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Enhancing Society Together

MarCom WG205

Design and Construction of Breakwaters on Soft Seabeds

PIANC-RHD-PP-001

Open

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28 August 2024

WG205

- PIANC Maritime Commission (MarCom) WG205 formed in September 2019.
- Working Group had over 25 people from 11 countries contributing.
- Group Leadership
  - Yoichi Watabe (Hokkaido Uni) – Chair
  - Hidenori Takahashi (Port and Airport Research Institute) – Secretary
- Report is now undergoing peer review ahead of publication.

Report Cover

Terms of Reference

- Investigate the geotechnical issues relating to breakwaters on soft soils.
- Focus on the replacement and base reinforcement approaches like gravity replacement, sand mattresses and geosynthetics, and ground improvement. Static and dynamic stability of breakwaters with and without basal reinforcement and anticipated consolidation settlement of breakwaters.
- For developing countries the high cost of construction is a major issue. The report shall provide guidance on breakwater design and construction on soft sediments that can be undertaken in a cost-efficient manner.
- Climate change impacts to be considered.

Caisson Installation Japan

Relevant UN Sustainable Development Goals

- The construction of breakwaters on soft sediments document facilitates many UNSDG's.
- Directly:

  4. Quality education – The document provides professional guidance.

  9. Industry, Innovation and Infrastructure – Guides resilient design.

  14. Life below water – Guidance on data collection to inform assessment and mitigation.

- *Indirectly:*

  1. No Poverty – Facilitating trade and economic growth with properly designed port infrastructure, particularly relevant in underdeveloped nations.

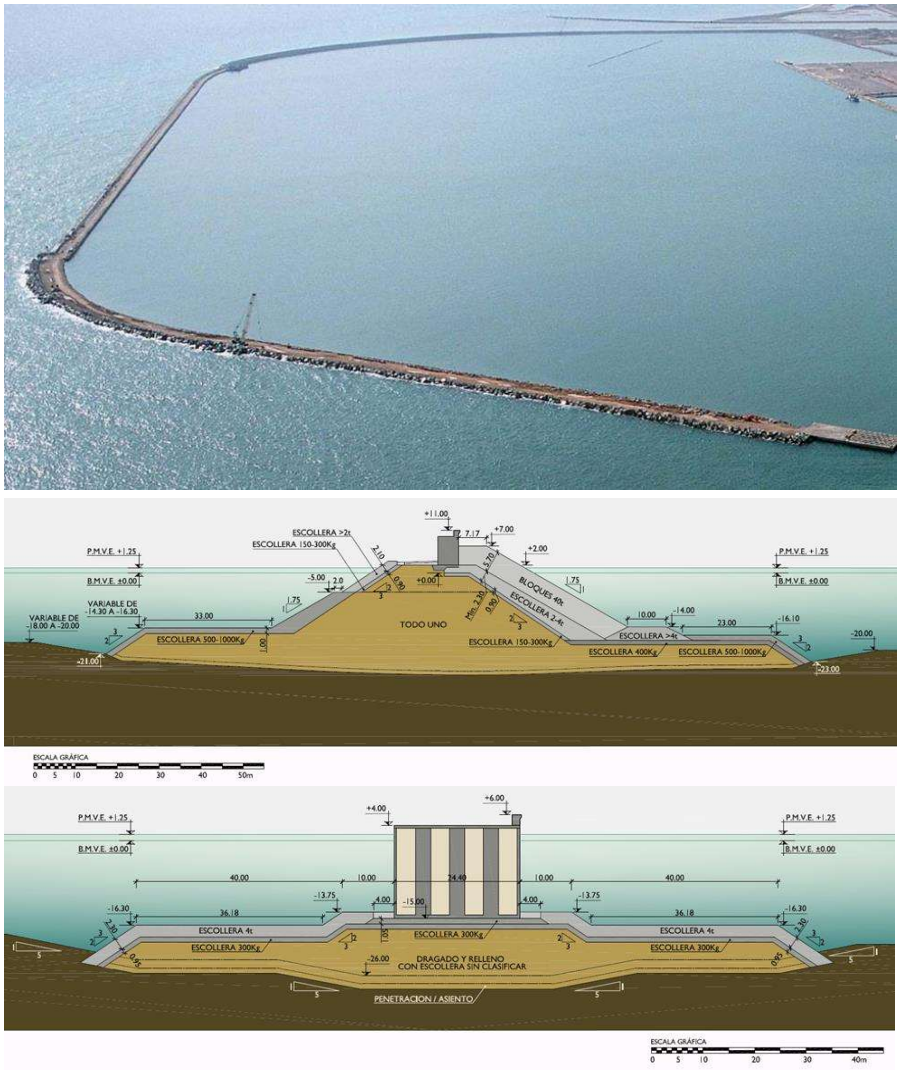
  8. Decent work and economic growth - As per 1.

