Building Materials in Dredging , Maritime and Waterfront Construction

Ir. Bernard Malherbe

Jan De Nul Group

Types of Infrastructures & Constructions

Breakwaters

Seadikes & Riverdikes

Bank- & Reclamation confinment/revetment

Reclamations

Quay-walls

Locks

Pumping culverts

Berthing structures (dolphins,…)

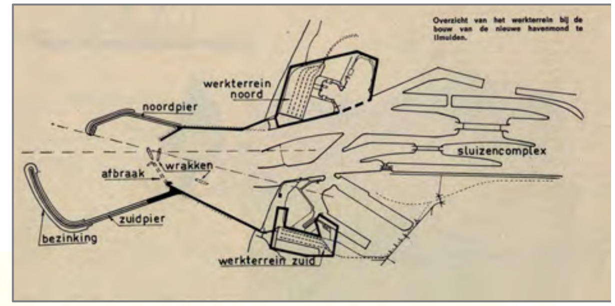
Sinkers

Pipe – and cable-landfalls

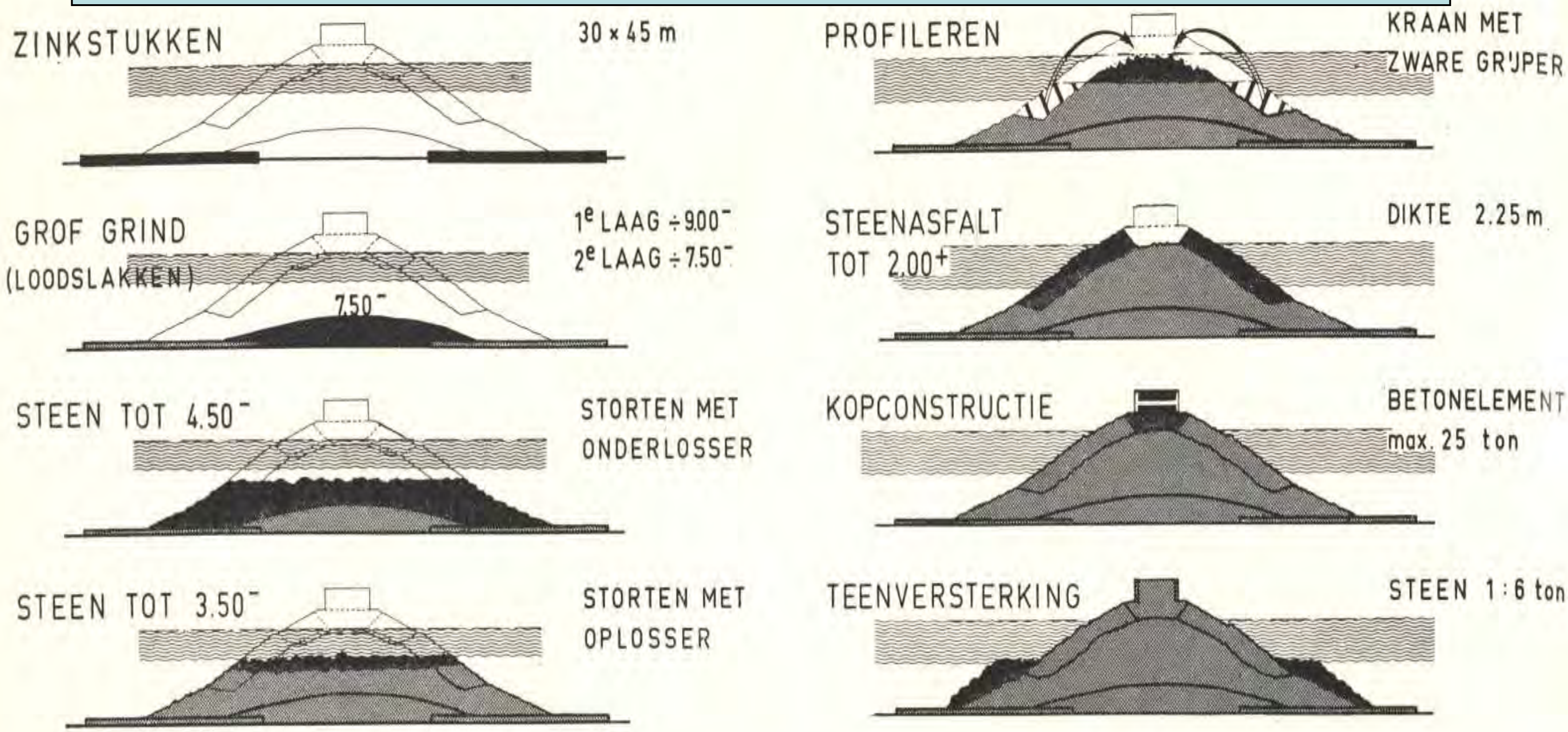
Beach & coastal protection structures

Port of IJmuiden (Nederland)

Construction method for breakwater extension: North & South Pier (1965)



Construction Stages of Rubble-Asphalt Breakwater



Underpart Breakwater

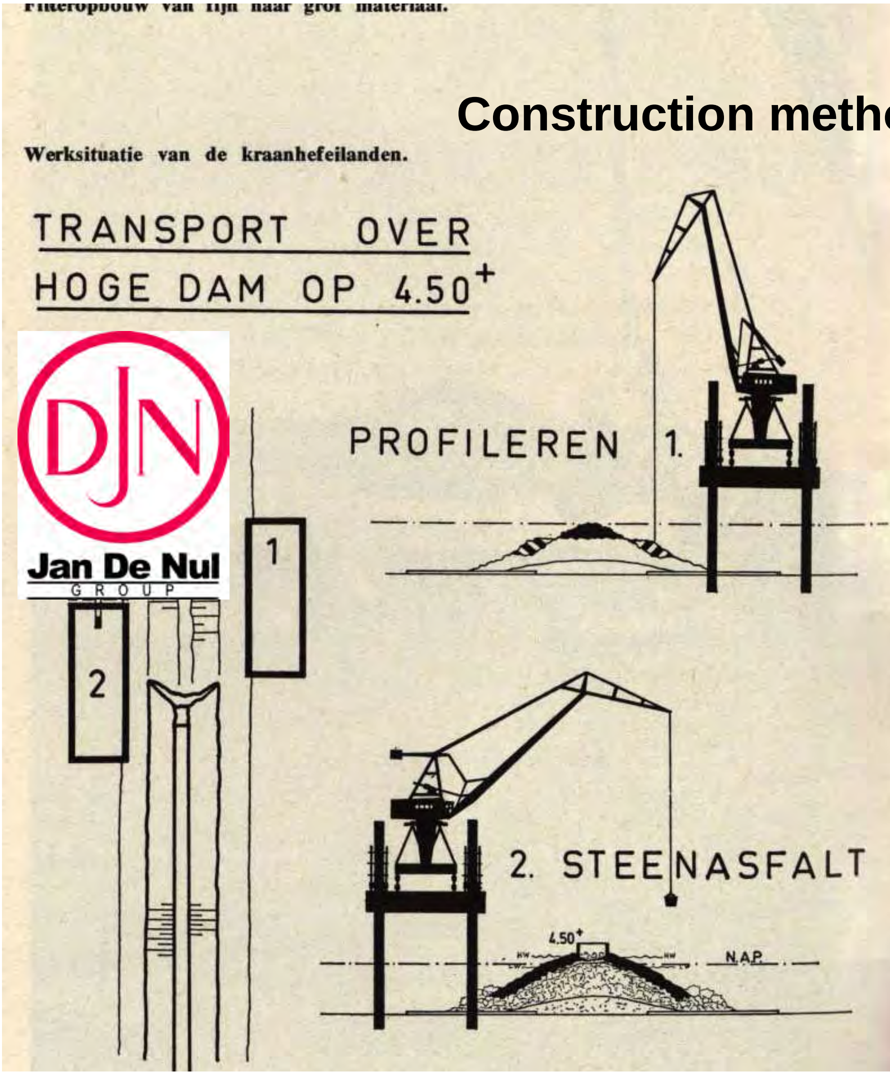
Upperpart Breakwater

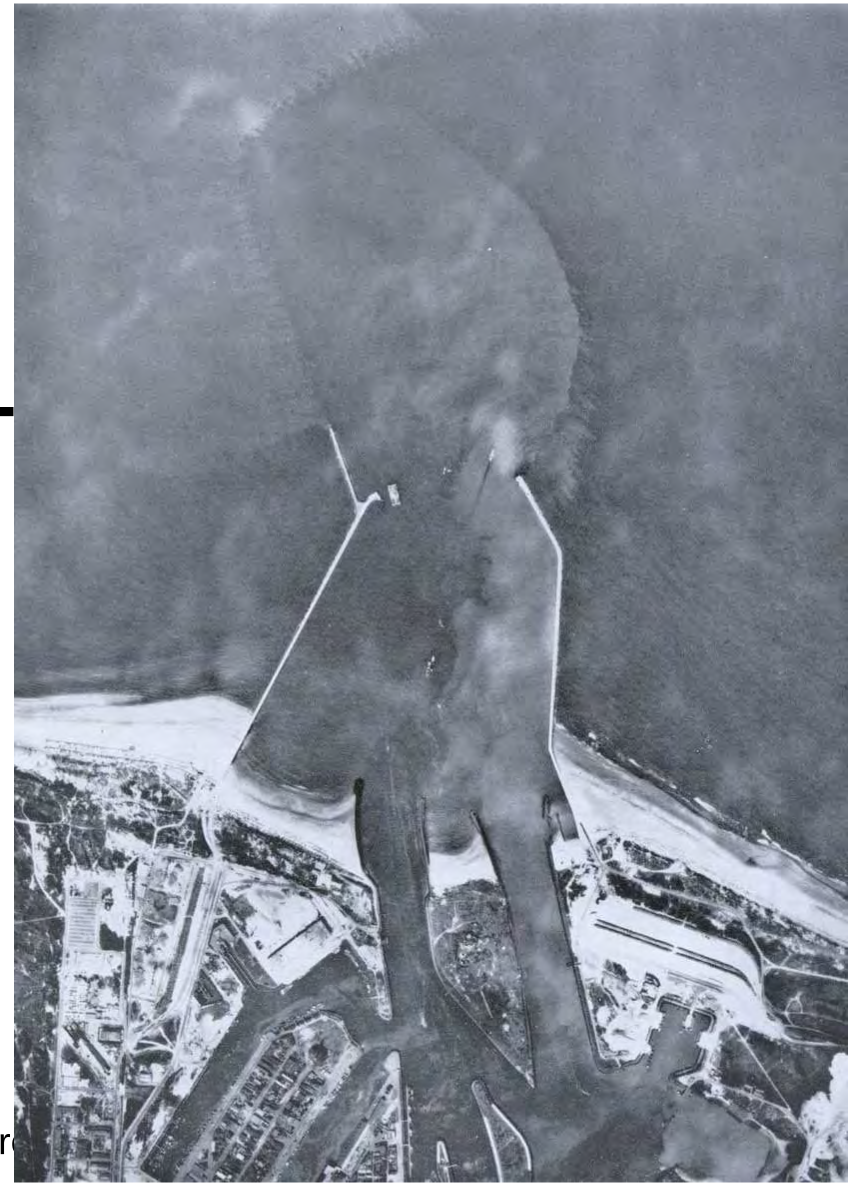
Construction Method of IJmuiden breakwaters

13. De twee belangrijkste concepties van de Combinatie IJmuiden: onderlossers en hefpontons met kraan, beide geadviseerd en in opdracht van Rijkswaterstaat ontworpen.

Te Poulseur (nabij Luik) staat een trein gereed voor vervo[illegible] van sto[illegible]en naar IJmuiden.

Construction method of IJmuiden's breakwaters





Port of Zeeebrugge (Belgium)

1903-2003

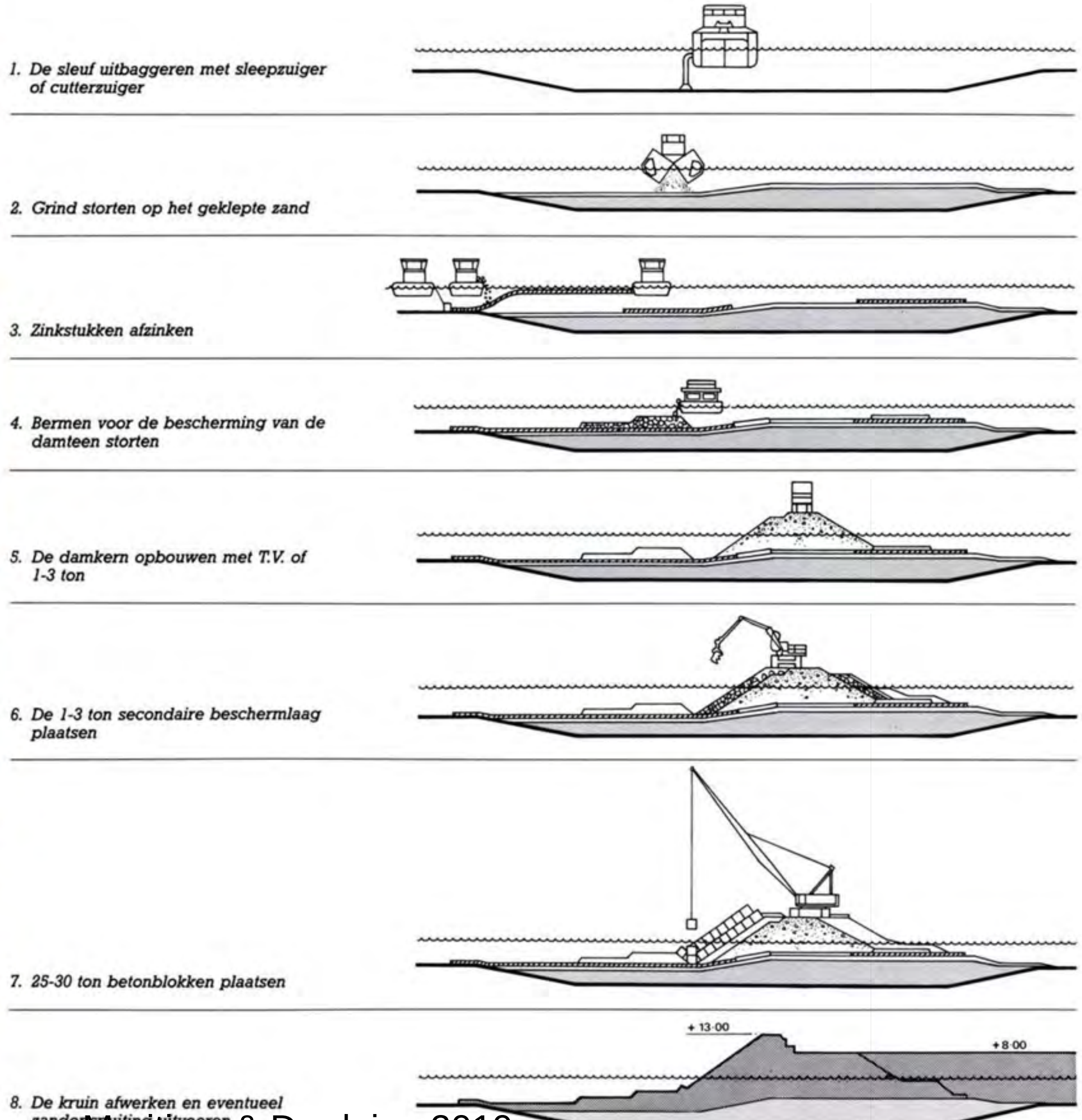
Anno 1976

Anno 1990

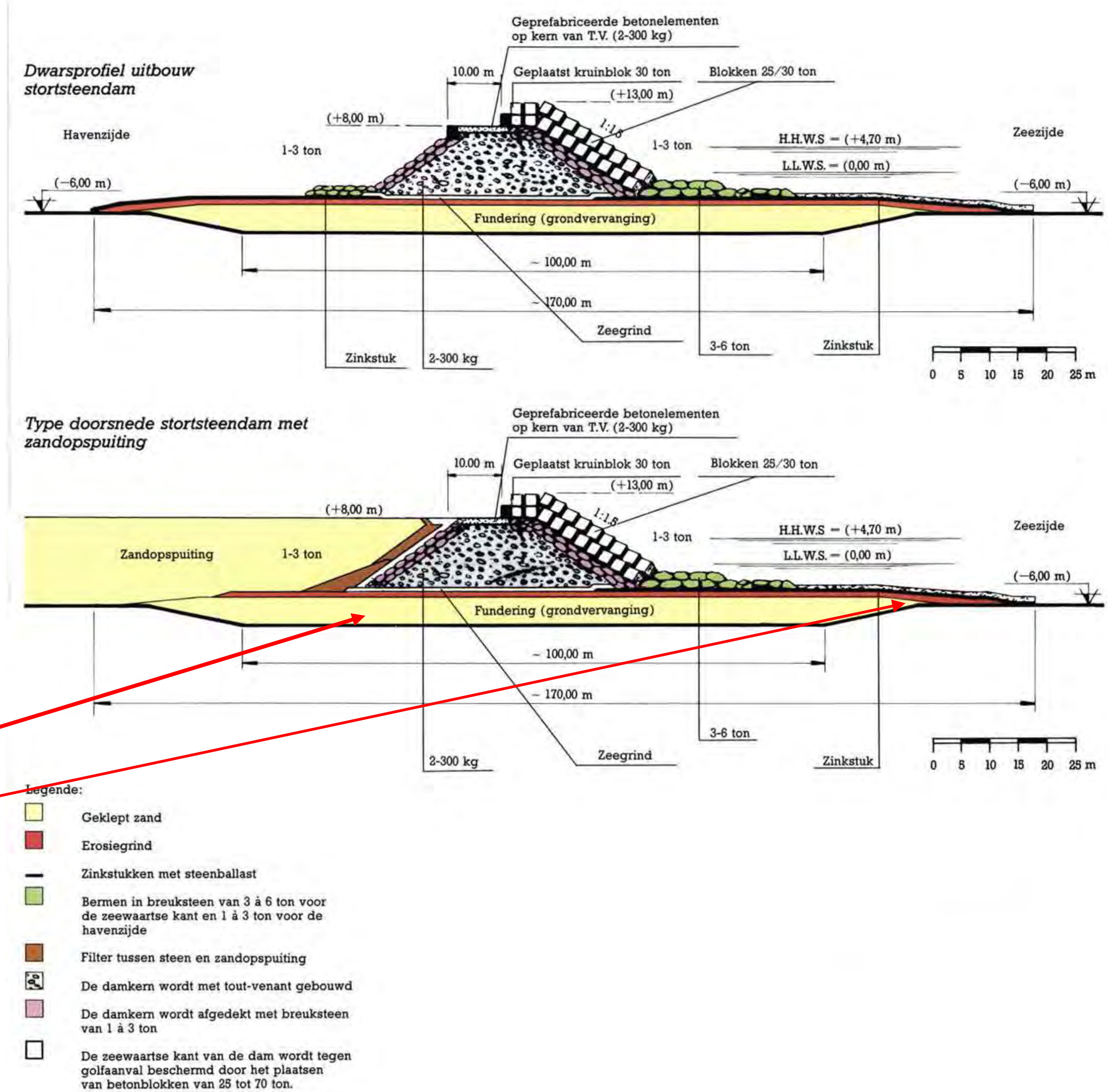
Anno 2003

Construction sequence of Zeebrugge breakwaters

De positie van afzinkpontons, zinkstuk en steenstorter gedurende het afzinken.



