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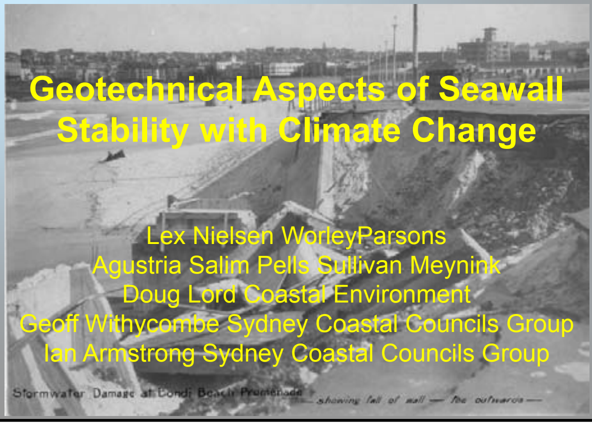
Geotechnical Aspects of Seawall Stability with Climate Change



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Geoff Withycombe Sydney Coastal Councils Group
Ian Armstrong Sydney Coastal Councils Group

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OUTLINE OF PRESENTATION

- Introduction
- Function and Types of Seawalls
- Geotechnical Failure Modes
- Climate Change Impacts
- Seawall Preliminary Assessment Form

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INTRODUCTION

- This project was undertaken by the Sydney Coastal Councils Group
- Funding provided by the Commonwealth Department of Climate Change and Energy Efficiency (DCCEE) through a Climate Adaptation Pathways (CAP) grant.
- The project was overseen by a National Reference Group comprising expertise from local government, state government, universities with coastal management expertise and industry specialists

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INTRODUCTION

Key elements of the project :

- Literature review of existing seawall types, remote sensing techniques, options for upgrading, certification requirements – WRL UNSW
- **Geotechnical assessment of structure types and common failure modes - WorleyParsons.**
- Economic aspects of the decision making process - Bond University under the direction of the Centre for Coastal Management (CCM) at Griffith University (GU).
- Field assessment utilised Ground Penetrating radar and air jetting to gain information on the structure of a buried seawall without disturbing the overlying dune and vegetation - UNSW.
- Three case studies: an open coast and an estuary seawall (WRL UNSW) and the current Gold Coast seawall (CCM GU).

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INTRODUCTION

- This paper deals with **geotechnical issues**
- Key indicators for in/appropriate structures
- Describes the function of a seawall/revetment
- Identifies primary failure modes and risks
- Identifyies geotechnical issues of stability and how these may change with climate change
- A pro forma checklist for key data that may be collected and added to an asset management system over time

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FUNCTIONS OF SEAWALLS/REVETMENTS

- A seawall:
  - Is a near vertical structure that retains the ground landward of the structure
- A revetment:
  - protects a stable slope from wave or current erosion or from wave inundation

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FUNCTIONS OF SEAWALLS/REVETMENTS

- Seawalls/revetments are located in a harsh environment:
  - breaking waves
  - relentless rise and fall of the tide
  - corrosive nature of seawater and salt spray
- Loadings are difficult to define:
  - random in nature
  - often exceeded over the design life
- Seawalls must be designed with maintenance in mind and with particular consideration given to the robustness of their fabric

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TYPES OF SEAWALLS/REVETMENTS

- massive or lightweight
- rigid or flexible
- vertical or sloping
- may comprise a wide range of materials including concrete, steel, timber, plastic, rock, stone-filled wire baskets and sand-filled geotextile bags

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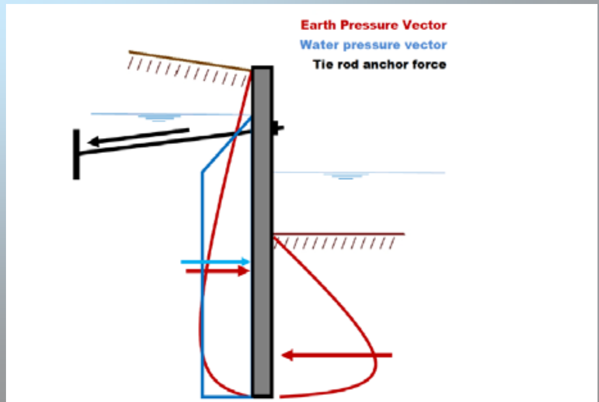
Types of Seawalls - Anchored Bulkhead