  10. Reduce inequality – As per 1.

  12. Responsible consumption and production – Facilitates intelligent and rational use of resources.

Report Content

- Characterisation of soft sediments including data collection and analysis.
- Different types of breakwaters looking at
  - Design considerations
  - Construction considerations
- Existing codes, standards and guidelines
- Analysis of stability and settlement
- Ground improvement techniques
- Monitoring



Mixed rubble mound and caisson breakwater (Barcelona)

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Characterisation of Soils

Soft soils include fine grained and organic soils with low undrained shear strength as well as loose sands.

- Where we might expect to find soft soils and issues likely to be encountered.
- Staging of investigations and what investigations may be required.
- Sampling techniques and when they should be considered. (extensive list)
- Analysis samples – what and why.

Table 2-10 Consistency of Clay in Terms of Unconfined Compressive and Shear Strength

Consistency	Unconfined Compressive Strength (q_u)	Undrained Shear Strength (C_u)
Very Soft	<25 kPa	<12 kPa
Soft	25 to 50 kPa	12 to 25 kPa
Medium	50 to 100 kPa	25 to 50 kPa
Stiff	100 to 200 kPa	50 to 100 kPa
Very Stiff	200 to 400 kPa	100 to 200 kPa
Hard	>400 kPa	>200 kPa

Table 2-9 Porosity, Void ratio, Density, Unit weight of Typical Soils in Natural State

Description	Porosity n (%)	Void ratio e	Water content w (%)	Density (tonne/m³)		Unit Weight (kN/m³)	
				ρ_d	ρ_{sat}	γ_d	γ_{sat}
Uniform sand loose	46	0.85	32	1.43	1.89	14.0	18.5
Uniform sand dense	34	0.51	19	1.75	2.09	17.2	20.5
Mixed grain sand loose	40	0.67	25	1.59	1.99	15.6	19.5
Mixed grain sand dense	30	0.43	16	1.86	2.16	18.2	21.2
Very mixed grain	20	0.25	9	2.12	2.32	20.8	22.7
Soft inorganic clay	55	1.2	45		1.77	12.0	17.4
Stiff inorganic clay	37	0.6	22		2.07	16.7	20.3
Soft slightly organic clay	66	1.9	70		1.58	9.1	15.5
Soft very organic clay	75	3.0	110		1.43	6.7	14.4
Soft bentonite	84	5.2	194		1.27	4.2	12.5