Engineering design of Zeebrugge Rubble-Mound Breakwaters on soft soil: soil-replacement and erosion protection



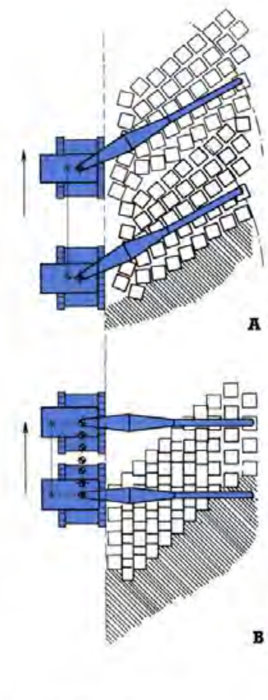
Dredging of soft soil-replacement trench & Construction of breakwater's core

Een zinkstuk op de zate.

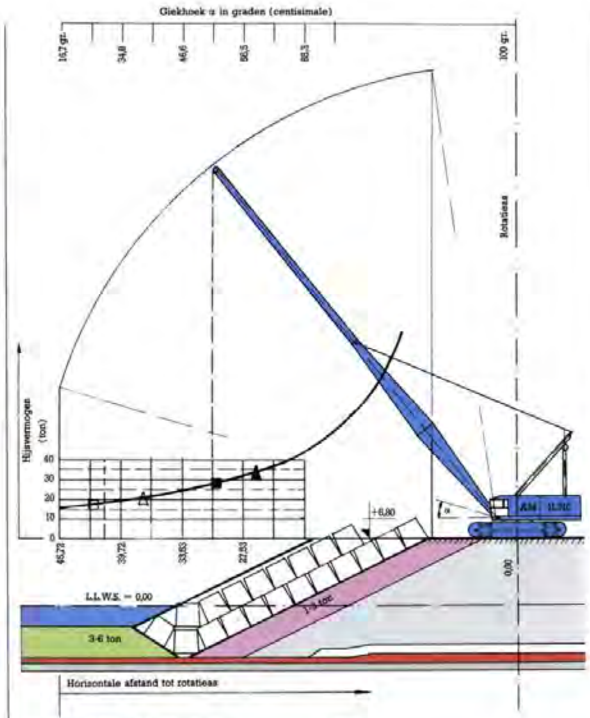
Construction and placement of willow fascines for erosion protection of soft soil-replacement

De positie van afzinkpontons, zinkstuk en steenstorter gedurende het afzinken.

Zeebrugge Port Extension: sequence of Rubble Mound Breakwater construction

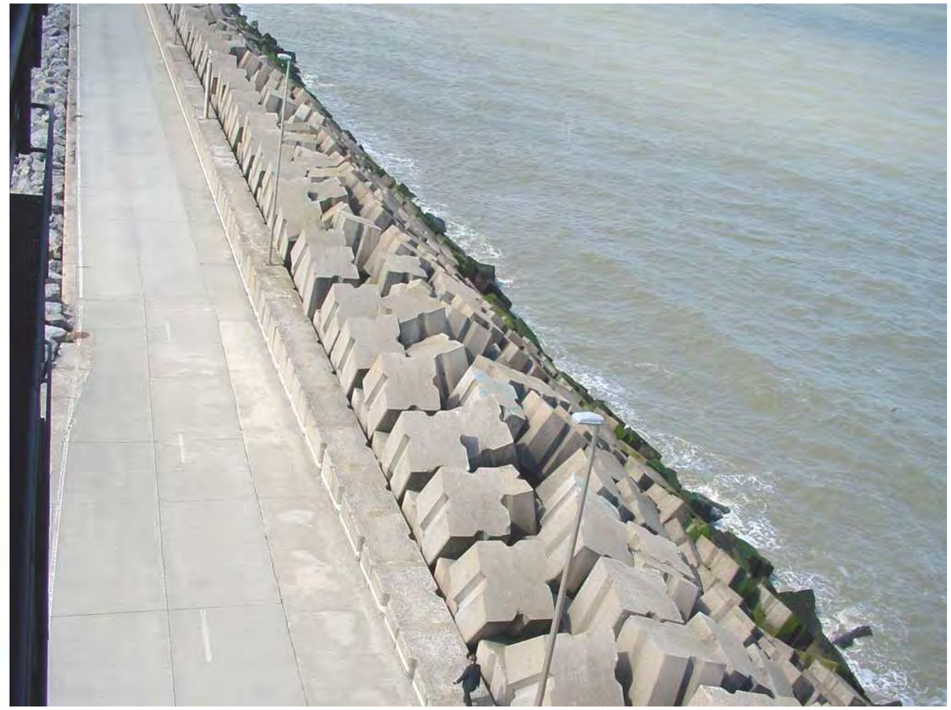


Plaatsingspatronen.



Samenhang tussen kraankapaciteit en ontwerp van de deklaag

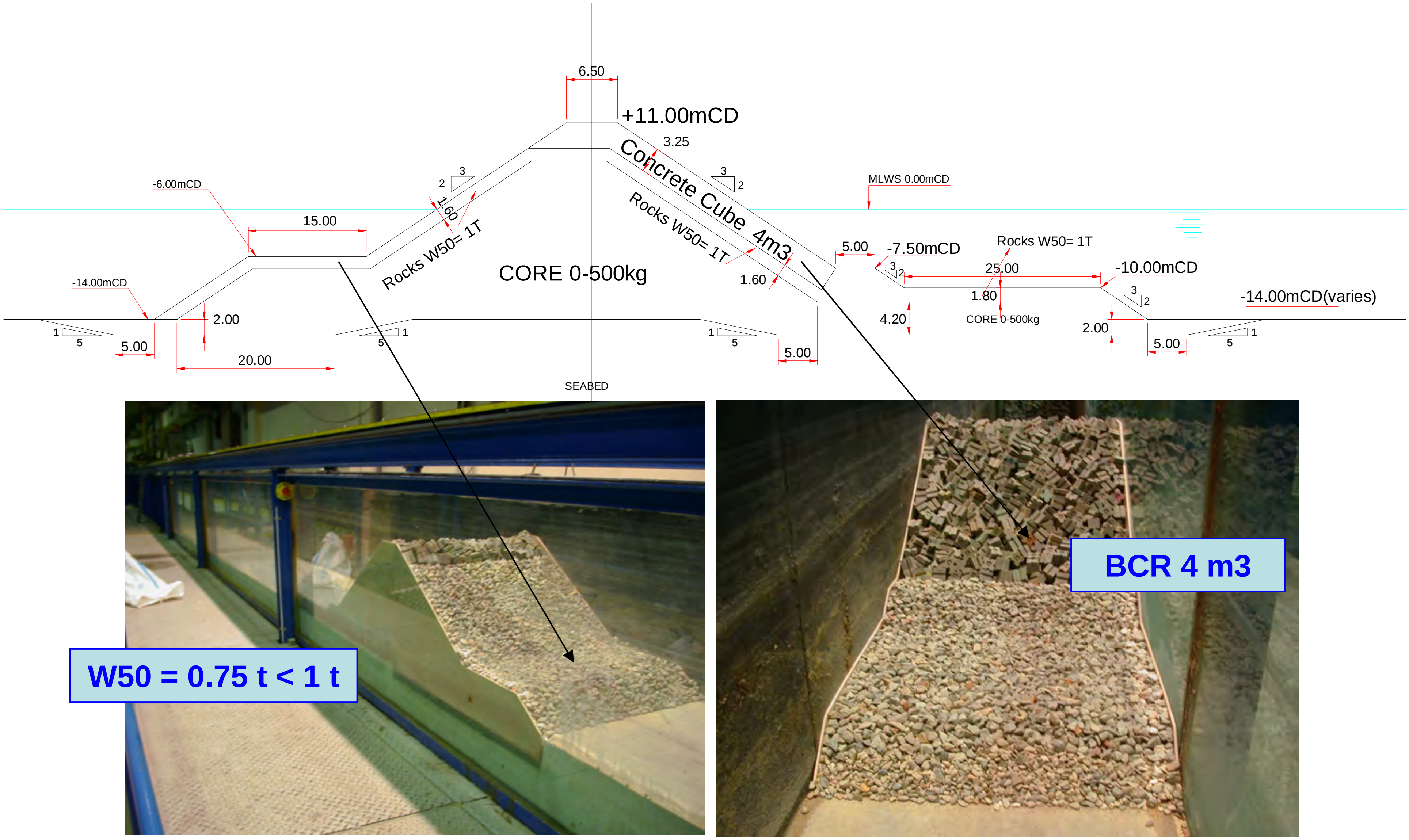
▲ 30 ton
■ 25 ton
△ onder water
□ onder water



Zeebrugge Port Extension:

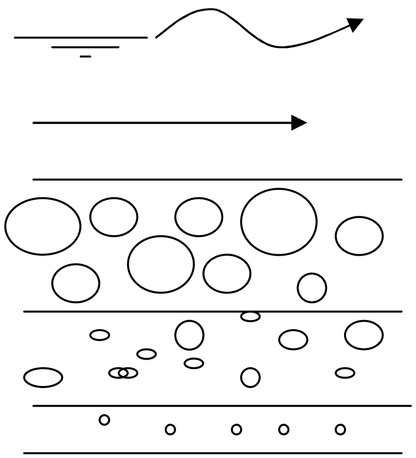
placement of 25t to 28 t concrete armour units of Rubble Mound Breakwaters

Melchorita Breakwater, PERU LNG (anno 2007)



Wave-Flume Testing of Breakwater

First engineering rule in maritime construction: Terzaghi filter rules



Armouring Layer

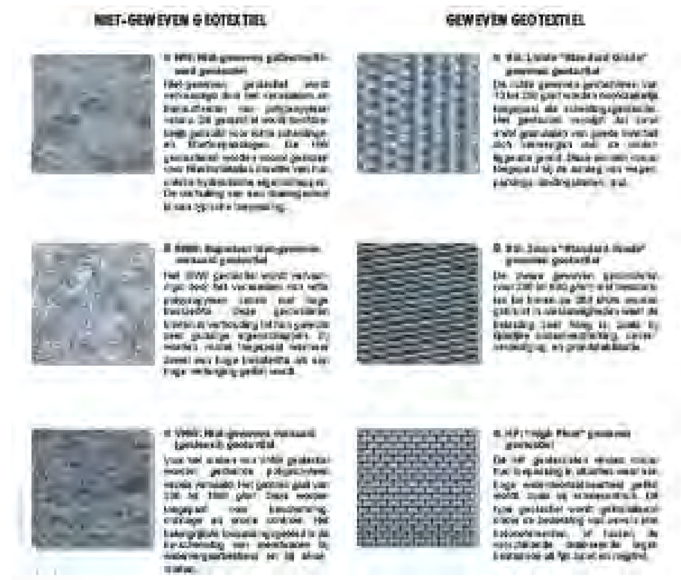
Underlayer

Filterlayer (mineral or geotextile)

Seabed or reclaimed material,…

Geotextile:

- **woven fabric**
- **Non-woven fabric**
- **Material: PP, HDPE,,..**



Permeable but sand-tight construction:

d15upperlayer / d85 underlayer < 5 (bulk of underlayer cannot migrate trough pores of upperlayer)

d50 upperlayer/d50 underlayer = 15 ….60

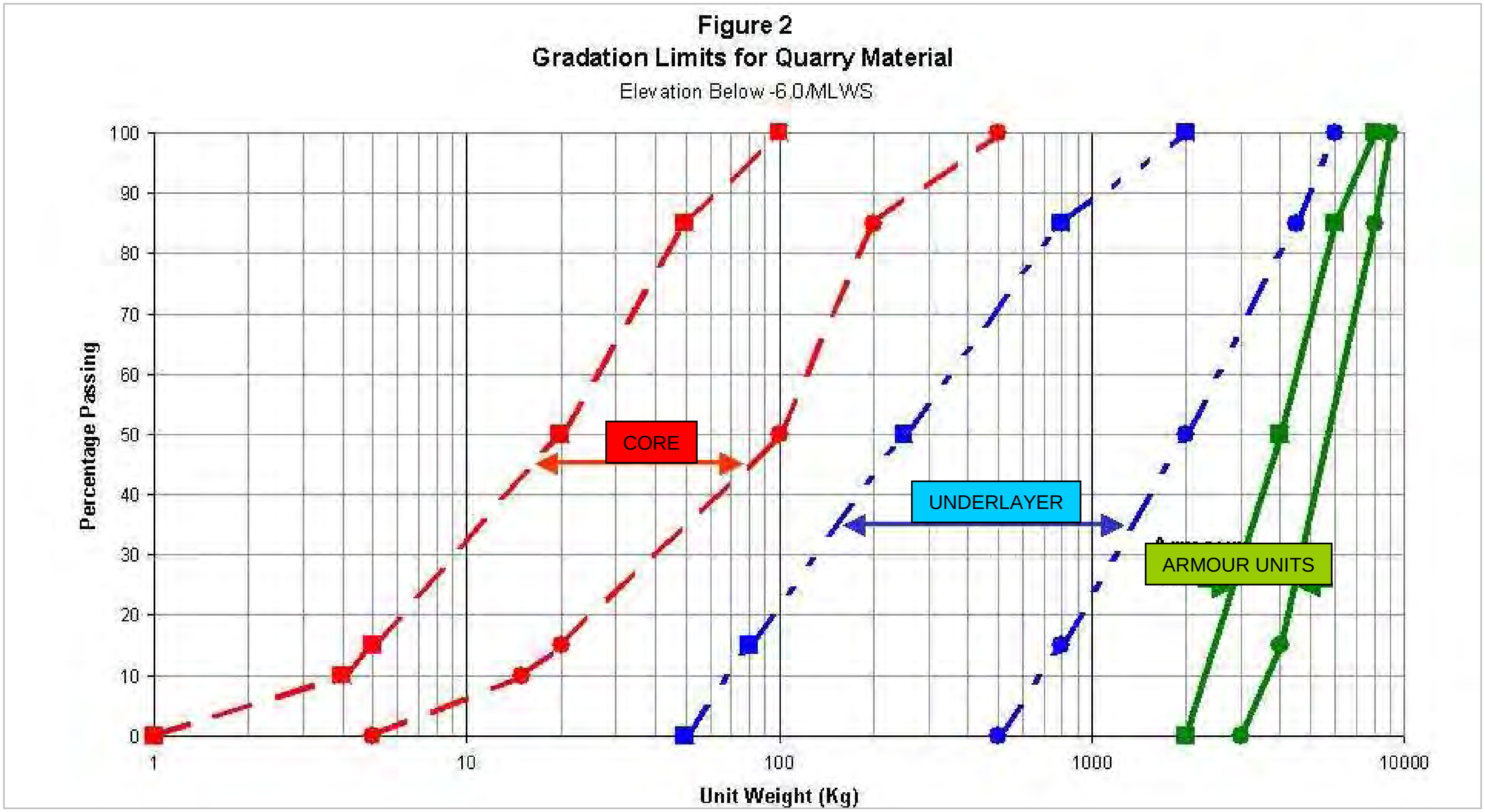
d15uperlayer / d15 underlayer = 5…40

Layer thickness:

Filter-layer (e.g. gravel-sand): > 0,10m

Underlayer & Armour Layer: 3 … 5 x d50

Gradation of Maritime Construction Materials



UNIFIED SOIL CLASSIFICATION (ASTM D-2487-98)

MATERIAL TYPES	CRITERIA FOR ASSIGNING SOIL GROUP NAMES			GROUP SYMBOL	SOIL GROUP NAMES & LEGEND
COARSE-GRAINED SOILS >50% RETAINED ON NO. 200 SIEVE	GRAVELS >50% OF COARSE FRACTION RETAINED ON NO 4. SIEVE	CLEAN GRAVELS <5% FINES	Cu>4 AND 1<Cc<3	GW	WELL-GRADED GRAVEL
			Cu>4 AND 1>Cc>3	GP	POORLY-GRADED GRAVEL
		GRAVELS WITH FINES >12% FINES	FINES CLASSIFY AS ML OR CL	GM	SILTY GRAVEL
			FINES CLASSIFY AS CL OR CH	GC	CLAYEY GRAVEL
	SANDS >50% OF COARSE FRACTION PASSES ON NO 4. SIEVE	CLEAN SANDS <5% FINES	Cu>6 AND 1<Cc<3	SW	WELL-GRADED SAND
			Cu>6 AND 1>Cc>3	SP	POORLY-GRADED SAND
		SANDS AND FINES >12% FINES	FINES CLASSIFY AS ML OR CL	SM	SILTY SAND
			FINES CLASSIFY AS CL OR CH	SC	CLAYEY SAND
FINE-GRAINED SOILS >50% PASSES NO. 200 SIEVE	SILTS AND CLAYS LIQUID LIMIT<50	INORGANIC	PI>7 AND PLOTS>"A" LINE	CL	LEAN CLAY
			PI>4 AND PLOTS<"A" LINE	ML	SILT
		ORGANIC	LL (oven dried)/LL (not dried)<0.75	OL	ORGANIC CLAY OR SILT
	SILTS AND CLAYS LIQUID LIMIT>50	INORGANIC	PI PLOTS >"A" LINE	CH	FAT CLAY
			PI PLOTS <"A" LINE	MH	ELASTIC SILT
		ORGANIC	LL (oven dried)/LL (not dried)<0.75	OH	ORGANIC CLAY OR SILT
HIGHLY ORGANIC SOILS		PRIMARILY ORGANIC MATTER, DARK IN COLOR, AND ORGANIC ODOR		PT	PEAT

OTHER MATERIAL SYMBOLS

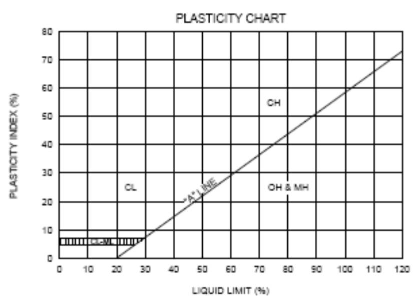
- Poorly Graded Sand with Clay
- Clayey Sand
- Sandy Silt
- Low to High Plasticity Clay
- Poorly Graded Gravelly Sand
- Topsoil
- Well Graded Gravel with Clay
- Well Graded Gravel with Silt
- Sand
- Silt
- Well Graded Gravelly Sand
- Gravelly Silt
- Asphalt
- Boulders and Cobble

SAMPLE TYPES

- Split Spoon
- Shelby Tube
- Rock Core
- Grab Sample

ADDITIONAL TESTS

CA	CHEMICAL ANALYSIS (CORROSIVITY)	(200)	(WITH % PASSING NO. 200 SIEVE
CD	CONSOLIDATED DRAINED TRIAXIAL		
CN	CONSOLIDATION	SW	SWELL TEST
CU	CONSOLIDATED UNDRAINED TRIAXIAL	TC	CYCLIC TRIAXIAL
DS	DIRECT SHEAR	TV	TORVANE SHEAR
PP	POCKET PENETROMETER (TSF)	UC	UNCONFINED COMPRESSION
(3.0)	(WITH SHEAR STRENGTH IN KSF)	(1.5)	(WITH SHEAR STRENGTH IN KSF)
RV	R-VALUE		
SA	SIEVE ANALYSIS: % PASSING #200 SIEVE	UU	UNCONSOLIDATED UNDRAINED TRIAXIAL
▽	WATER LEVEL (WITH DATE OF) MEASUREMENT	WA	WASH ANALYSIS
		(200%)	(WITH % PASSING NO. 200 SIEVE)



PENETRATION RESISTANCE (RECORDED AS BLOWS / 0.5 FT)

SAND & GRAVEL		SILT & CLAY		
RELATIVE DENSITY	BLOWS/FOOT*	CONSISTENCY	BLOWS/FOOT*	COMPRESSIVE STRENGTH (TSF)
VERY LOOSE	0 - 4	VERY SOFT	0 - 2	0 - 0.25
LOOSE	4 - 10	SOFT	2 - 4	0.25 - 0.50
MEDIUM DENSE	10 - 30	FIRM	4 - 8	0.50 - 1.0
DENSE	30 - 50	STIFF	8 - 15	1.0 - 2.0
VERY DENSE	OVER 50	VERY STIFF	15 - 30	2.0 - 4.0
		HARD	OVER 30	OVER 4.0

* NUMBER OF BLOWS OF 140 LB HAMMER FALLING 30 INCHES TO DRIVE A 2 INCH O.D. (1-3/8 INCH I.D.) SPLIT-BARREL SAMPLER THE LAST 12 INCHES OF AN 18-INCH DRIVE (ASTM-1586 STANDARD PENETRATION TEST).