Earth pressure and hydrostatic loading schema for an anchored bulkhead

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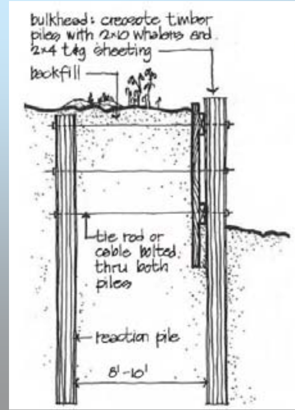
Types of Seawalls - Anchored Bulkhead



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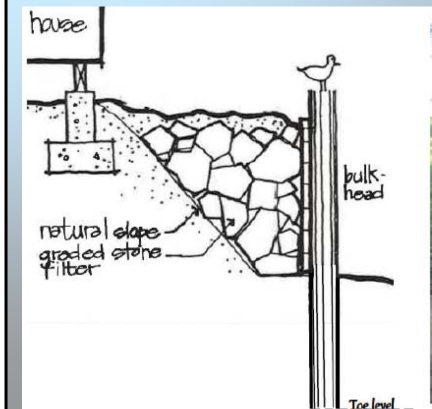
Types of Seawalls – Free Standing Bulkhead



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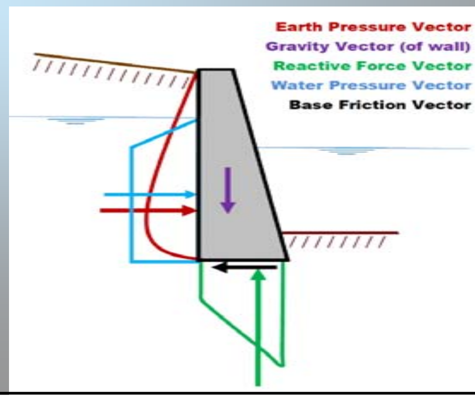
Types of Seawalls – Gravity Structure



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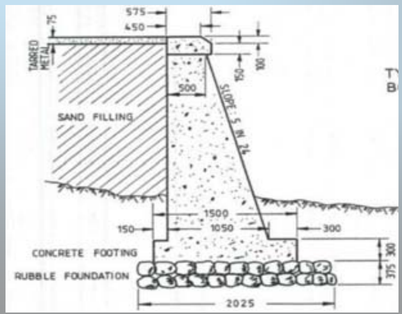
TYPES OF SEAWALLS
Concrete Gravity Seawall – Bondi & Bronte



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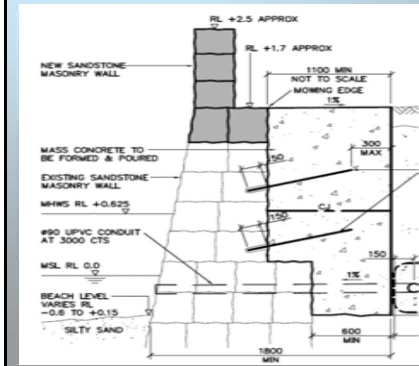
TYPES OF SEAWALLS
Blockwork Gravity Seawall



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TYPES OF SEAWALLS
Sandbag Gravity Seawall (Geofabrics Australasia)

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TYPES OF SEAWALLS
Rock Boulder (left) and Gabion (right) Gravity Seawall

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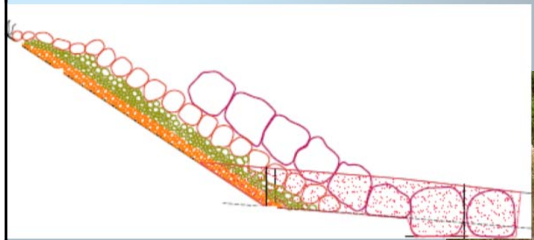
TYPES OF REVETMENTS
Rock Revetment

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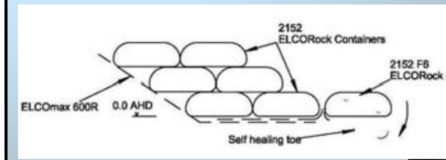
TYPES OF REVETMENTS
Sandbag Revetment Geofabrics Australasia



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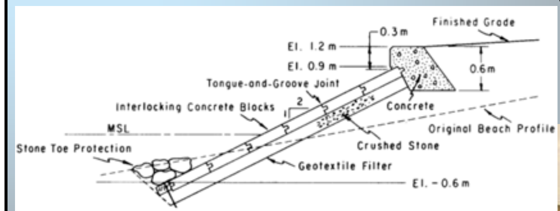
TYPES OF REVETMENTS
Rigid Sloping Revetment