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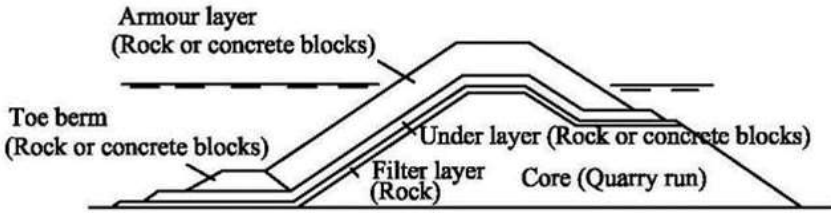
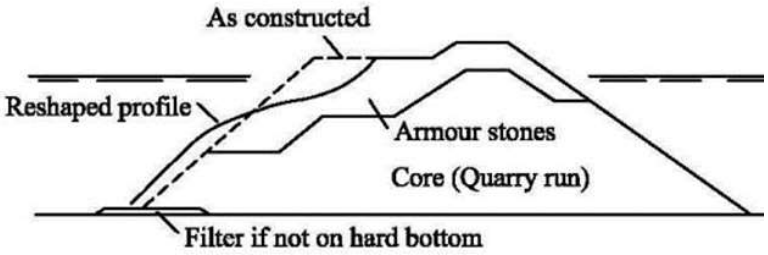
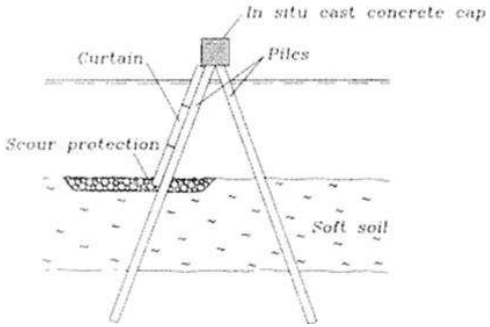
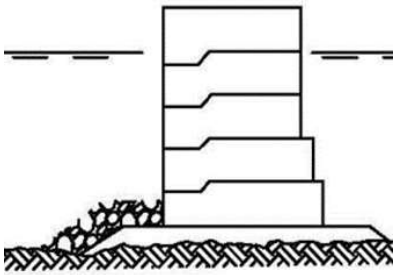
Breakwater Types (Options)

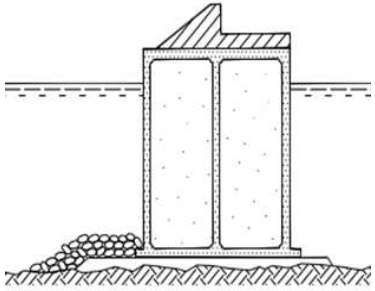
- Rubble mound – single layer, conventional and reshaping.
- Caisson – conventional, high foundation perforated face and suction.
- Blockwork
- Piled
- Wide base plate
- Floating

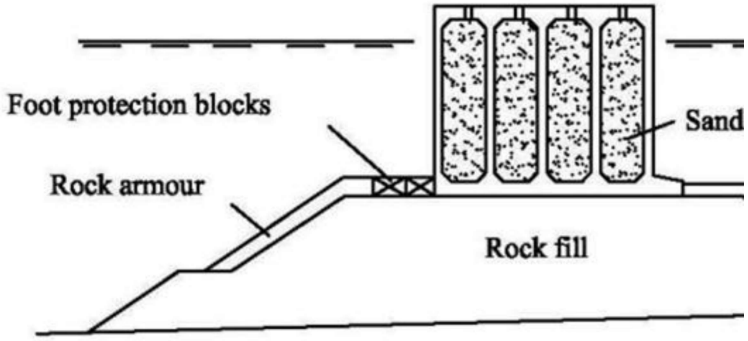












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Breakwater Types (Selection)

- Design Considerations
  - Selection criteria (for soft soils)
  - Loading types and associated soil-structure
  - Failure modes on soft soil
  - Modelling of fluid-soil-structure interaction
- Construction Considerations
  - Construction methodology and impact on design
  - Role soil conditions have on materials and construction

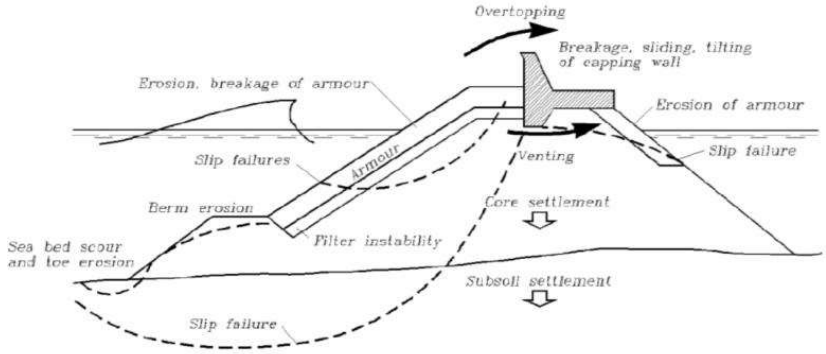

Figure 3.7 Standard rubble mound failure modes (Burcharth, 1992)