ACME Consulting	LEGEND TO SOIL DESCRIPTIONS	FIGURE 1
Job No. ABC-12345		

LGD A NNNN07 GINT US LAB.GPJ 9/26/05

Determining parameters for:

- **Non-cohesive grains:**
    - **grain-size distribution**
    - **volume-mass & specific density**
    - **permeability**
- **Cohesive grains:**
    - **water content (w) & Atterberg Limits (SL, PL, LL)**
    - **Plasticity-Index : PI = LL – PL**

      (PI = high > Clay; PI = low > Silt)
    - **Liquidity Index: LI = (w-PL)/(LL-PL)**
    - **Activity : A = PI / (% < 0,075mm)**

      (A < 0,75 Inactief; A 0,75-1,25: Normal; A > 1,25: Active)
    - **shear resistance, cohesion**
    - **deformation properties (compressibility,…)**
    - **permeability**

A. Natural Building Materials

Clay

- **What is Clay ?**

  For geologists, Clay is a fine-grained sediment, constituted of mainly alumino-silicate minerals (> 45 %), that are plate or flake-like grains with equivalent Stoke's diameters of 0,020 mm en 0,0001 mm.

  For geotechnicians, Clays are soils constituted of particles with equivalent Stoke's diameters lesser than 0,002mm. Geotechnicians distinguish between under- normal or over-consolidated Clays, depending upon their consolidation degree as a function of their overburden history.

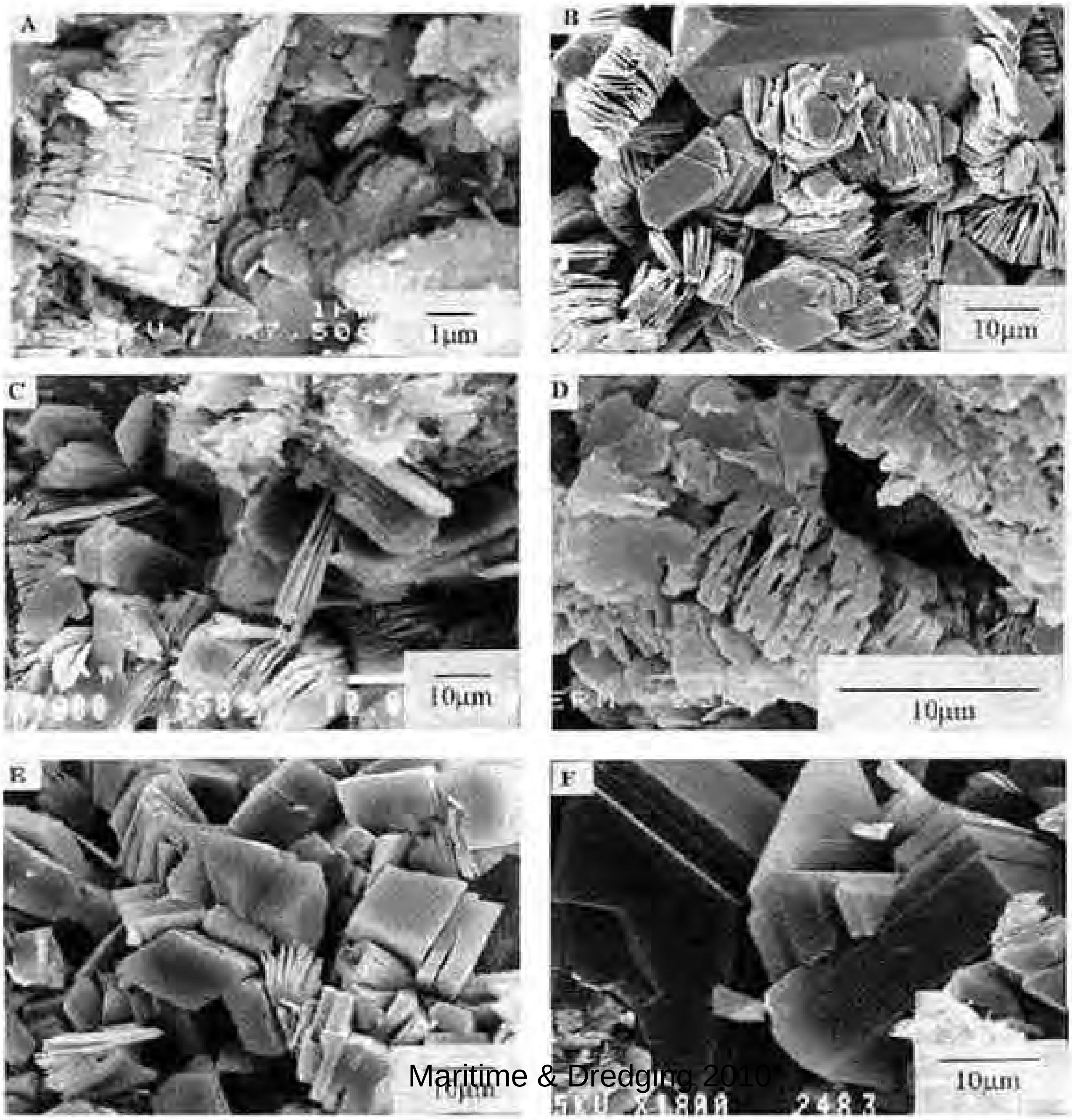
- **Typical geotechnical propertes of Cllays**

  Low water-content : w < 35 %

  Low permeability : k < 10^{-11} m/sec

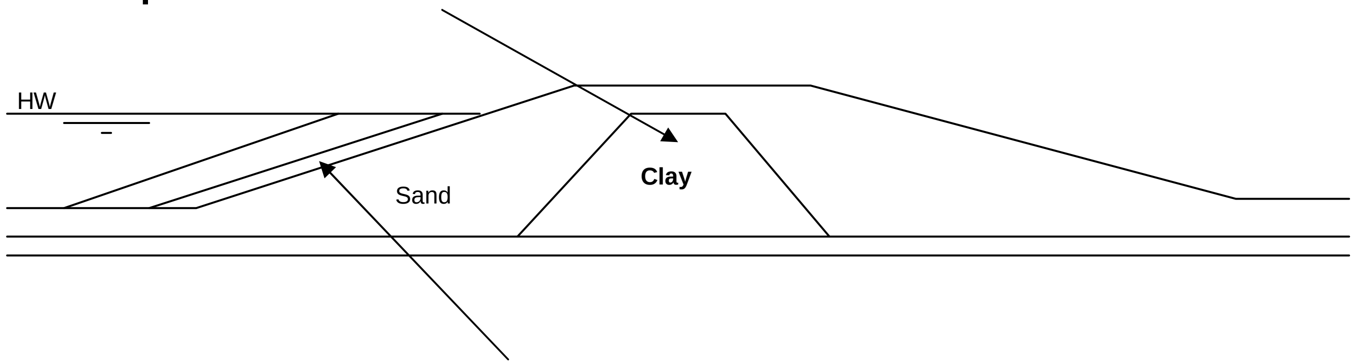
  High cohesion : cu = 10 tot 150 kPa

Electronic microscope shots of Clay Minerals Illite & Kaolinite



Clay as Building Material

- **Domain of application of Clays**
  - **Impermeable cores of dikes**



  - **Impermeable revetment of water-retention dikes**

  - **Colmatation layer of upland disposal facilities, ponds,...**

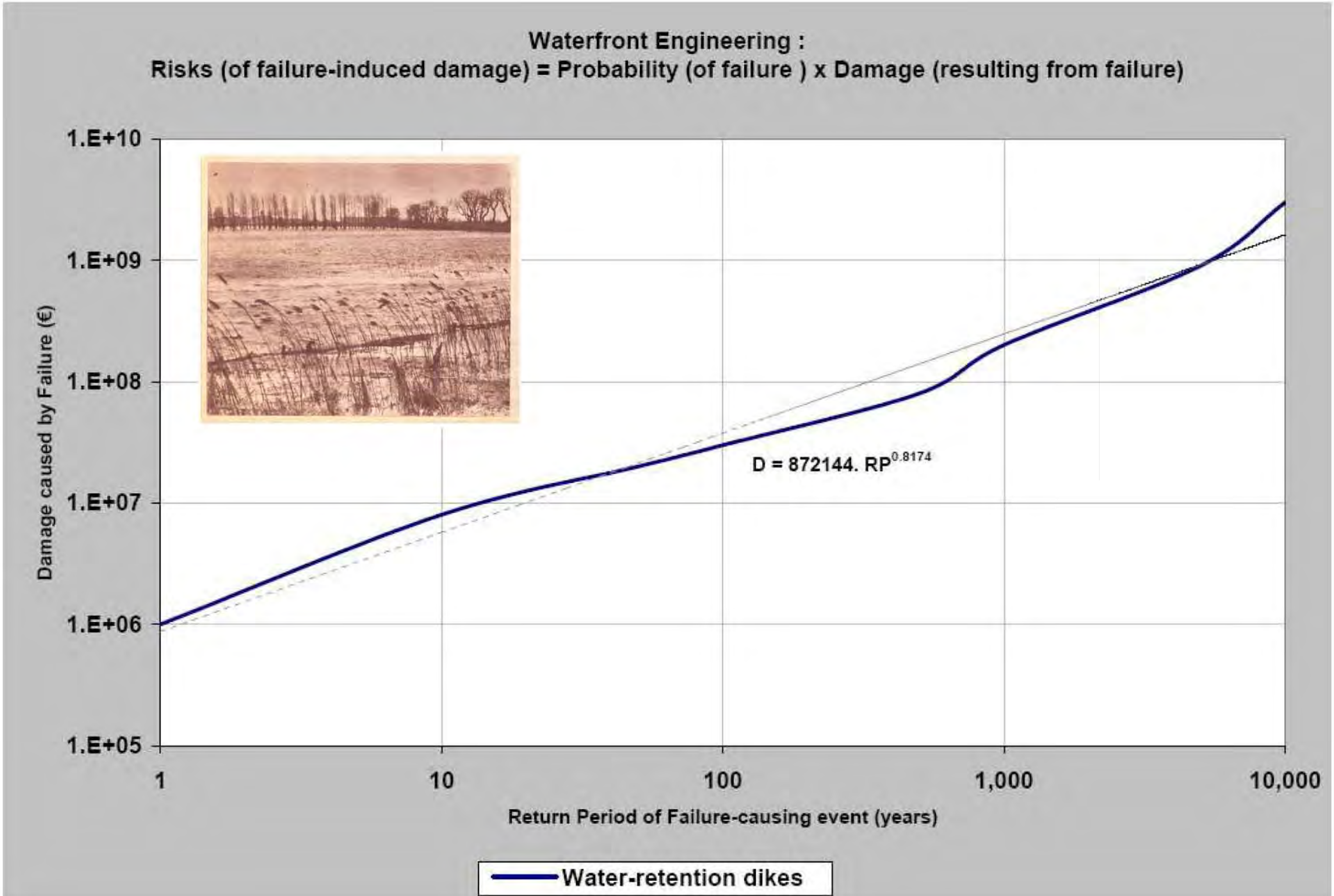
- **Workability of Clay depends upon**

  Plasticity

  Natural water-content close to PL

Waterfront-dikes as water-retention structures: body of sand with clay-core

- **Deltaplan (Netherlands)**
- **Sigma Plan (Belgium)**



Ref after data contained in MKBA Rapport Sigma Plan, 2002

Mud

- **What is Mud ?**

  Mud is a mixture-sediment : a mixture of fine sand,silt - particles (0,063mm to 0,002mm) and clay-minerals. Generally Mud has a high content in organic fractions (2 to 10 %) and $CaCo_3$ (till 35 %).

  Mud is the typical sediment for estuaria, shallow seas and sheltered deposition areas. Mud has generally a high water-content. Mud is the building material for what will become Clay after consolidation.

  Mud is a cohesive sediment with low shear-strenght. Till recently, Mud was considered as inappropriate for recycling or re-use.

- **Geotechnical properties of Mud:**

  High water- content : w = 100 to 250 %, , beyond LL

  Medium to high cohesion: cu = 1 tot 30 kPa

  Flocculation (aggregation to larger particles, called Flocks)

  Sand-admixture (co-precipitation in flocks)

  Transition sediment between suspensions and soil: classic geotechnical laws do not apply…rheology is the science of stress-strain behaviour for such Non-Newtonian Fluids. Parameters influencing shear-strength: initial rigidity (yield stress) , dynamic viscosity and thixotropy (typical for Bingham fluids, a particular form of Non-Newtonian fluids)

Mud as Building Material

After dewatering (accelerated consolidation by lagooning, sun-drying, filter-pressing, chemical dewatering,….), Mud can reach dry-volume-masses of 500 to 600 kgds/m3 (bulk-densities of order of 1,45 to 1,60).

> **Dewatered Mud can be re-used as an impermeable, cohesive, shapeable building-material with low-permeability: landscaping voor sight or sound-screen, fill-material with high deformation properties,……**
>
> **Gravitational dewatering by lagooning (load : 400 to 600 kgds/m2)**
>
> **Mechanical dewatering by chamber filter-pressses.**
>
> **Chemical dewatering by admixture of CaO (8 to 16 %): exothermic reaction (evaporation) and water-adsorption.**

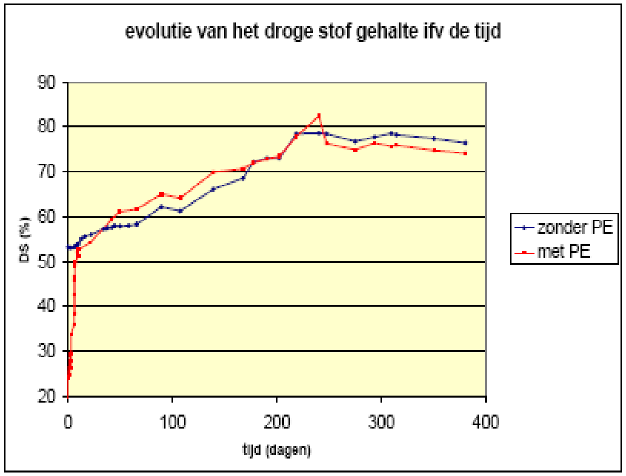
Lagooning of Dredged mud, Ring-canal in Ghent, Belgium

ENVISAN Grondverwerkingscentrum Hulsdonk

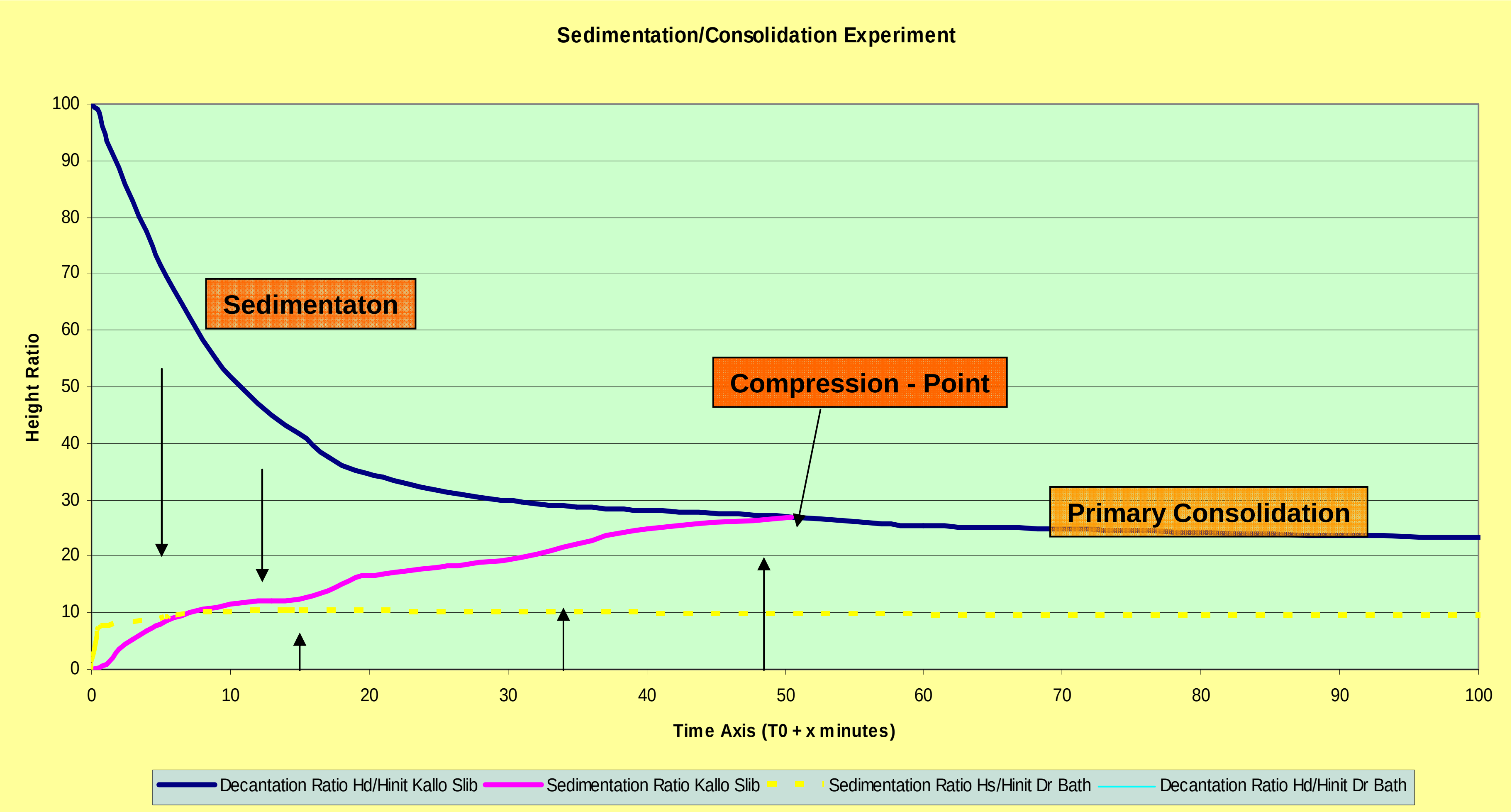
Day 1: just after filling the experimental lagoon with fresh Mud

Day 36: Crust-drying with superficial cracks

Day 100: After crust-revolving



Decantation and Consolidation Properties of Mud



Sand

- **What is Sand ?**

  Sand is typically a detrital sediment, constituted of individual particles and with a relitavely low intergranular cohesion.The particles have equivalent Stoke's diameters of 0,063 mm to 2 mm.

