village, Tai Po	-	-	✓	✓
17	Tai Po Market (near Lam Tsuen River)	-	✓	-	✓
18	To Tau Wan Village, Ma On Shan	-	-	✓	✓
19	Sai Kung Town Centre and Tui Min Hoi	✓	✓	✓	✓
20	Nam Wai /Heung Chung, Sai Kung	-	-	✓	✓
21	Tseung Kwan O South (Tseung Kwan O Waterfront Park)	-	✓	-	✓
22	Yuen Long Central Low-lying Areas (Tai Tseng Wai, Chung Hau Yu Man San Tsuen, Shan Pui Tsuen, Wang Chau, Yuen Long Town Centre)*	-	-	✓	✓
23	Yuen Long North West Low-lying Coastal Areas (Sha Kiu Tsuen, Fu Tso Tsuen, Lau Fau Shan, Hang Hau Tsuen, Sheung Pak Nai, Ha Pak Nai)	-	-	✓	✓
24	Luen On San Tsuen, Tai Lam	-	-	✓	✓
25	Kar Wo Lei, Tuen Mun	-	-	✓	✓
26	Sham Tseng San Tsuen	-	-	✓	✓

Remark:
1. Enhancement measures for 26 areas to be implemented in batches
2. Design details to be formulated for each area case by case
3. The global mean SLR at mid-century under the intermediate GHG emissions scenario in AR6 are comparable with the projections under medium GHG concentration scenario in AR5, for which the proposed enhancement plans are still considered to be applicable under AR6
4. * Yuen Long Barrage Scheme under planning and design has been considered. It will ease the flooding situation at the residential areas in Yuen Long Town Centre.

Possible Options for Enhancement Measures

Making reference to overseas and local experience, this Study recommends to consider different kinds of adaptation options to reduce the extent and degree of coastal impacts and management measures to heighten the public awareness of potential coastal hazards and flood prevention, enhancing the resilience of community and coastal areas. Nowadays, relevant government departments have formulated early alert systems and emergency preparedness measures to deal with extreme weather in particular locations. The emergency preparedness measures include notification to affected stakeholders, opening of temporary shelters, provision of sand bags and assistance in evacuation, etc.

Overseas Enhancement Measures

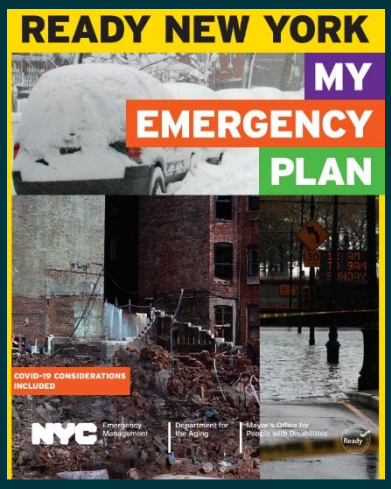
Wave wall

Flood wall

Demountable flood barrier around building

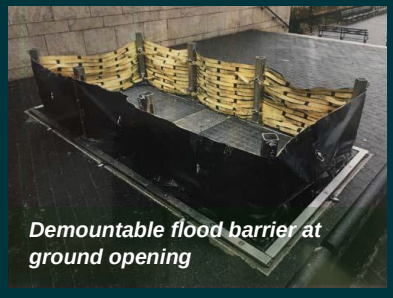
Demountable flood barrier at entrance/exit

Water-filled tube barrier



Emergency plan

Demountable flood barrier at open area



Demountable flood barrier at ground opening

Swing gate

Sliding gate

Demountable flood barrier

Local Enhancement Measures Implemented

Sai Kung – Wave wall

Tseung Kwan O – Pavement upgrade

Tai O – Demountable flood barrier

Yuen Long – Flood wall

Heng Fa Chuen–Planter wall

Water level indicator

Tai Po – Flap valve at culvert

Lei Yue Mun – Demountable flood barrier

Heung Chung – Non-return valve

Heng Fa Chuen – Demountable flood barrier

Warning sign

Implementation Strategy

Successful overseas experience in handling coastal hazards have demonstrated that mitigation of coastal hazards is not simply the government's responsibility but also requires preparedness by coastal residents, property owners and communities. This Study provides the relevant stakeholders the information of the dynamic nature of their environment, the coastal hazards that they are experiencing or will experience in future, and measures available to reduce vulnerability and maintain our future options for further enhancement. This information will be helpful for the relevant stakeholders to consider the required resources in deciding enhancement and management measures.

Taking into account the collaboration effort between relevant stakeholders, and requirements of statutory procedures in implementing the proposed enhancement measures, this Study expects that these measures could be implemented within 5 years in batches, alleviating coastal risks of the identified existing residential areas.

5 Recommendations & Way Forward

Recommendation on Follow-up Actions

- Implement design work and construction of improvement works
- Devise action plans for implementation of management measures
- Liaise / coordinate with the relevant government departments / private sectors / stakeholders for implementation arrangement

Recommendation for Further Planning

- Continuously monitor and review the development of climate change
- Review and update the relevant design standards and practices in a timely manner
- Conduct further studies for long-term planning and management of coastal protection