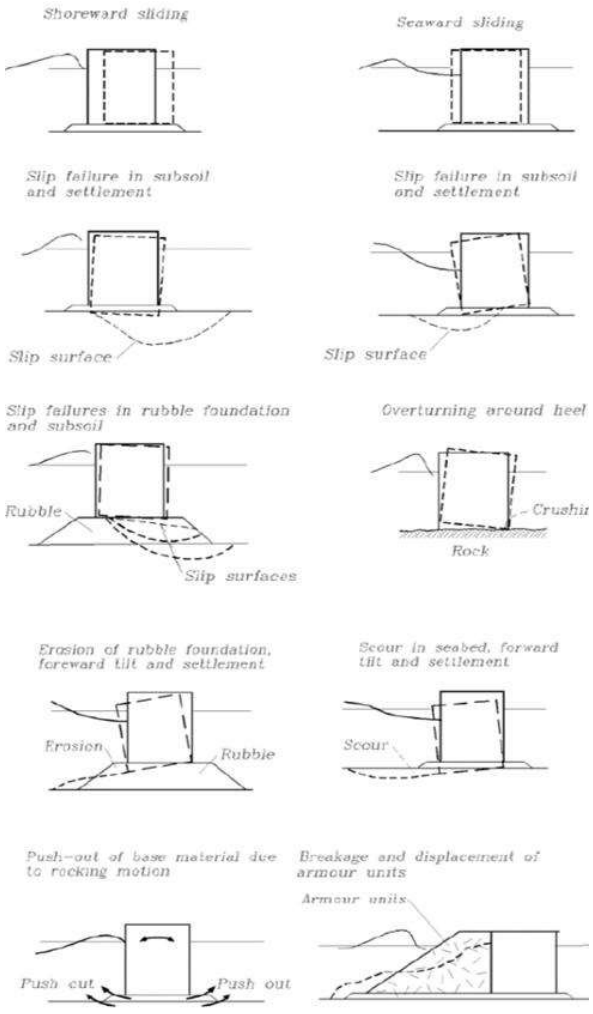

Figure 3.6 Failure modes for a conventional caisson breakwater (PIANC WG 28, 2003)

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Codes and Standards

The report directs readers to existing reference material to assist in design.

- Codes of Practice including PIANC reports and internationally recognised manuals.
- National standards from around the globe.
- Provides guidance on references for:
  - Limit state vs. Performance based design
  - Environmental design parameters
  - Soil investigations, geotechnical design and seismic
  - Reclamation and dredging.

PIANC Report No.2	The stability of rubble mound breakwaters in deeper water	1985
PIANC Report No.12	Analysis of rubble mound breakwaters	1992
PIANC Report No.21	Guidelines for the design and construction of flexible revetments incorporating geotextiles in marine environment	1992
PIANC Report No.23	Site investigation requirements for dredging works	2000
PIANC Report No.28	Breakwaters with vertical and inclined concrete walls	2003
PIANC Report No.40	State-of-the-art of designing and constructing berm breakwaters	2003
PIANC Report No.113	The application of geosynthetics in waterfront areas	2011
PIANC Report No.144	Classification of soils and rocks for the maritime dredging process	2017
PIANC Report No.196	Criteria for the selection of breakwater types and their related optimum safety levels	2016

Table 5-1 International Codes of Practice/Standards for Maritime Works/Breakwaters

Code Suffix	Document Title	Origin	Subject									
A = detailed/very useful B = moderately useful C = some limited detail 0 = not included			General Maritime Design	Safety Levels Design Life, Reliability	Actions (General)	Actions (hydraulic)	Partial factors	Probabilistic design methods	Geotechnical design methods	Seismic design methods	Foundation design	Ground Improvement
BS 6346	BS 6349: Code of Practice for Maritime Works	UK	A	A	A	A	A	C	C	C	C	C
OCDI	Technical Standards and Commentaries for Port and Harbour	Japan	A	A	A	A	A	B	A	A	A	B

Stability and Settlement Analysis

This is a complex area and the assessment of settlement and stability with soft soils requires professional geotechnical input. As such, the report offers only a high-level exploration of geotechnical calculations with references to relevant sources.

- Stability analysis
  - Soil strength and modelling of soil.
  - Failure modes for different types of breakwaters including bearing capacity, sliding, overturning and slope stability.
- Settlement analysis.
- Dynamic analysis looking at wave and seismic loading.