  Sand-grains are generally mono-mineral particles of Quartz (Si O_2), Feldspars (Al, Mg Si O_4) or of organic origin: these latter are generally coral-fragments, shell-fragments,…constituted of Calcite, Aragonite,.(Ca Co_3).

- **Geotechnical properties of sands are:**

  Low in-situ water-content : $w < 35$ %

  High permeability : $k > 10^{-6}$ m/sec

  Subrounded or rounded grains of 0,063 mm to 2,0 mm

  Sorting degree, d50, d90,….of grain-size distribution

  Compaction properties with generally a rapid compaction and a maximum compaction-density corresponding to a typical water-content (Proctor-density)

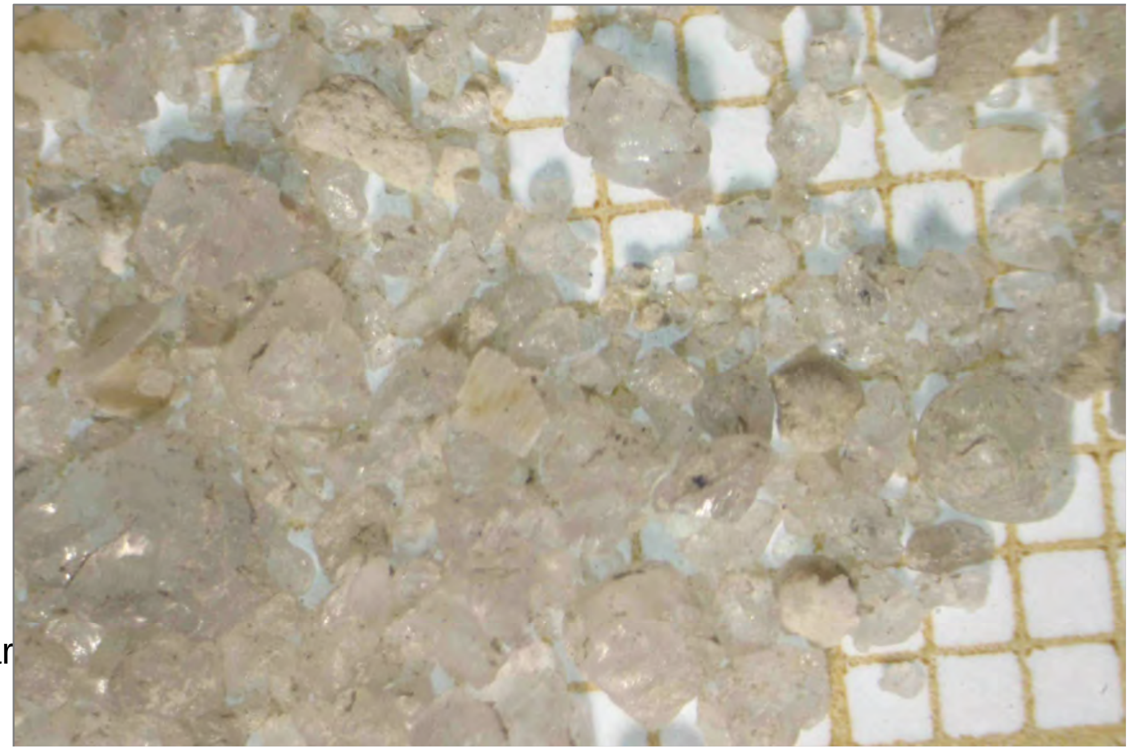
  Angle of Internal Friction (varying between 27° and 40°) , determining shear-strength, equilibrium inflow-slope, active/passive soil stresses,…

Carbonate sand (Dubai)

d50 = 0,654 mm

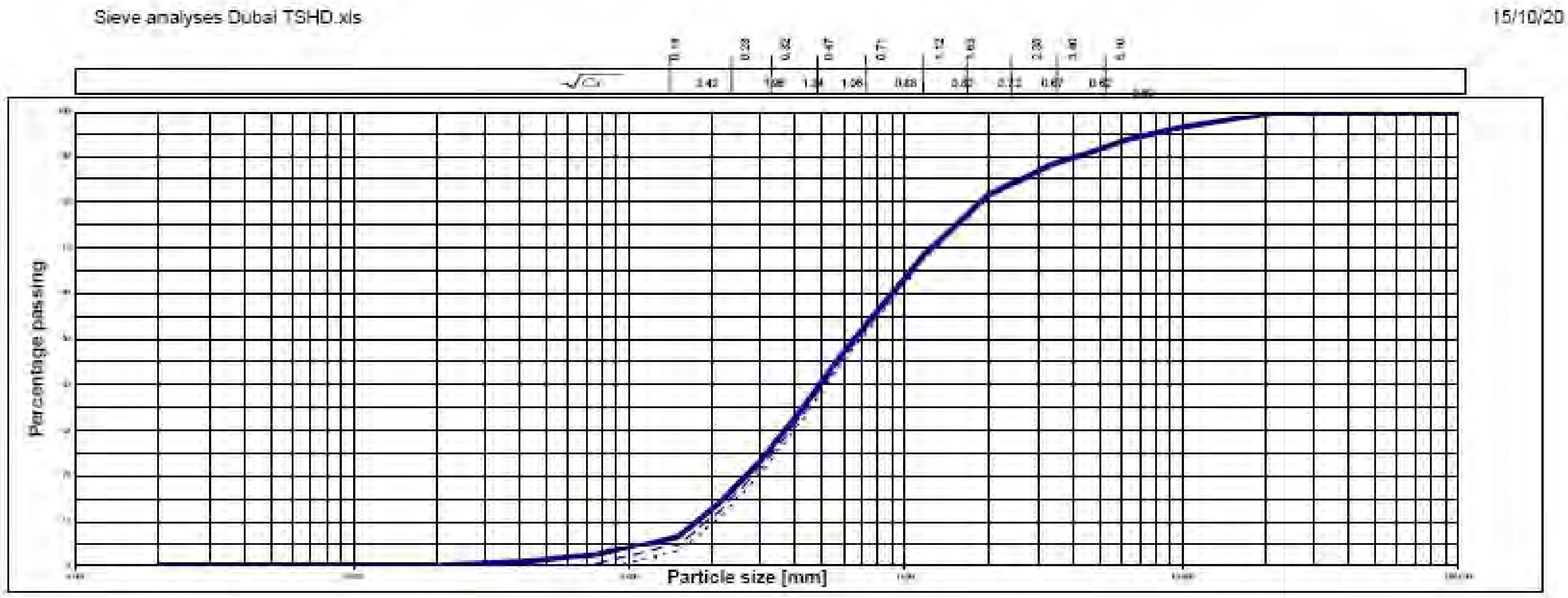
Quartz sand (S Afrika)

d50 = 0,700mm



Mar

Grain-size distribution of Carbonate Sand



Clay	Silt 2%			Sand 79.5%			Gravel 18.5%			C & B
0%	fine 0%	medium 0%	coarse 2%	fine 10.9%	medium 34.4%	coarse 34.3%	fine 11.7%	medium 6%	coarse 0.7%	0%

1			d_{50} [mm]	dmf [mm]	$\sqrt{C_r}$	ψ	$\sqrt{C_r}$ old
full sample			0.654	1.124	1.413	0.814	1.185
without fraction < 0.09 mm	3.5%		0.691	1.177	1.341	0.843	1.231
without fraction < 0.063 mm	2%		0.675	1.154	1.379	0.831	1.379
reduced fraction < 0.14 mm reduced to 20%	6.3%		0.654	1.124	1.413	0.814	1.185

Sand as Building Material

Sand is generally easy to excavate, to dredge, to transport and to reclaim (provided it is not too dilatant). Sand is also relatively cheap a building material, and depending upon reserves, hauling distances generally with prices within 4 to 15 €/m3.

Therefore is sand one of the most widely used building materials in waterfront and maritime engineering.

Applications are:

- **Bulk of dikes**
- **Beach-restaurations**
- **Land-reclamations**
- **Dike-reinforcements**
- **Aggregate for concrete**
- **Drainage-layers on disposal facilities**
- **Core of breakwaters**
- **Soil-substitution material**
- **….**

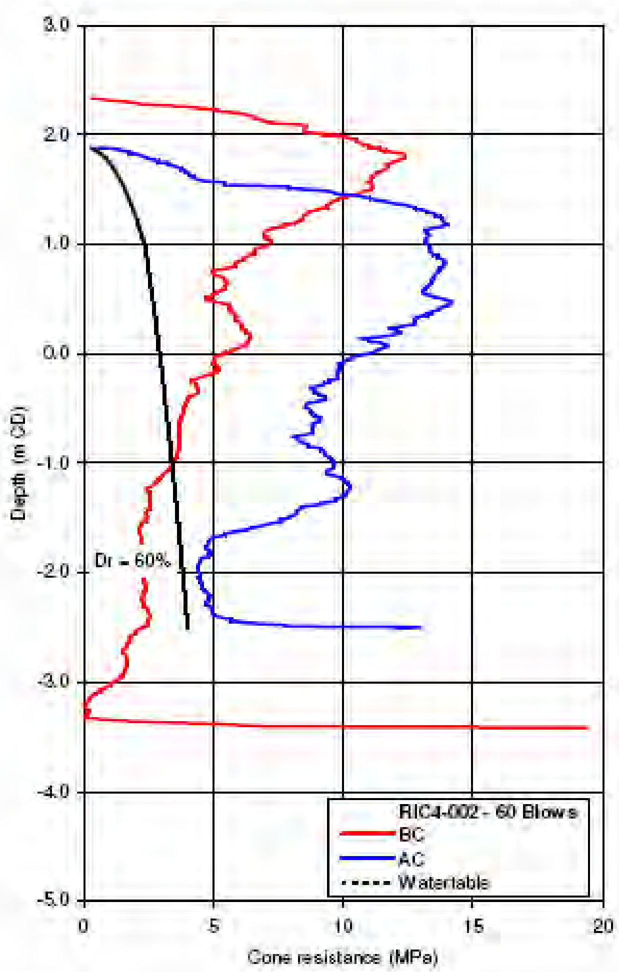
One of the World's largest land-reclamations: Chek Lap Kok airport in Hong Kong (1982)

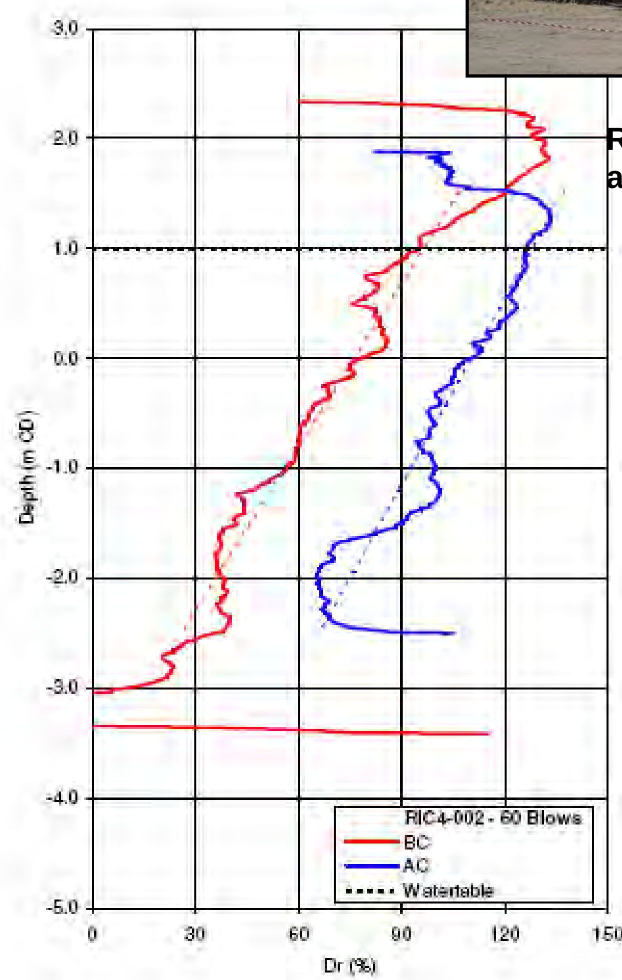
Hydraulic fill of dredged sand and accelerated consolidation with vertical drains

Land-reclamation at Pulau Tekong, Singapore (740 Mm3, 1999)

Reclamation of Western Port Area at Zeebrugge (Belgium) for Flanders Container Terminal, FCT

Compaction of hydraulic sand-fills



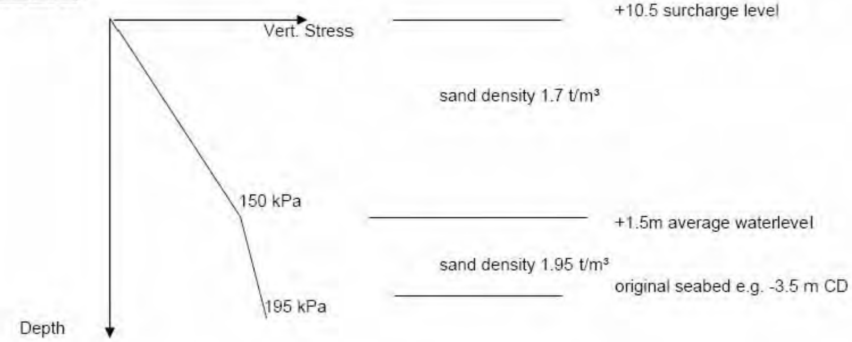


Rapid Impact Compaction (RIC), at Ras Laffan Port, Qatar

Compaction typical results VEB ########

Compaction degree of reclaimed and dumped sand

A. Layout



B. Compaction degree

normal values relative density in reclaimed and dumped sand

reclaiming above waterlevel :	**Dr 50%-60%**	**ϕ : 37.5%-40%**
dumping below waterlevel	**D 40%-50%**	**ϕ : 35%-37.5%**
reclaiming below waterlevel :	**D 15%-35%**	**ϕ : 27.5%-35%**

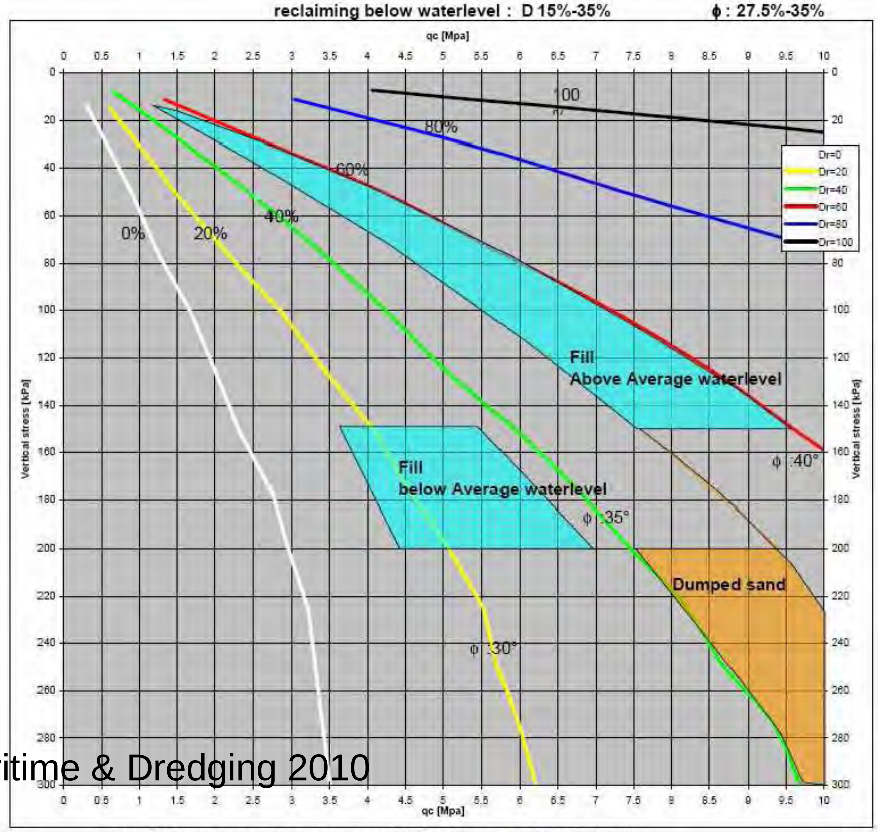
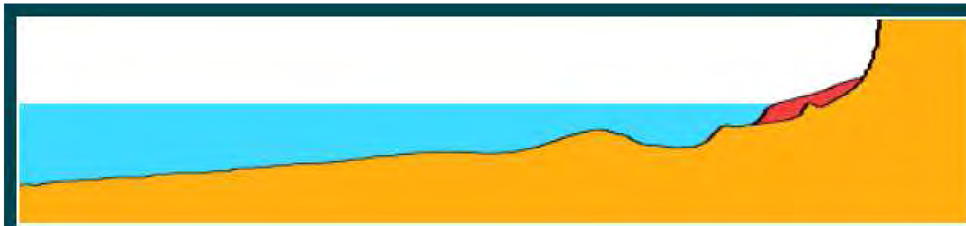
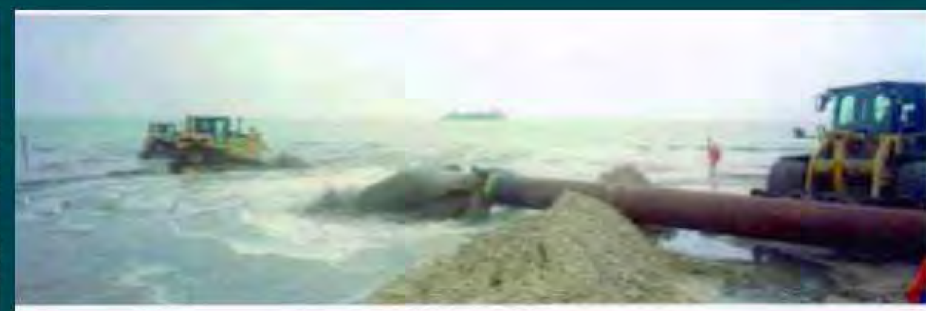