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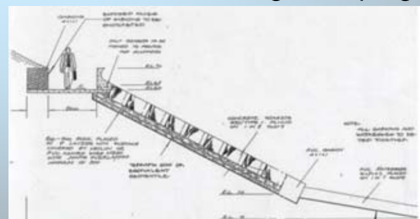
TYPES OF REVETMENTS
Semi-Rigid Sloping Pattern Placed Unit Revetment



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TYPES OF REVETMENTS
Flexible Reno Mattress Revetment

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TYPES OF REVETMENTS
Environmentally Friendly Revetments

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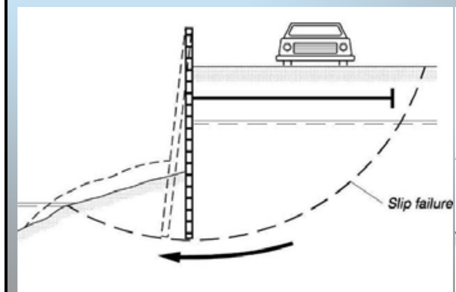
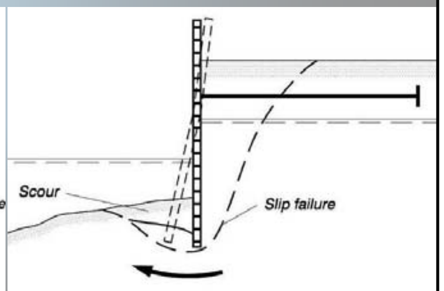
Geotechnical Failure Modes
Anchored Bulkheads - Rotational Slip Failure





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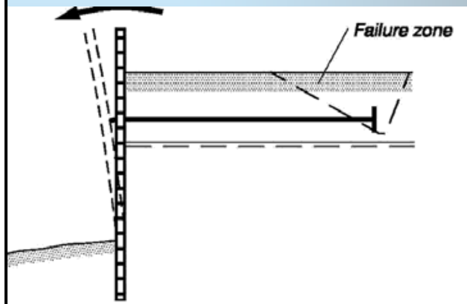
Geotechnical Failure Modes
Anchored Bulkheads – Anchor Pull-out Failure



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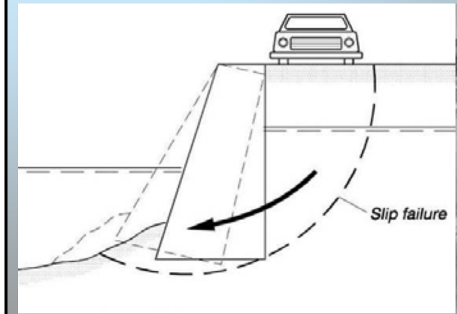
Geotechnical Failure Modes

Rigid Gravity Seawalls – Rotational Slip Failure



Rotation slip failure of counterfort gravity seawall resulting from toe erosion

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Geotechnical Failure Modes

Rigid Gravity Seawalls – Backfill Wash-out Failure

Loss of backfill of mass gravity seawall at South Bondi Beach 13th June 1974 as a result of toe scour and undermining of the footing

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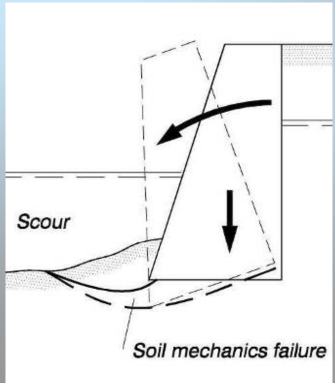
Geotechnical Failure Modes

Rigid Gravity Seawalls – Toe Bearing Failure



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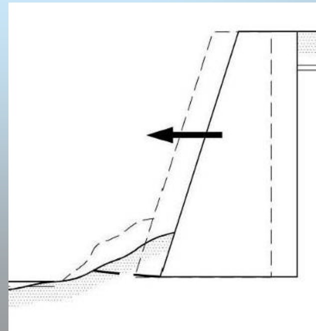
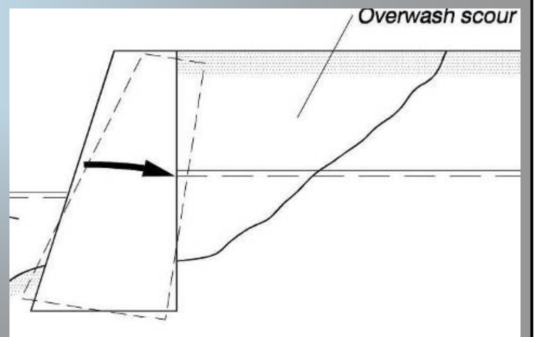
Geotechnical Failure Modes