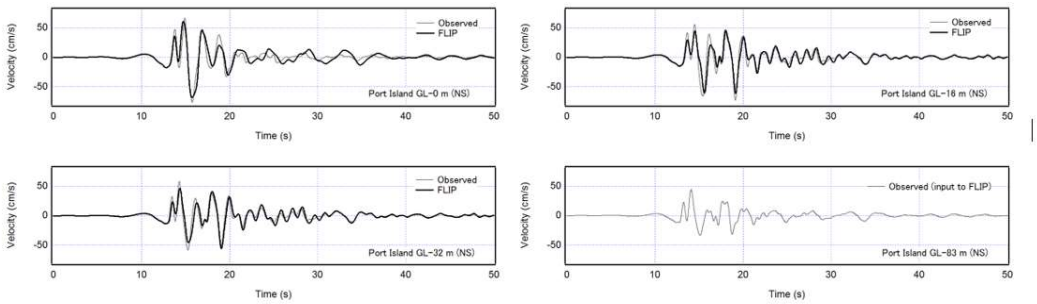

Figure 6.3 Application of FLIP to the vertical allay records at Port Island in Kobe Port during the 1995 Nanbu earthquake

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Ground Improvement Techniques

The report contains extensive practical advice on numerous methods to manage soft soils, exploring considerations in construction and ground improvement methods.

Ground improvement methods explored:

- Staged Construction.
- Ground replacement
- Ground removal by displacement
- Consolidation acceleration
- Dynamic compaction
- Stone or sand columns
- Soil mixing
- Geosynthetics – reinforcement
- Compaction by blasting
- Micro-piling

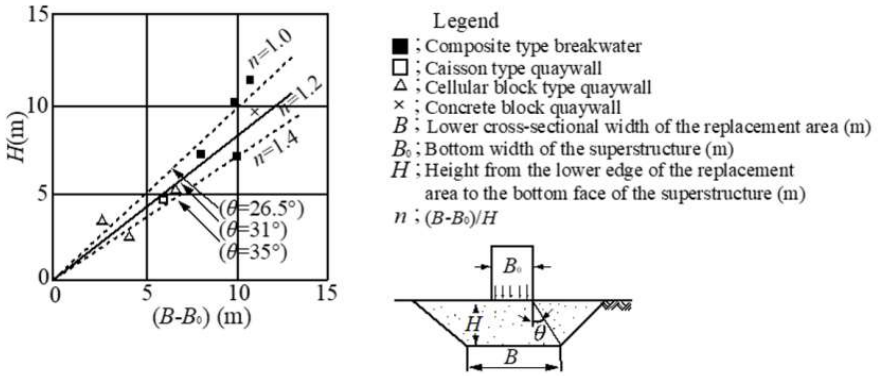

Figure 7.4 Relationship between Replacement Widths and Depths

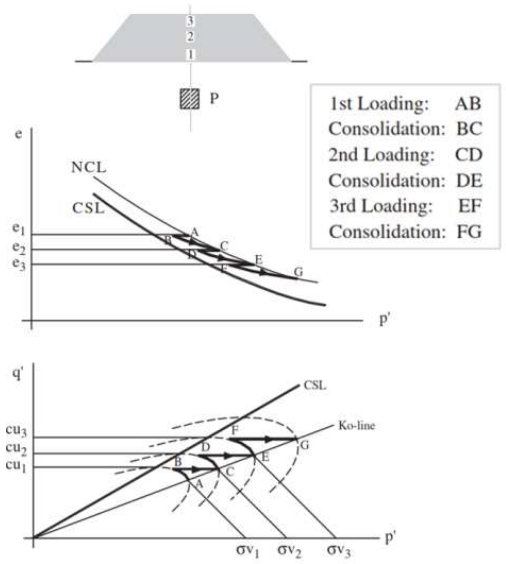

Figure 7.2 Principle of staged construction

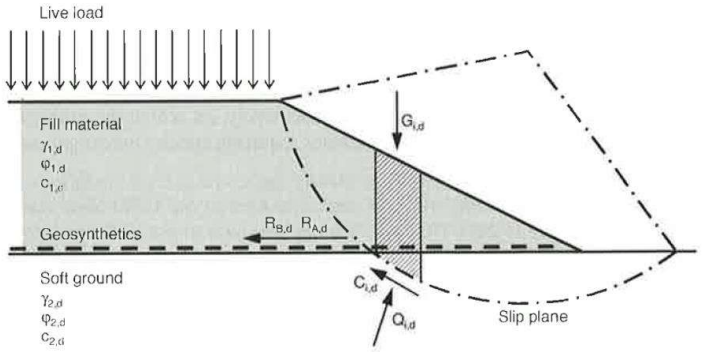

Figure 7.28 Analysis of global stability with intersected reinforcement (after EBGEO (2011),