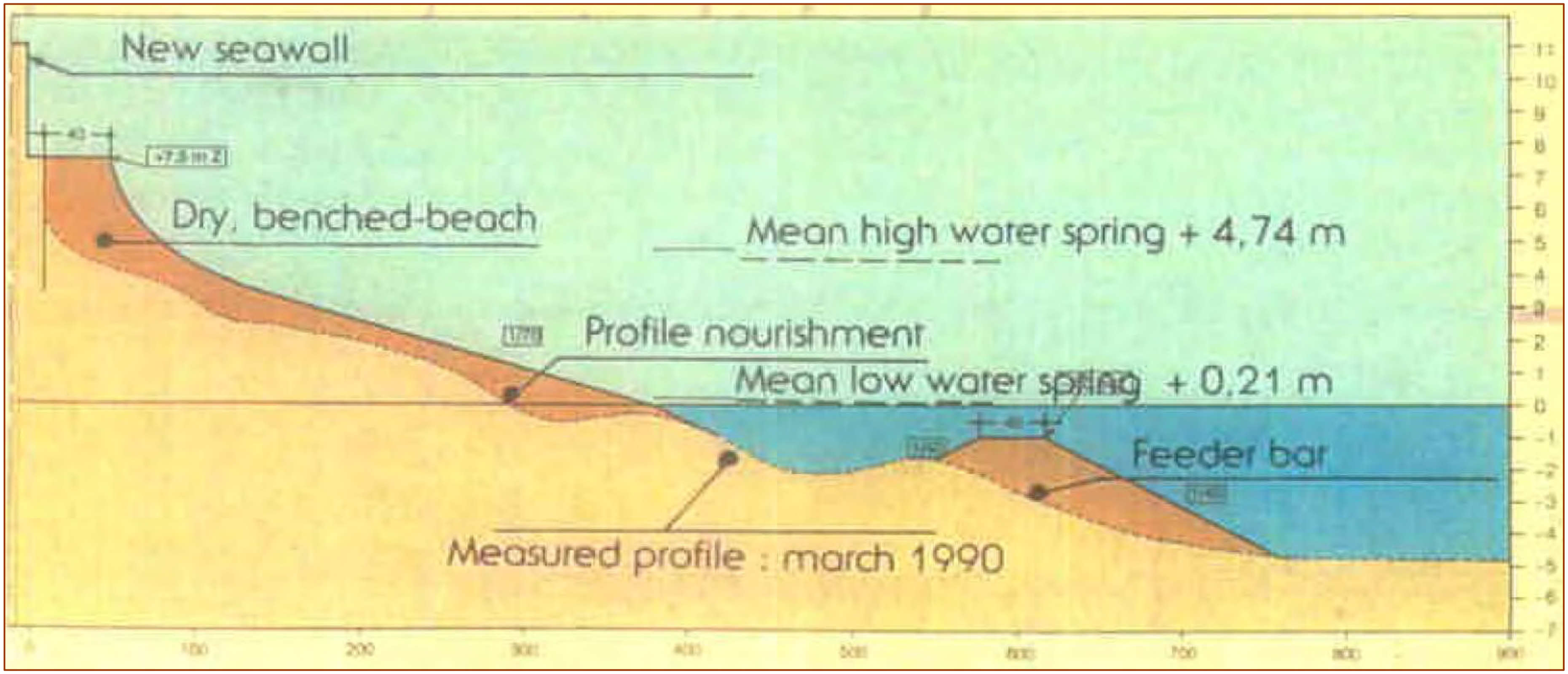
Table 1. According to Schmertzmann(1978) , Villet and Mitchell (1981))

Classic Beach Replenishment: reclaiming supratidal beach at Cancùn, Mexico



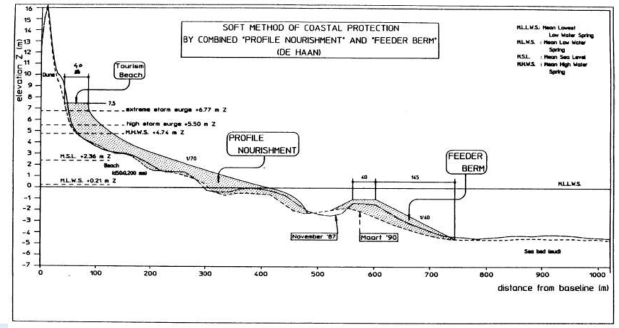


Sand as building material for Coastal Protection: Profile Nourishment and Feeder Berm for "soft" coastal protection at De Haan, Belgium



Dumping Feeder Berm

De Haan Coastal Protection Works: a major pioneering achievment. Less than 5 % losses per year during the first 10 years.



Gravel

- **What is Gravel ?**

  Gravel is a detrital sediment, constituted of individual particles with almost no intergranular cohesion. Particles have typically equivalent Stoke's diameters between 2 and 64 mm.

  Gravel-particles are either mono-mineral particles like Silex ($Si\ O_2$), either rock-fragments of Limestone, Granite, Basalt,..

  Gravel can also be fabricated by crushing rock

- **Geotechnical properties and determining parameters of gravel are:**

  Specific volume-mass: between 2600 and 2800 kg/m3

  Grain-shape and form

  Sorting-degree of grain-size distribution

  Abrasivity

Gravel as Building Material

- **Filterlayer between sand and rubble-mound rock-layers**
- **Ballast material in caissons**
- **Protection-layer of geotextiles**
- **Bedding and blinding layer under concrete blocks, caissons,… (quay-walls)**
- **Back-wedge of gravity quay-walls to decrease active soil pressure**
- **Bank-revetment**
- **Ballasting of fascine-matrasses**
- **Backfill of pipeline/cable trenches**
- **Erosion-protection at toe of structures**
- **Gravel-columns for consolidation of low-bearing capacity soils**
- **Soil-substitution material**
- **…..**

Rocks

What is Rock ?

Rock is either an assemblage of critallized minerals (Igneous and Metamorphic Rocks) or of sediment-particles (Sedimentary rocks) or the result of massive bio-chemical precipitation of specific minerals ((Limestones,…). Rock for waterfront/maritime engineering is produced in quarries, according to specific criteria of grading.

Rock is produced by blasting, break-hammering or cutting geologic rock-formations and grades run from 'Quarry-run' (the rest-product of quarry) to Underlayer Rock and Armour Rock, till individual rock-weights of approx. 10ton.

Rocks to be used in waterfront-engineering such as rubble-mound breakwaters must comply to a number of criteria, such as:

- **homogeneity of rock-formation**
- **high specific density (> 2.400 kg/m3)**
- **limited internal faulting**
- **limited abrasivity and brittleness,…**

Rocks that generally fulfill these criteraia are massive Limestones, Granites, Diorites, Quartzite,….

Rocks that often exhibit brittleness are: Basalt, Gabbro,…

Rocks that often exhibit abrasivity: Calcarenite, Sandstone…

Advantages of Natural Rock in Waterfront engineering are numerous:

- **Easy to install: smaller fraction can be placed in bulk, coarser fraction (> 1 ton) with standard heavy-duty crawler cranes, hydraulic excavators,…**
- **Easy to maintain**
- **Flexibele adaptative to subsoil settlements or irregularities**
- **Extremely sustainable for limestones, granites,…provided a number of rock-mechanic characteristics-criteria are fulfilled**
- **Manageable prices (between 40 tot 100 €/ton: quarried, transported and installed)**
- **Wide range of grades:**
    - **Fine grades: 30/60 mm, 40/100 mm, 50/150 mm, 90/200 mm**
    - **Medium grades: 5/40 kg, 10/60 kg, 40/200 kg , 60/300 kg**
    - **Coarse grades: 300/1.000 kg, 1.000/3.000 kg, 3.000/6.000 kg, 6.000/10.000 kg**

Granite Quarry, Seychelles

Limestone quarry at Al-Kabra, Saudi Arabia

Quarry operations for producing rocks

Jumbo-Drilling of drill-holes

Loading & transport of blasted rocks

Bulk- placement of breakwater-core, Dubai, UAE

Determining Parameters of Rocks:

- **Color: for aesthetic or environmental reasons (visual-impact, landscape-integration,…)**
- **Specific Density :**
  - **Oven-dry density ρd (in kg/m3)**
  - **Density after water-absorption (in kg/m3)**
- **waterabsorption: Wab = 100 x Mass of water absorbed/Dry Mass(%)**
- **intrinsic porosity : Por = ca. Wab x ρd**
- **weathering degree**
- **homogeneity: internal faulting, layering, veins (Quartz,…),…**
- **compression strength UCS (Uniaxial Compression Strength in MPa)**
- **tensile strength**
- **accoustic properties Vacc (m/sec):**
- **abrasion-resistance: inter-rock abrasivity (Micro-Deval test)**
- **resistance to frost/thaw cycli**
- **drop-test resistance**
- **bulk porosity of rock-layer :**
  - **quarry – Run : 33 %**
  - **Filter-Layer (5 – 60 kg): 39 %**
  - **Underlayer (60 kg – 1000 kg): 38 %**
  - **Armour Layer (1000 kg – 10 t): 36 %**

Loss in rock between Quarry weighing-bridge and final placement in breakwater.

(Losses are due to intermediate stockpilings, settlements, losses during placement,…)

Losses of stockpile, transport & settlement

Total losses integrated, incl placement

Layer	Grade	Theoretical layer-thickness [m]	Percentage of losses %	Practical layer-Thickness [m]	Practical fill density Tons/geometric design-volume
Core (Quarry-Run)		≥ 1m	5%		2,14
Filter-Layer	5 – 40 kg	0,40	10%	0,44	2,15
Filter-Layer	10 – 60 kg	0,50	10%	0,55	2,15
Under-Layer	60 – 300 kg	0,80	10%	0,88	2,18
Under-Layer	0.3 - 1.0 ton	1,25	10%	1,38	2,18
Armour-Layer	1 - 3 ton	1,80	15%	2,07	2,20
Armour-Layer	3 - 6 ton	2,40	15%	2,76	2,20
Armour-Layer	6 - 10 ton	2,90	15%	3,34	2,20

Rock: some indicative parameter-values

Parameter	Unit	Sandstone	Limestone	Granite	Gabbro	Porphyre
Density	Kg/m3	2200-2600	2700 -2900	2600-2800	2800-3000	2550 -2800
Waterabsorption	%	4,0 – 8,0	0,5 - 3	< 0,5	< 0,2	< 0,5
Compression strength UCS	MPa	20- 80	60 -200	80 - 300	100-400	200-500
Tensile strength	MPa	2-4	2 - 5	2-4	1 - 2	1-2
Sonic velocity	m/sec	4.000	5.000	7.000	8.000	7.500

Tolerances for Rocks used in Breakwaters

Location	Quarry run, Filter-Layer		Under-Layer & Armour - Layer, (Wem > 300 kg)	
	Wem< 300 kg	Wem > 300 kg	Absolute tolerance	Average tolerance
	[m]	[m]		
Above water	0.20	0.40	0.35 * Dn50	0.30 * Dn50
	-0.20	-0.20	-0.30 * Dn50	-0.25 * Dn50
From 0 tot – 5m	0.50	0.80	0.60 * Dn50	0.50 * Dn50
	-0.30	-0.30	-0.50 * Dn50	-0.40 * Dn50
From – 5 tot -15 m	0.50	1.20	O.60 * Dn50	
		-0.40		
More than -15 m	-0.50	1.50	-0.50 * Dn50	
		-0.50		

Wem = arithmetic average weight

(the total weight of a sample of one grade, divided by the number of stones)

W50 = mediane weight of one grade

(50% > / 50%<)

Exchange factors between W50 and Wem

Rock-grade	W50 [kg]	Factor	Wem [kg]
10 – 60 kg	35	1,30	27
60 – 300 kg	180	1,15	157
0.3 - 1.0 ton	650	1,10	591
1 - 3 ton	2.000	1,05	1.905
> 3 ton		1,00	

Exchange factors from d50 to dn50

Rock-grade	D50 [m]	Factor	Dn50 [m]
10 – 60 kg	0,28	0,84	0,24
60 – 300 kg	0,48	0,84	0,41
0.3 - 1.0 ton	0,74	0,84	0,63
1 - 3 ton	1,08	0,84	0,91
3 - 6 ton	1,41	0,84	1,19
6 – 10 ton	1,71	0,84	1,45

dn50 = nominal rock-diameter for perfect spheric rock (= $\{ W50 / \rho_s \}^{0,333}$)

d50 = average real irregular stone diameter (= $\{ W50 / (\rho_s/0,60) \}^{0,333}$)

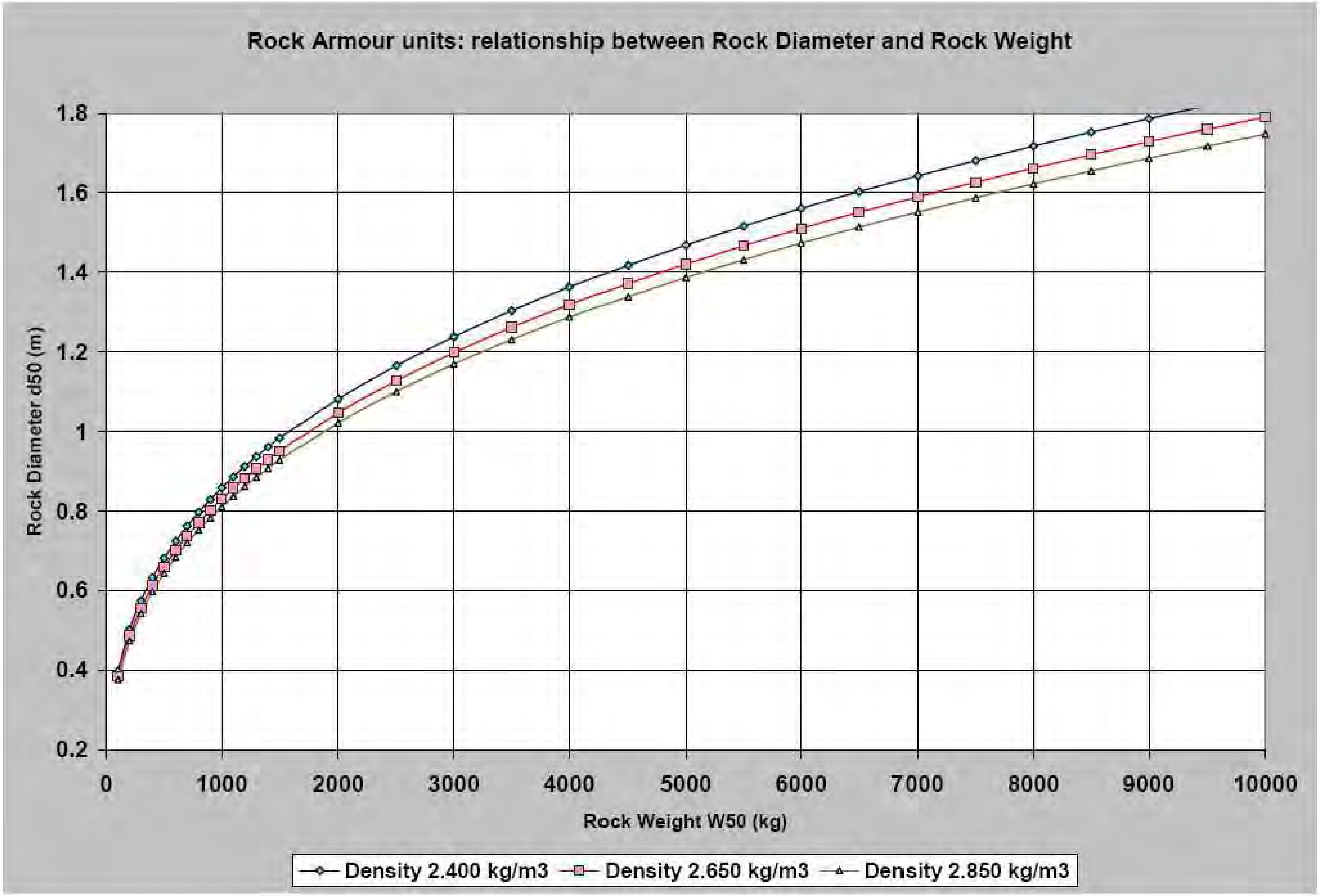
d 50 = dn50 / 0,84

Examples of typical dimensions and weights of Rocks in Breakwaters

Layer	Grade	W 50	ρs	Rock volume	D 50
		[ton]	[ton/m3]	[m3]	[m]
Filter-Layer	5 – 40 kg	0,023	2,650	0,008	0,242
Filter- Layer	10 – 60 kg	0,035	2,650	0,013	0,280
Under-Layer	60 – 300 kg	0,180	2,650	0,068	0,484
Under-Layer	0.3 - 1.0 ton	0,650	2,650	0,245	0,742
Armour - Layer	1 - 3 ton	2,000	2,650	0,755	1,079
Armour- Layer	3 - 6 ton	4,500	2,650	1,698	1,415
Armour - Layer	6 – 10 ton	8,000	2,650	3,019	1,714

$$D_{50} = \left(\cdot \frac{\frac{W_{50}}{\rho s}}{0.6} \right)^{1/3}$$

Form-factor = 0,60


Rock Armour units: relationship between Rock Diameter and Rock Weight
Rock Diameter d50 (m)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Rock Weight W50 (kg)
Density 2.400 kg/m3
Density 2.650 kg/m3
Density 2.850 kg/m3

Narrow grading		Wide grading		Very wide grading	
$D_{85}/D_{15} < 1.5$		$1.5 < D_{85}/D_{15} < 2.5$		$D_{85}/D_{15} > 2.5$	
Class	D_{85}/D_{15}	Class	D_{85}/D_{15}	Class	D_{85}/D_{15}
15–20 t	1.1	1–10 t	2.0	10–1000 kg	4.5
10–15 t *	1.1	1–6 t	1.8	10–500 kg	3.5
6–10 t *	1.2	100–1000 kg	2.0	10–300 kg	3.0
3–6 t *	1.3	10–60 kg *	1.8		
1–3 t *	1.4				
0.3–1 t *	1.5				

Table 5.17 *Examples of heavy and light gradings*

Note:
The gradings indicated with * are standard gradings in accordance with EN 13383 (see Section 3.4.3).