Rigid Gravity Seawalls – Sliding and Overturning Failures





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Geotechnical Failure Modes

Blockwork Gravity Seawalls – Wave Overtopping Failure

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Geotechnical Failure Modes

Flexible Sandbag Revetment – Wave Overtopping and Bag Pull-out Failures (low Gtx/Gtx friction)

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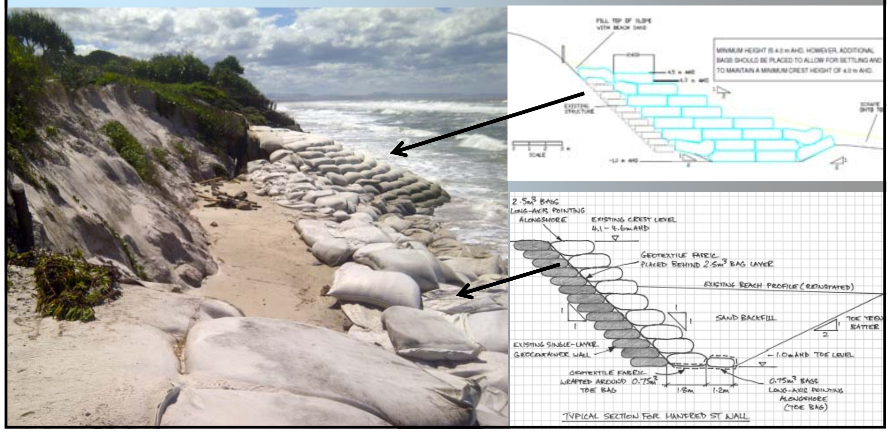
Geotechnical Failure Modes



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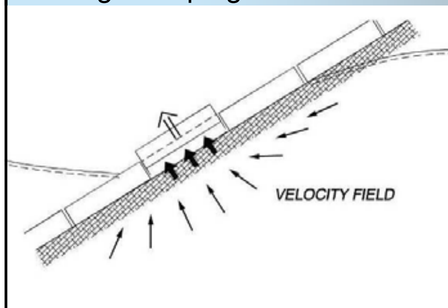
Geotechnical Failure Modes

Rigid Sloping Revetment – Push-out and Subsidence Failure



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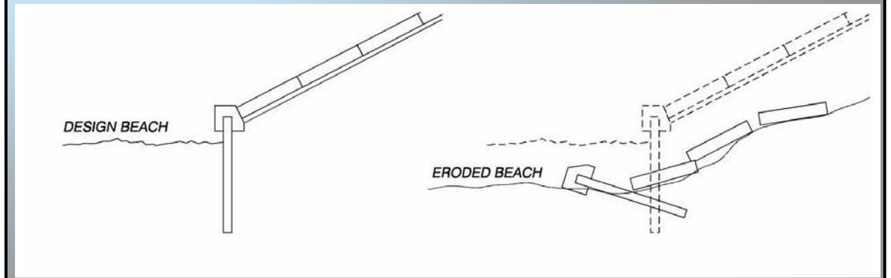
Geotechnical Failure Modes
Rigid Sloping Revetment – Toe Erosion Failure



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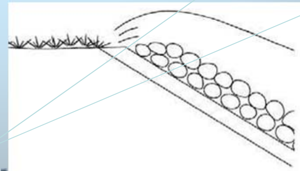
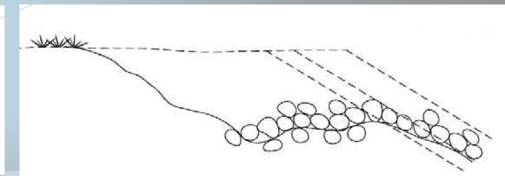
Geotechnical Failure Modes
Flexible Sloping Revetment – Overtopping Failure





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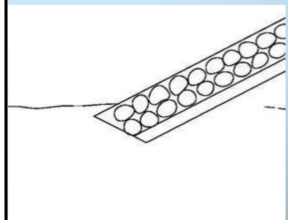
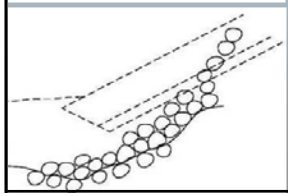
Geotechnical Failure Modes
Flexible Sloping Revetment – Toe Erosion Failure