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Monitoring

- Monitoring during construction
  - Explores monitoring methods in this early phase
  - How the data is used to manage risks.
- Settlement and consolidation analysis
- Reference projects provide useful examples

Table 8-3 List of field observation items and equipment

Field observation item	Description	Equipment
Ground settlement	Observation and verification of the progress of consolidation during construction Setting of the earth fill crown heights according to the amount of settlement Setting of the consolidation ground constants	CB settlement plate Hydraulic type settlement gauge Stratified settlement gauge Piezometer
Stability of structure (revetment, etc.)	Confirmation of the increases in ground strength and determination of the availability of additional earth fill reclamation through stability analysis Examination of revetment stability using a stability management chart Continuous observation of the behaviour of earth fill ground using real time GPS	RI-CPT Clinometer Observation of displacement using GPS
Long-term settlement predictions	Utilisation of the observation data for predictions of long-term settlement and analysis of the increases in ground strength	GPS bathymetric survey Earth pressure gauge

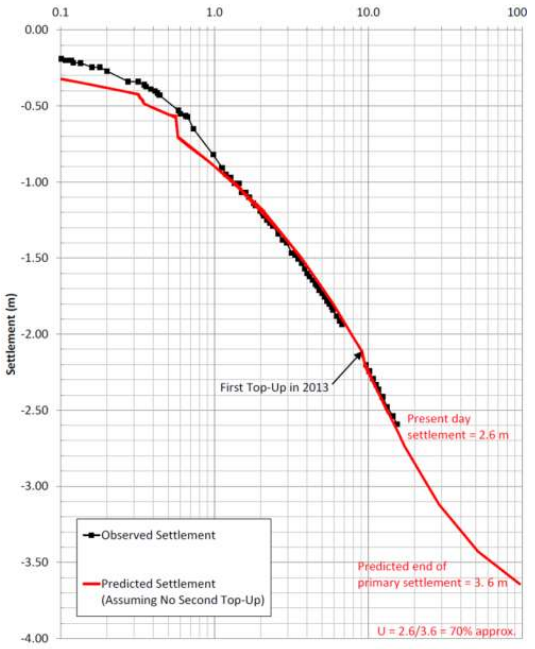
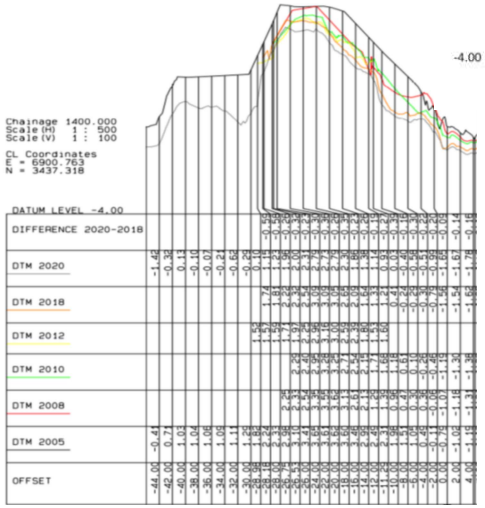


Figure B.11 Measured settlment over time (East Bund)



Port of Brisbane
Future Port Expansion

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When and Why

Available soon

- Report is with Maritime Commission (MarCom) for Peer Review.
- Anticipate PIANC to make available to members later this year.

Who should be excited

- The report provides a valuable reference for all stages of projects:
  - Planning
  - Design
  - Construction
  - Maintenance
- More than breakwaters
  - Breakwaters
  - Reclamation
  - Seawalls

Questions?

Jaywick Sands, Essex

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