Rock supply works for breakwaters

Breakwater construction using earth-moving equipment and geotextiles

Singapore: Reclamation of Pulau Ubin and Pulau Tekong Islands

Key Figures:

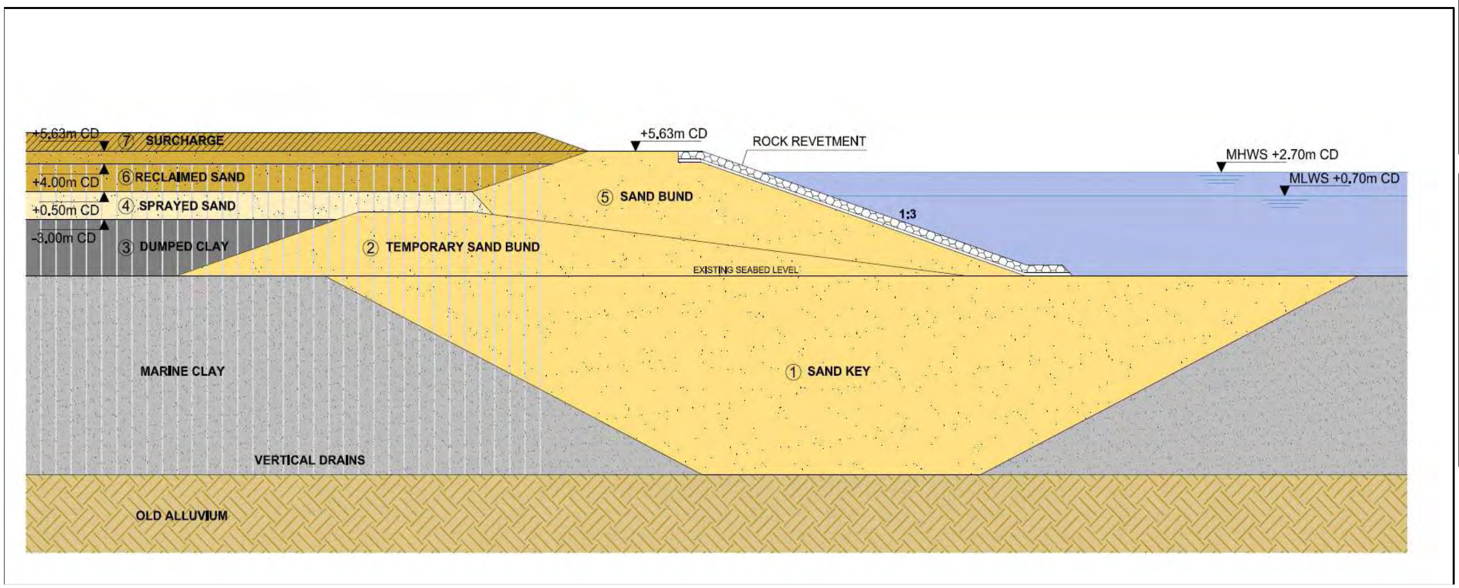
- **Client : Housing and Development Board**
- **Surface of land to create : 1.480 ha**
- **Volume of Sand to reclaim: 164 Mm3**
- **Length of Breakwater : 14.800 m'**
- **Period: 2000 – 2005**
- **Investment : 850 M €**

Area D1, November 2001
Southern part of Pulau Tekong

Area A- at Pulau Tekong Kechil, June 2002

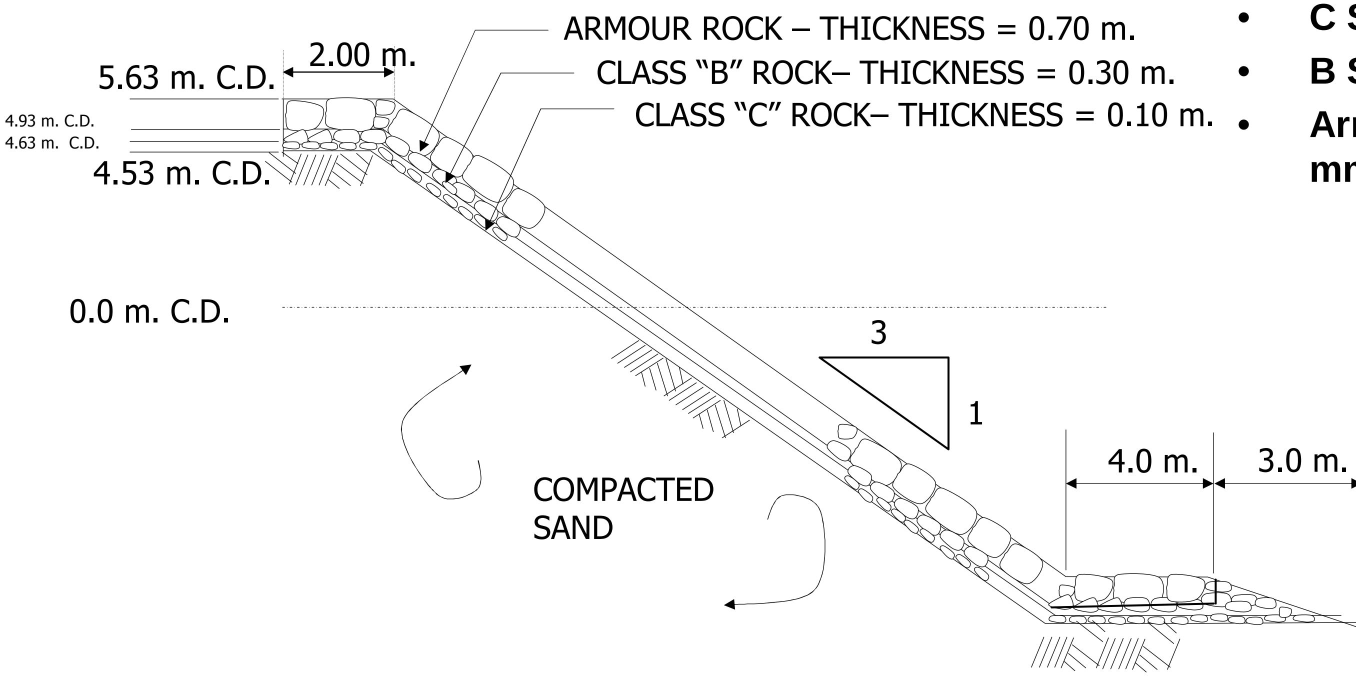
Singapore: Reclamation of Pulau Ubin and Pulau Tekong Islands

Design Elements:
- Storm Surge level: CD + 3m
- Natural waterdepths: CD- 2 to -20m
- Design Wave Heigth: Hs = 0,6 m
- Design Wave Period : Tm = 2,9 sec
- Vcurr = 1,5 m/sec



Dredging of soil-substition trench: sandkey

Singapore, Pulau Ubin and Pulau Tekong Reclamation and Rock-Works



- **C Stone: 50 to 100 mm**
- **B Stone: 150 to 350 mm**
- **Armour Stone: 600 to 800 mm**

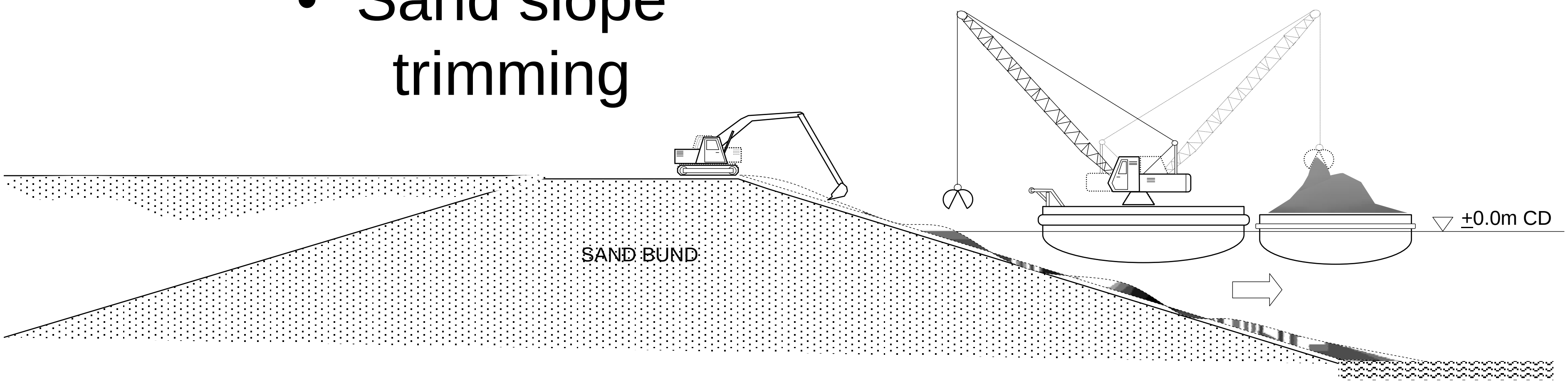
Karimun,(Ind) Quarry of Granitic Rock

Sieving, grading, crushing of rock : dressing of the various grades

Drop-test of Armour RAU on Underlayer, laying on geotextile

Pulau Ubin : Pulau Tekong: Method Statement

- Sand slope trimming



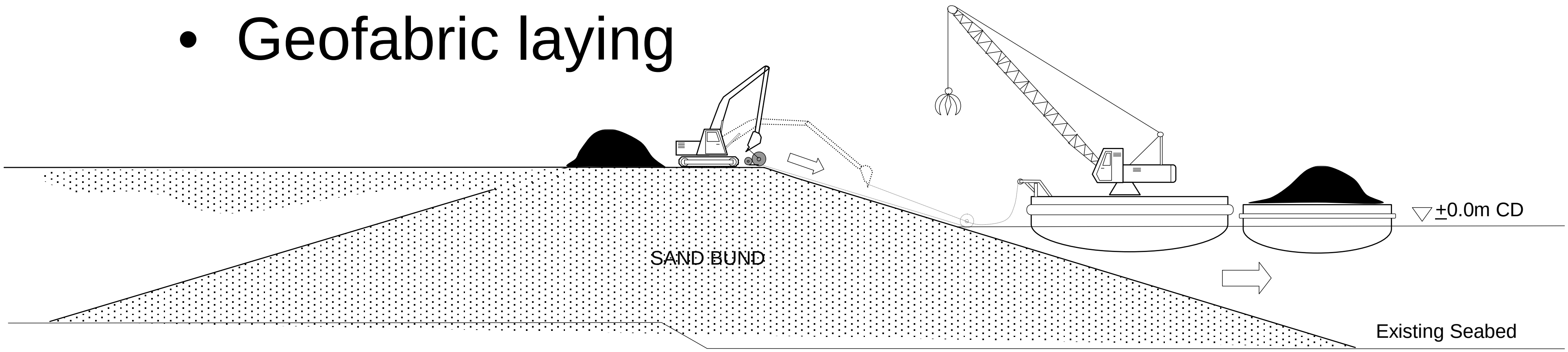
- **Crane barge is used to carry out the sand slope preparation (cut and fill) below water level, while land-based excavator carries out the sand slope preparation above water level.**
- **Excess sand below ± 0.0m CD is loaded to a coaming barge or hopper barge and is used for the next area.**
- **Excess sand above ± 0.0m CD is loaded to a tipper lorry and is used for the next area.**

Trimming of Sand-slopes


DN 40

Pulau Ubin/ Pulau Tekong: Method Statement

- Geofabric laying

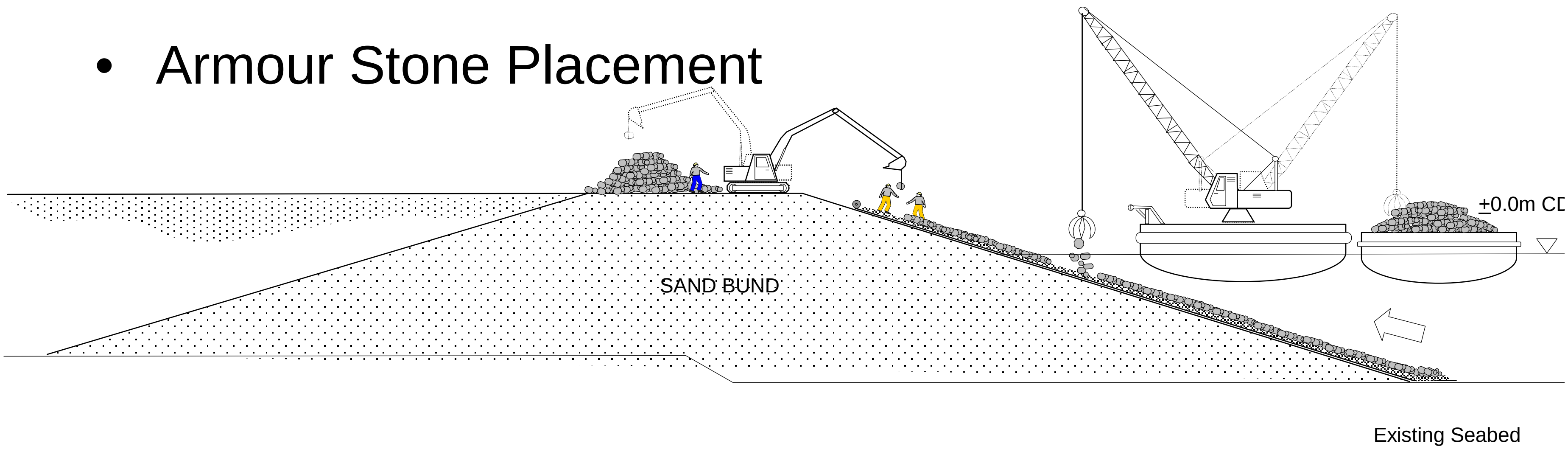


- **Class B & C material is stockpiled near the working area for both land and marine prior to placement of the fabric.**
- **Survey pegs at the crest line and at the slope down to the lowest water level are used as guides for the alignment of fabric during placement.**
- **Geo-fabric on roll is positioned at the crest (+4.53mCD) and unrolled down the slope to the water level with the aid of an excavator to control and maintain the proper alignment.**


JAN DE NUL Civil Works
02

Pulau Ubin/Pulau Tekong: Method Statement

- Armour Stone Placement



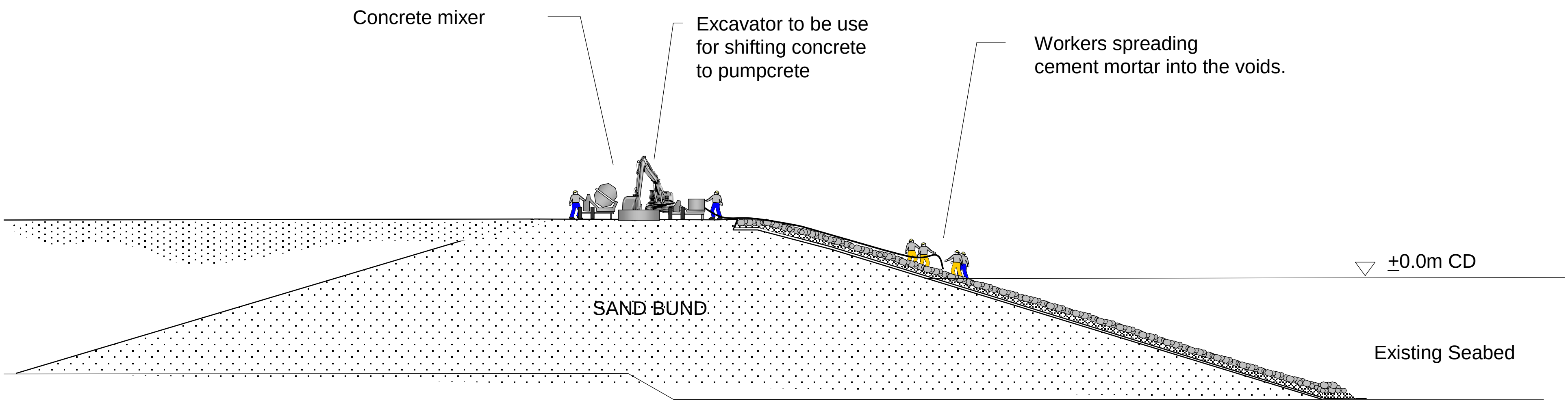
- **Upon successful inspection of the class ‘B’ profile, the placement of armour stones follows.**
- **For the lower part of the slope or below water level, armour stones are placed to the designed levels by a floating crane barge or by the hydraulic excavator on the pontoon starting from the bottom.**
- **Above ± 0.00m CD, each armour stone is placed / pitched tightly and accurately to the lines, levels and slopes as shown on the**


EE FONG
EE FONG


EE FONG

Pulau Ubin/Pulau Tekong: Method Statement

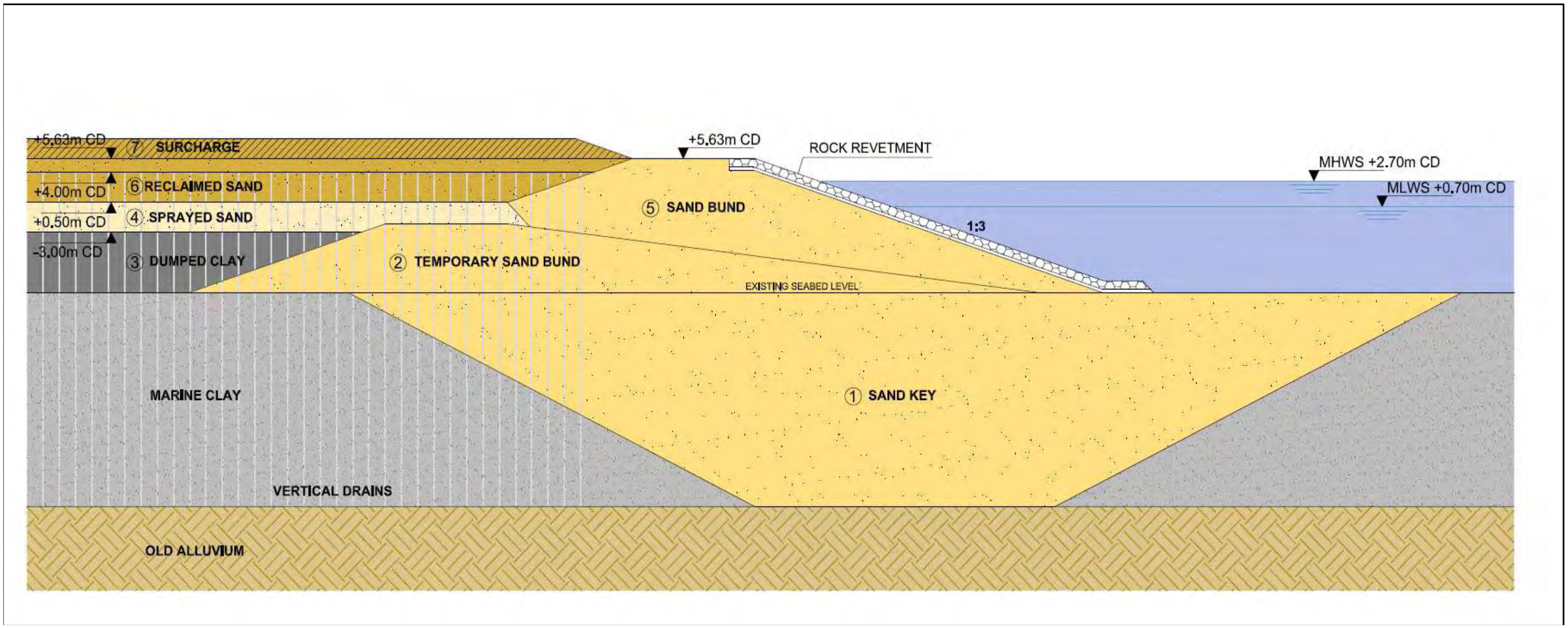
- Cement mortar placement



- **Upon the success of armour stone profile inspection, and once the expected sand bund settlement was obtained, gaps between armouring stones from elevation +1.5mCD shall be filled up by cement mortar.**
- **Cement mortar shall be mixed on site and suitable concrete pump shall be used for placement.**


KOBELCO

Singapore: Reclamation of Pulau Ubin and Pulau Tekong Islands



Singapore, Pulau Ubin and Pulau Tekong Reclamation and Rock-Works (2000-2005)

Volume

- Dredging of sandkey trenches and filling with sand (dredging depth -20 mCD to -60 mCD): 20,400,000 m^3
- Construction of sand bunds including vibroflotation: 23,700,000 m^3
- Infilling of reclamation area with dredged clay: 15,000,000 m^3
- Filling on top of the marine clay with sand: 150,000,000 m^3
- Installation of geofabric: 1,000,000 m^2
- Construction of sloping rock revetment: 1,000,000 m^3
- Installation of Prefabricated Vertical Drains: 80,000,000 m
- Installation of a sheet pile wall serving as a silt curtain: 8.5km
- Installation and management of a staging ground receiving excavated good earth and soft clay from trucks for barging to Pulau Tekong: 6,300,000 m^3 GE / 10,500,000 m^3 SC
- Construction of a white sandy beach: 700,000 m^3
- Dredging of access channels, including rock blasting: 3,000,000 m^3
- Marine installation of gravel compaction piles: 74,000 m^3
- Installation of silt curtains with floaters: 6 km