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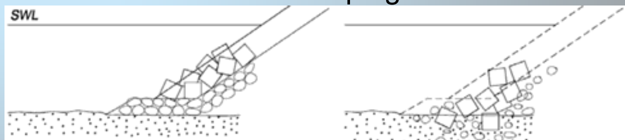
Geotechnical Failure Modes
Flexible Sloping Revetment –Subsidence Failure



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CLIMATE CHANGE IMPACTS

Climate Change Variables

- Key climate change variables are **mean sea level** and **wave climate** (*Guidelines for Responding to the Effects of Climate Change in Coastal and Ocean Engineering,* NCCOE, 2011).
- Changes to mean sea level can result in changes to bed levels, water depths, the incident wave climate and ground water levels.
- 1 m by 2100 would be significant in most locations
- A sea level rise is likely to:
  - increase nearshore wave heights (increasing nearshore water depths)
  - decrease freeboard on the crest levels thereby increasing the risk of wave overtopping
- Ground water levels also would rise commensurate with the sea level rise.
- Changes to the offshore wave climate can affect beach alignments, nearshore wave conditions and, hence, scour levels and wave impact forces.

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CLIMATE CHANGE IMPACTS

Effects of Climate Change

- The width of the beach berm fronting a promenade seawall would reduce.
- Increase in the frequency of wave impact onto seawall structures.
- Increasing incident wave heights as water depths increase.
- Increasing toe scour.
- Relative reduction in crest levels.
- Rise in ground water levels.

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CLIMATE CHANGE IMPACTS

- Increased wave heights would reduce the stability of revetment armouring and could cause the dislodgement of armour units and revetment failure.
- Increased toe scour could reduce overall wall stability, induce toe failures and slip failures.
- Increased water levels and wave heights could result in dangerous overtopping, crest failure of revetments and scour behind revetment and seawall structures. This could induce slip failures, overturning and bearing failures due to removal of backfill or increased hydrostatic loading
- Rise in ground water levels can increase overturning moments.

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CLIMATE CHANGE IMPACTS

Potential Remedial Works

- Constructing “falling toe” scour blankets for mass gravity seawalls.
- Extending toe protection for flexible revetments by increasing the extent and mass of the toe armour.
- Increasing armour size on flexible sloping revetments by placing an additional layer of larger units, building upon what is there already.
- Increasing revetment crest levels by placing armour on top or by constructing a wave deflector wall.

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PRO-FORMA (1)

SEAWALL PRELIMINARY ASSESSMENT FORM

DATE:		INSPECTED BY:	
LOCATION:			
GPS:			

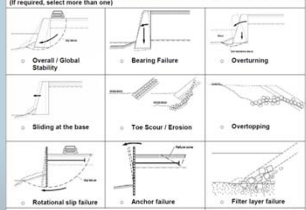
SEAWALL TYPE: (tick)
- ☐ Bulkhead Wall (i.e., sheetpile wall, pile)
- ☐ Rigid mass gravity seawalls (i.e., concrete wall)
- ☐ Flexible mass gravity seawalls (i.e., concrete block, sandstone blocks, rock blocks)
- ☐ Rigid / Semi-Rigid revetments (i.e., concrete slab elements)
- ☐ Flexible revetments (i.e., rock rubble revetment)
- ☐ Sandbag revetments
- ☐ Other:

DIMENSIONS & DETAILS OF THE SEAWALL: Record if it is an estimate or measure.
- Wall material (rock, sandbag, etc): ______
- Crest width: ______
- Toe width: ______
- Height of protection / Wall: ______
- Embedment depth: ______
- Slope angle: ______
- Wall element size (if any): ______
- Retained material (sand, clay, etc.): ______
- Filter behind wall (yes, no, NA): ______
- Other comments: ______

SKETCH:

OBSERVATION	YES/ NO/ NA	COMMENTS (i.e., size of cracks, distance from wall, movement, settlement, etc)
A. TOE CONDITION		
1. Is the material near the toe bulging out?		
2. Is the toe exposed from its embedment?		
3. Has rock armour been displaced?		
B. WALL CONDITION		
4. Has the wall element moved relative to other wall elements?		
5. Has the wall moved laterally away from the retained material?		
6. Has the wall tilted toward the sea?		
7. Has the wall tilted toward the land?		
C. TOP OF WALL CONDITION		
8. Has the wall settled excessively?		
9. Has any gap been observed between the wall and the retained material?		
10. Is the wall too low and the surface of retained material continuously wet due to high tide, or wave overwash?		
D. RETAINED MATERIAL CONDITION		
11. Has the surface of the retained material immediately behind the wall settled excessively or cracked?		
12. Has the surface of the retained material (i.e., 2 to 3 m away from the wall) settled or cracked?		
13. Is there any evidence of surface erosion?		
14. Is the surface drainage **not** working properly?		
15. Is there any localised settlement / collapse, or cavity behind the wall?		
16. Is the surface of the retained material (i.e., 2 to 3 m away from the wall) bulging out?		

Select the following images of the potential failure modes that best suit the site observation. (If required, select more than one)



POTENTIAL FAILURE MODE (BASED ON OBSERVATION ABOVE)	When "Yes" to any of the questions as numbered above:
○ Overall / global stability	1, 7, 11, 12
○ Bearing failure	1, 3, 6 or 7, 8
○ Overturning	2, 6, 9
○ Anchor or tie rod pull out	2, 6, 9, 16
○ Sliding at the base / dislodgement of blocks	3, 4, 5, 9
○ Internal erosion	3, 4, 9, 11, 14, 15
○ Toe Erosion / scour	2, 3
○ Overtopping / overwash scour	9, 10, 11, 13, 14, 15

Other comment (i.e., structural condition of the wall, corrosion, spalling, vandalism, etc.)

Is further assessment by a geotechnical consultant required? (Y/N)	
Is any remedial action / work needed to be undertaken immediately? (Y/N)	
If known, what is the remedial action required?	

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PRO-FORMA – PAGE 1 (top)

SEAWALL PRELIMINARY ASSESSMENT FORM

DATE:		INSPECTED BY:	
LOCATION:			
GPS:			

SEAWALL TYPE: (tick)
- ☐ Bulkhead Wall (i.e., sheetpile wall, pile)
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- ☐ Other:

DIMENSIONS & DETAILS OF THE SEAWALL: Record if it is an estimate or measure.
- Wall material (rock, sandbag, etc): ______
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- Toe width: ______
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- Embedment depth: ______
- Slope angle: ______
- Wall element size (if any): ______
- Retained material (sand, clay, etc.): ______
- Filter behind wall (yes, no, NA): ______

SKETCH:

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PRO-FORMA – PAGE 1 (bottom)

OBSERVATION	YES/ NO/ NA	COMMENTS (i.e., size of cracks, distance from wall, movement, settlement, etc)
A. TOE CONDITION		
1. Is the material near the toe bulging out?		
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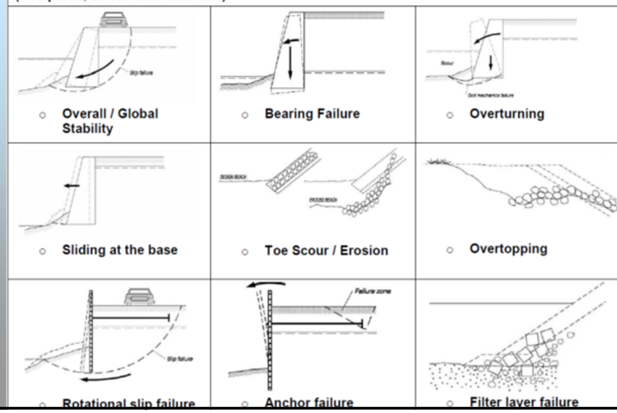
PRO-FORMA - PAGE 2 (top)

Select the following images of the potential failure modes that best suit the site observation. (If required, select more than one)



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PRO-FORMA - PAGE 2 (bottom)

POTENTIAL FAILURE MODE (BASED ON OBSERVATION ABOVE)	When "Yes" to any of the questions as numbered above:
○ Overall / global stability	1, 7, 11, 12
○ Bearing failure	1, 3, 6 or 7, 8
○ Overturning	2, 6, 9
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○ Overtopping / overwash scour	9, 10, 11, 13, 14, 15
Other comment (i.e., structural condition of the wall, corrosion, spalling, vandalism, etc.)	
Is further assessment by a geotechnical consultant required? (Y/N)	
Is any remedial action / work needed to be undertaken immediately? (Y/N)	
If known, what is the remedial action required?	

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and thanks to Deborah Lam and
Chris Adamantidis for many of the photographs

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