Palm Jebel Ali, Dubai
Construction Phases

Dykes, Breakwaters and Coastal Defence

Palm Jebel Ali Construction Phases

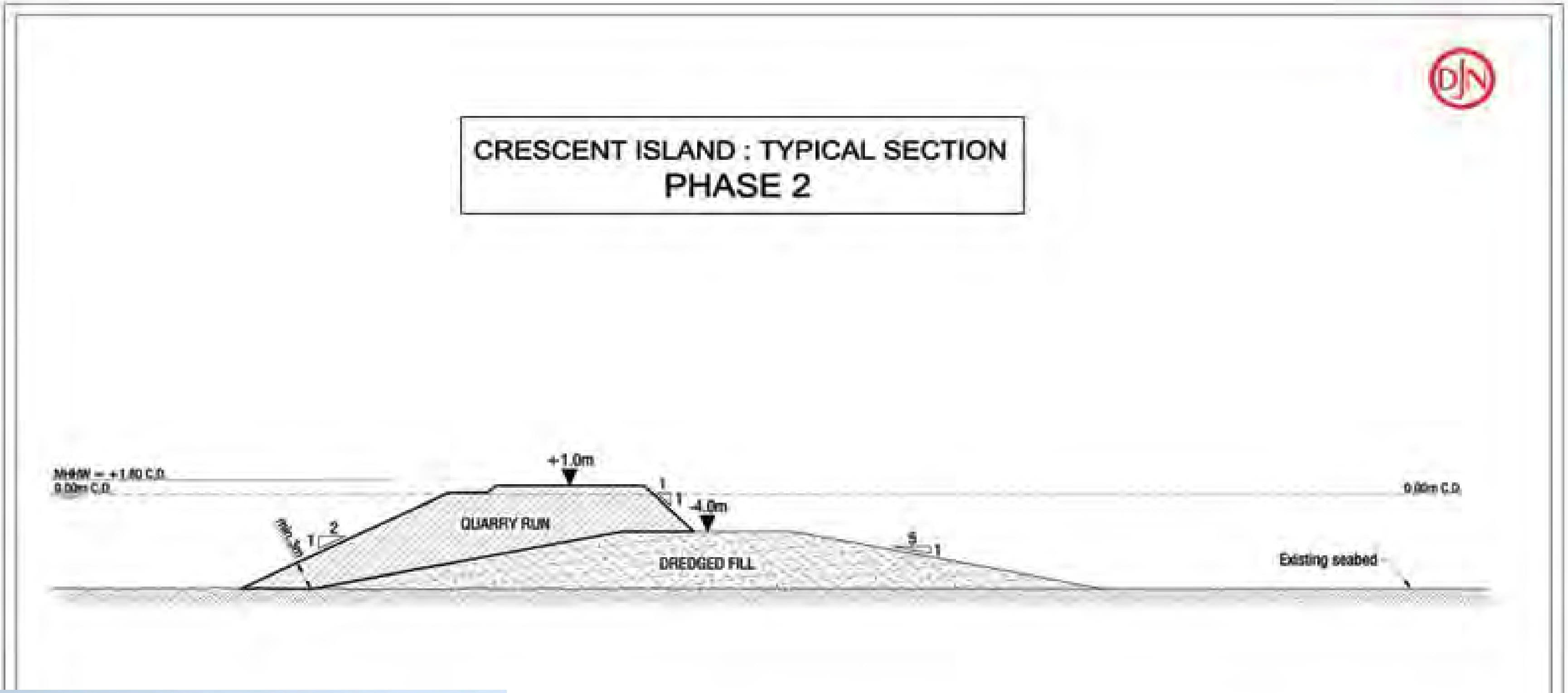
Landfill works with THSD's 'Juan Sebastian de Elcano'

CRESCENT ISLAND : TYPICAL SECTION
PHASE 1

PALM ISLAND 2
CRESCENT ISLAND

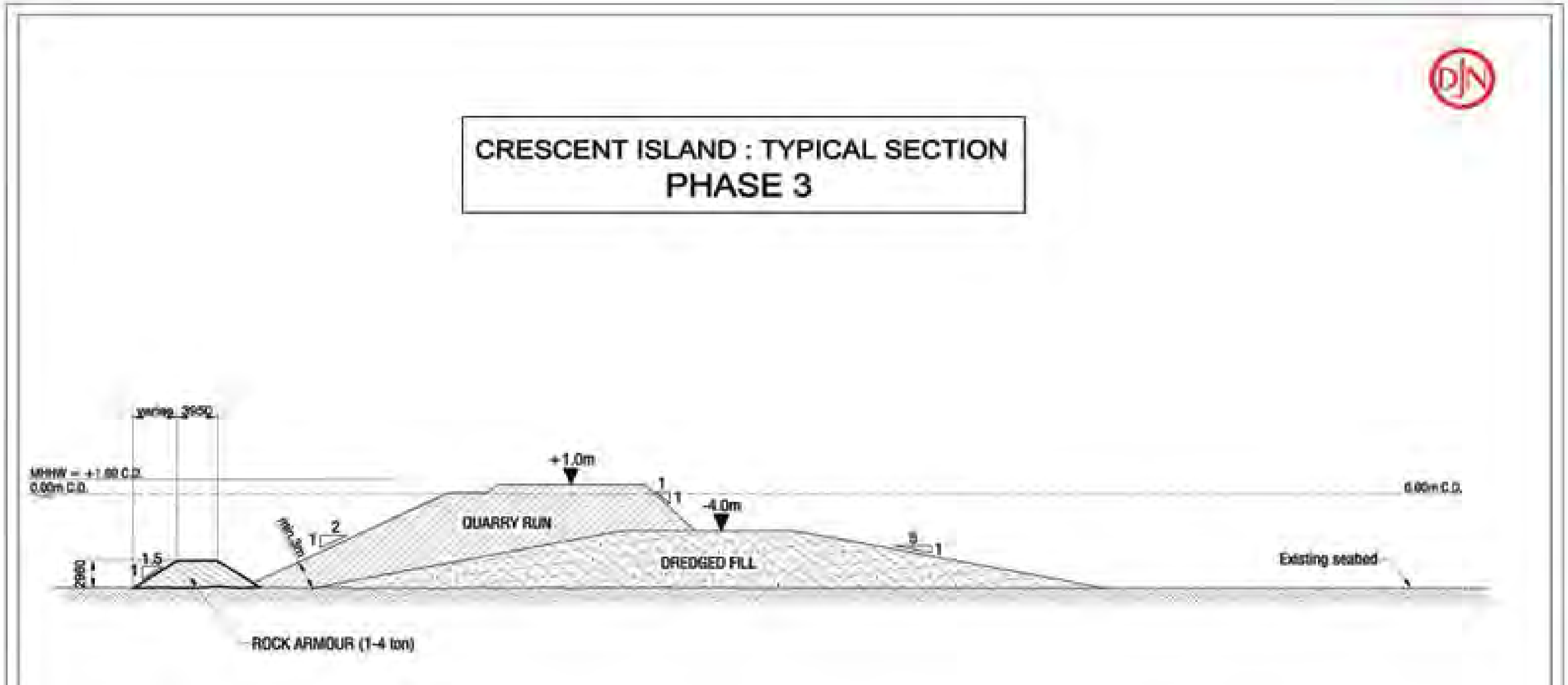
TYPICAL SECTION

SCALE : 1 / 400

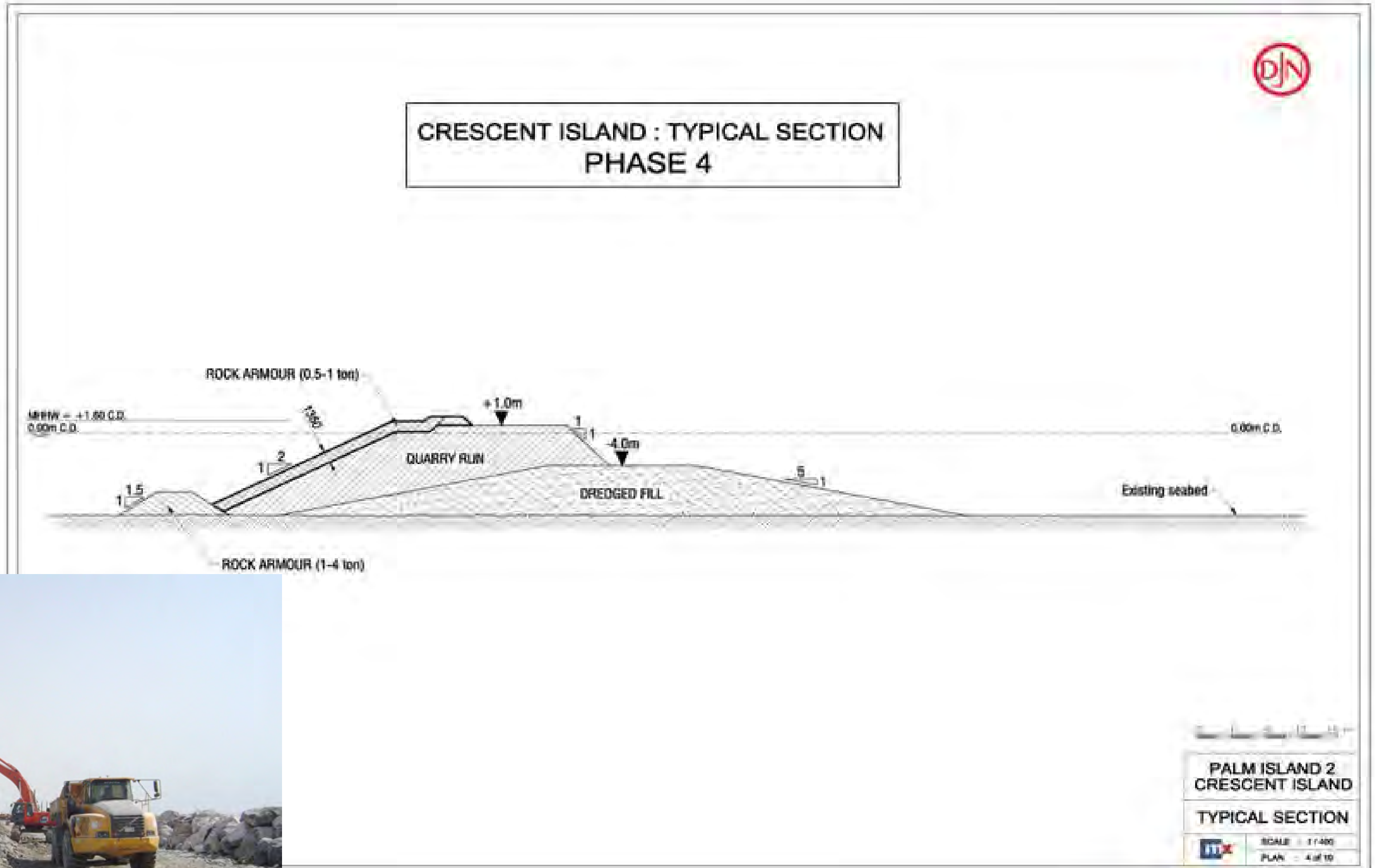

CRESCENT ISLAND : TYPICAL SECTION
PHASE 2
+1.0m
-4.0m
QUARRY RUN
DREDGED FILL
Existing seabed
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION

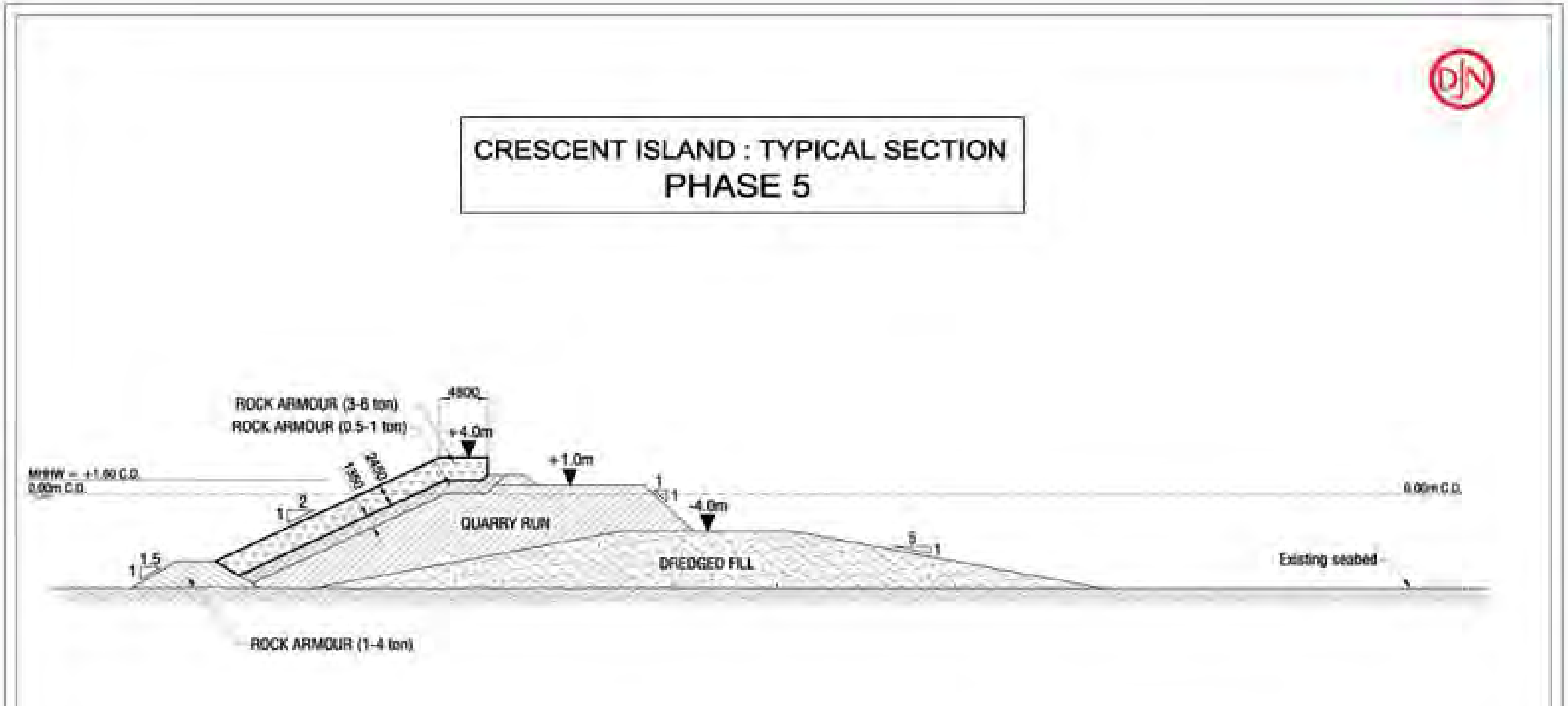

10 7 2004


11 8 2004

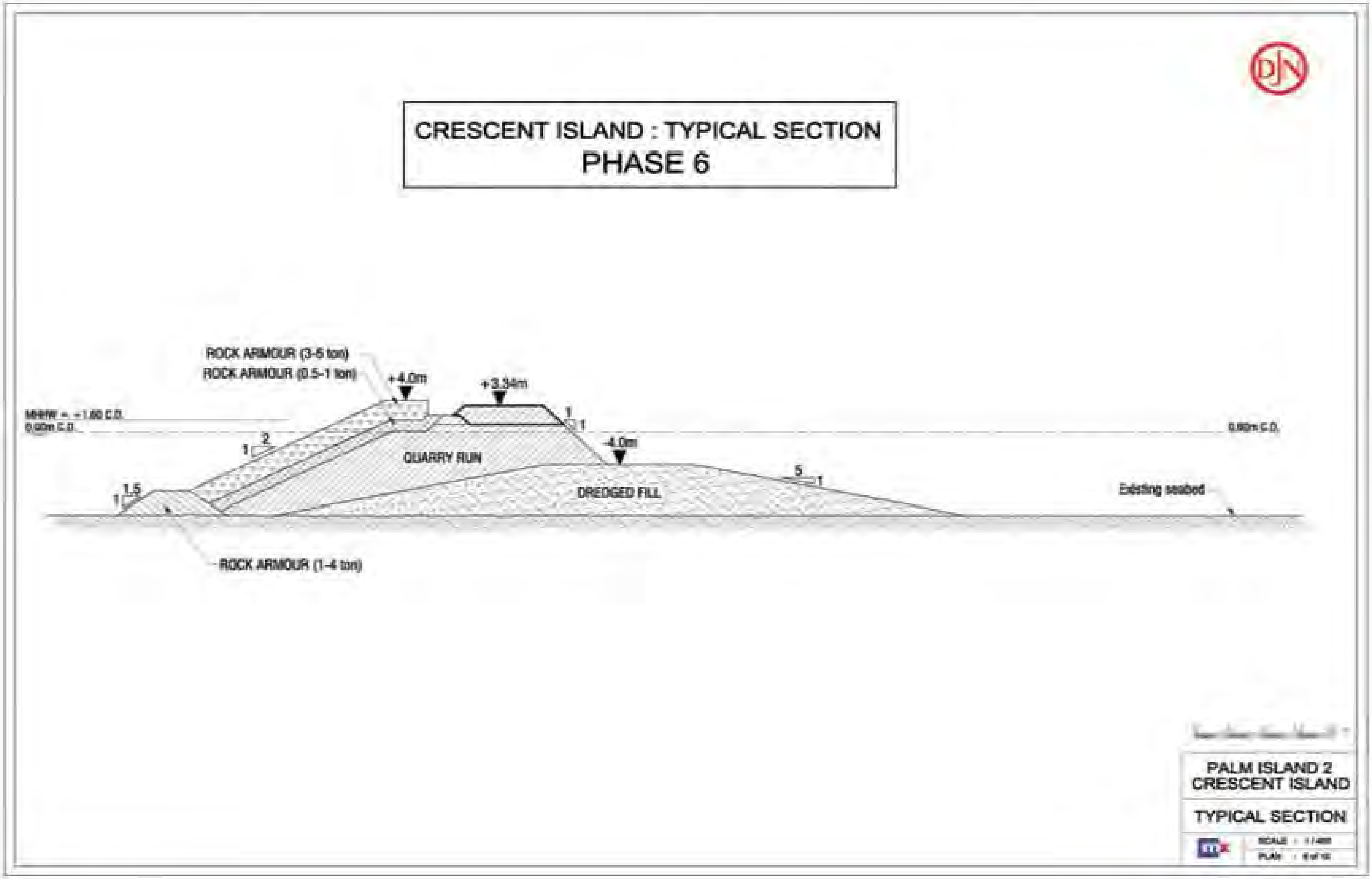

CRESCENT ISLAND : TYPICAL SECTION
PHASE 3
+1.0m
-4.0m
QUARRY RUN
DREDGED FILL
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION

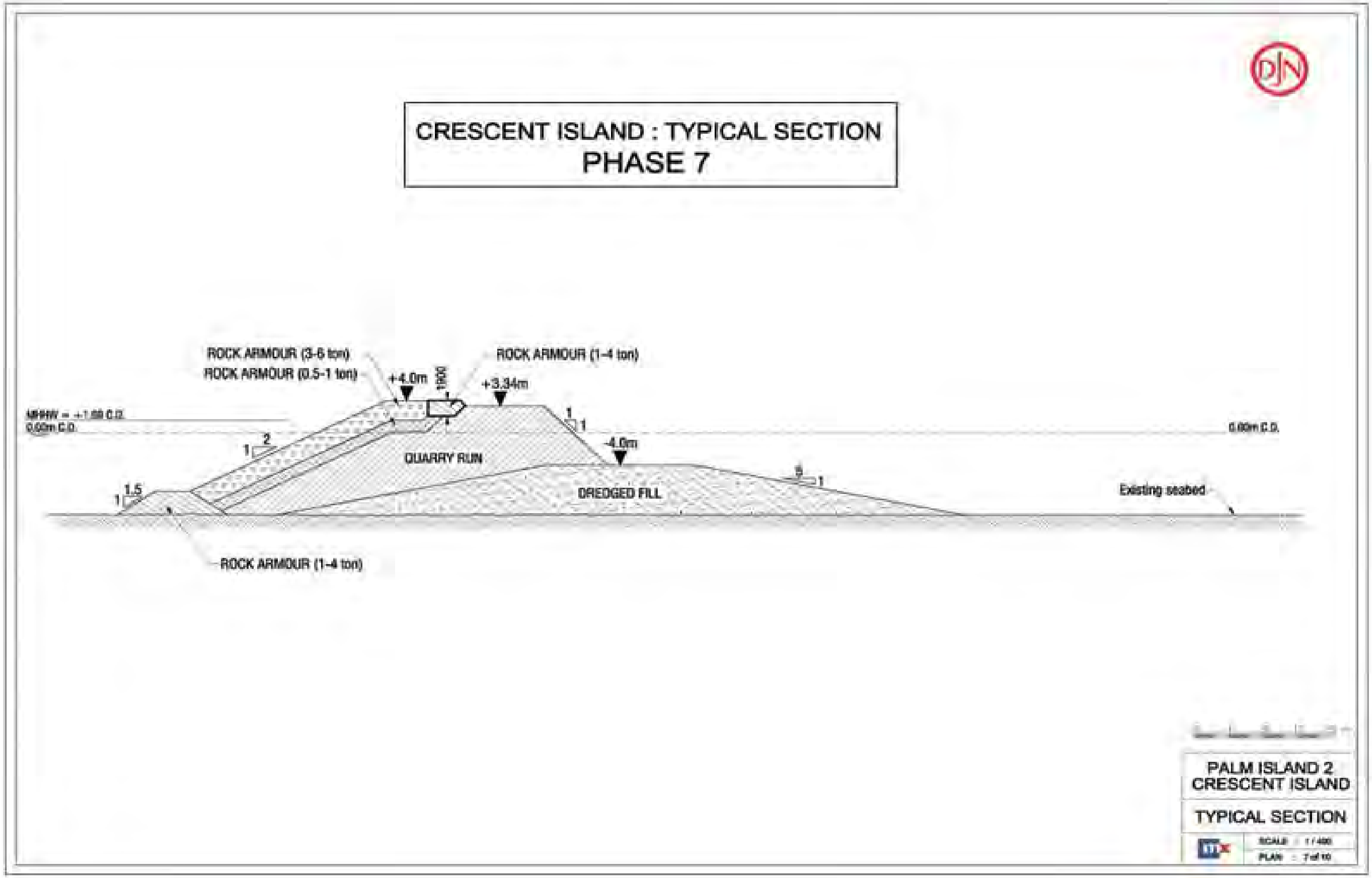
Dykes, Breakwaters and Coastal Defence

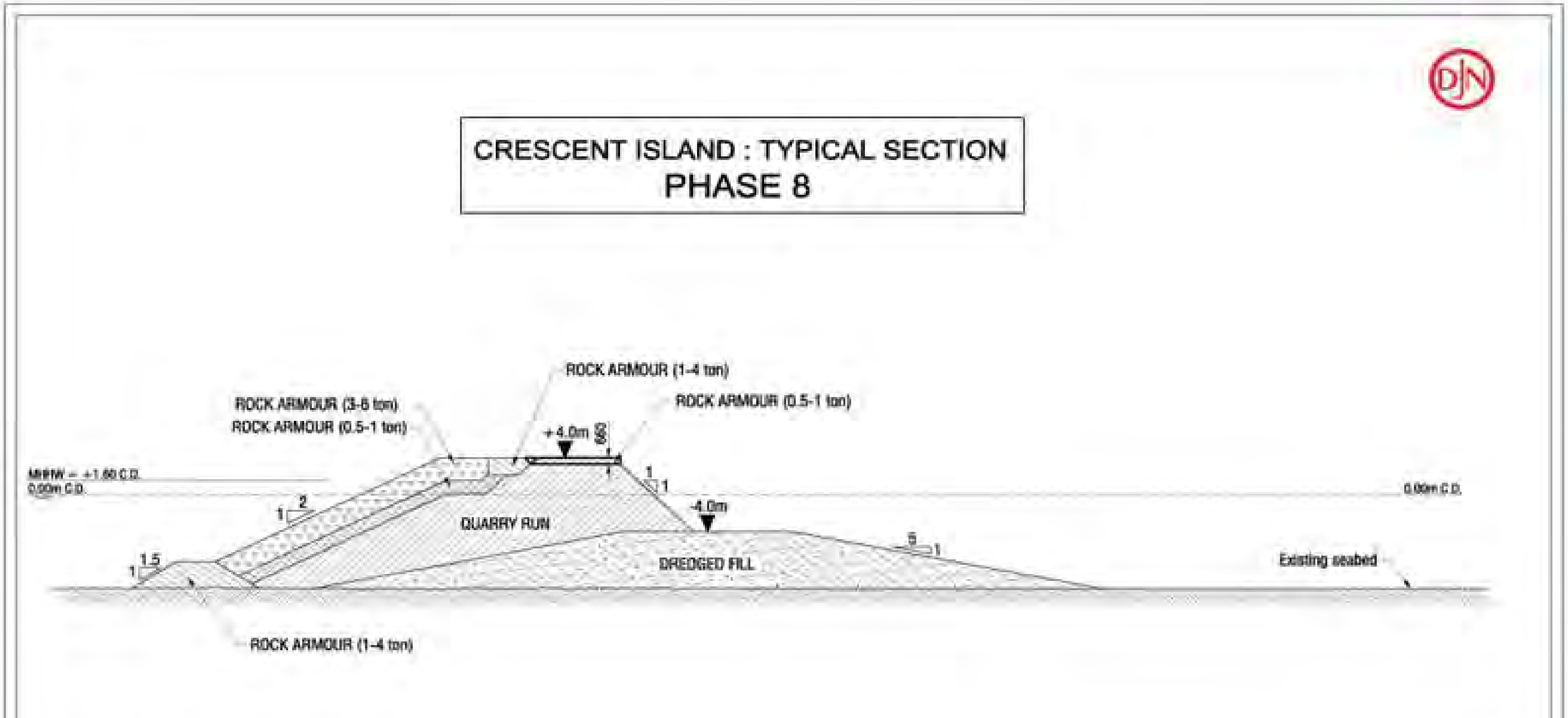


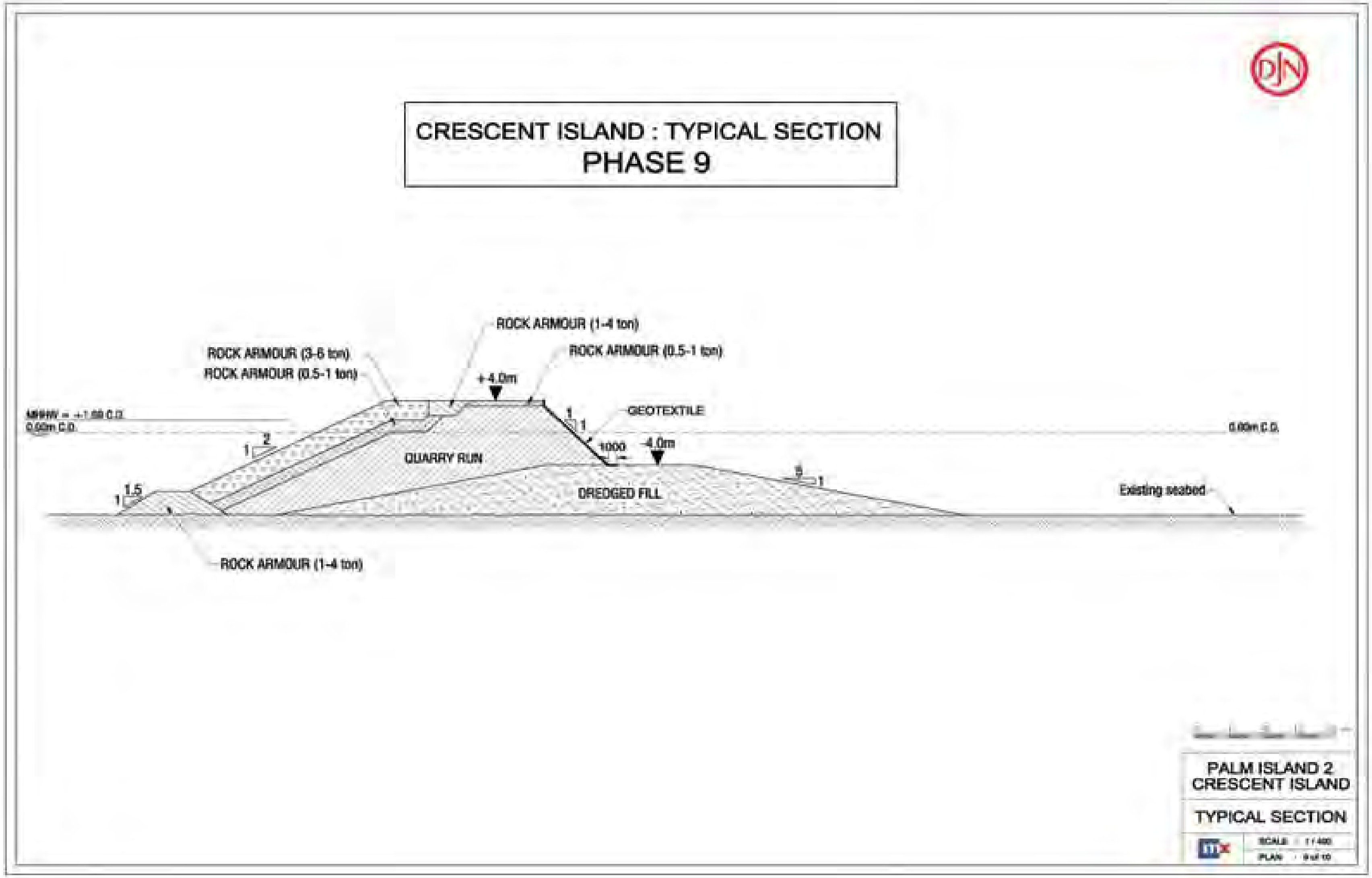

CRESCENT ISLAND : TYPICAL SECTION
PHASE 5
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
4800
+4.0m
+1.0m
-4.0m
QUARRY RUN
DREDGED FILL
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION

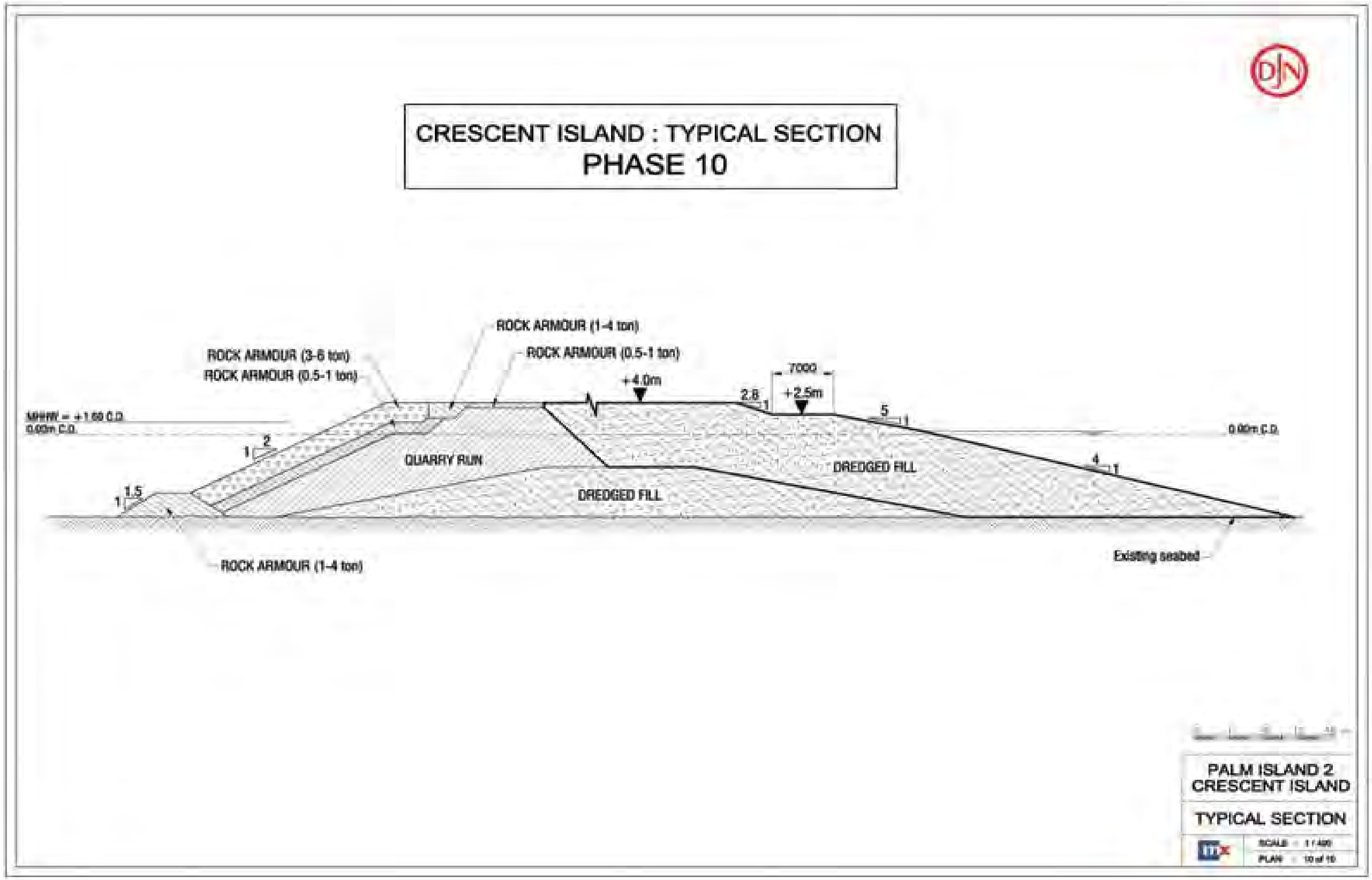

3 7 2004


CRESCENT ISLAND : TYPICAL SECTION
PHASE 6
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
+4.0m
+3.34m
0.00m C.D.
QUARRY RUN
-4.0m
DREDGED FILL
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION


CRESCENT ISLAND : TYPICAL SECTION
PHASE 7
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
+4.0m
1900
ROCK ARMOUR (1-4 ton)
+3.34m
0.00m C.D.
1
2
1.5
1
QUARRY RUN
-4.0m
DREDGED FILL
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION


CRESCENT ISLAND : TYPICAL SECTION
PHASE 8
ROCK ARMOUR (1-4 ton)
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
ROCK ARMOUR (0.5-1 ton)
+4.0m
MHHW = +1.60 C.D.
0.00m C.D.
QUARRY RUN
-4.0m
DREDGED FILL
0.00m C.D.
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION


CRESCENT ISLAND : TYPICAL SECTION
PHASE 9
ROCK ARMOUR (1-4 ton)
ROCK ARMOUR (0.5-1 ton)
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
+4.0m
GEOTEXTILE
0.00m C.D.
1000
-4.0m
QUARRY RUN
DREDGED FILL
Existing seabed
ROCK ARMOUR (1-4 ton)
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION


CRESCENT ISLAND : TYPICAL SECTION
PHASE 10
ROCK ARMOUR (1-4 ton)
ROCK ARMOUR (3-6 ton)
ROCK ARMOUR (0.5-1 ton)
ROCK ARMOUR (0.5-1 ton)
+4.0m
7000
2.8
+2.5m
5
1
QUARRY RUN
DREDGED FILL
DREDGED FILL
4
1
1.5
1
2
1
ROCK ARMOUR (1-4 ton)
Existing seabed
PALM ISLAND 2
CRESCENT ISLAND
TYPICAL SECTION

New Island Development (NID)

Scope
Reclamation and construction of underwater revetment berm

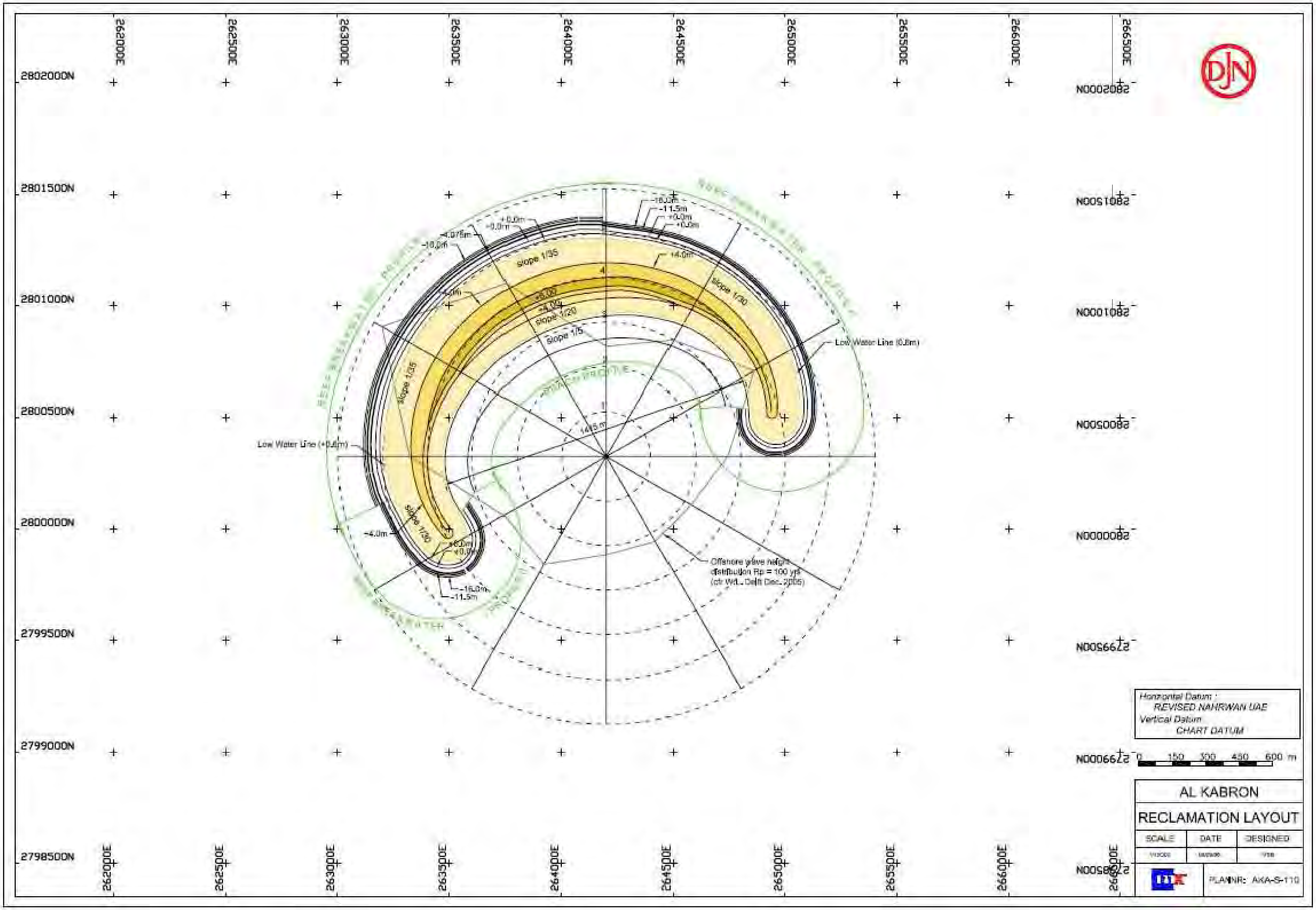
Soil
Sand and calcarenite

Volume
Dredging: 29 million m³
Reclamation: 29 million m³

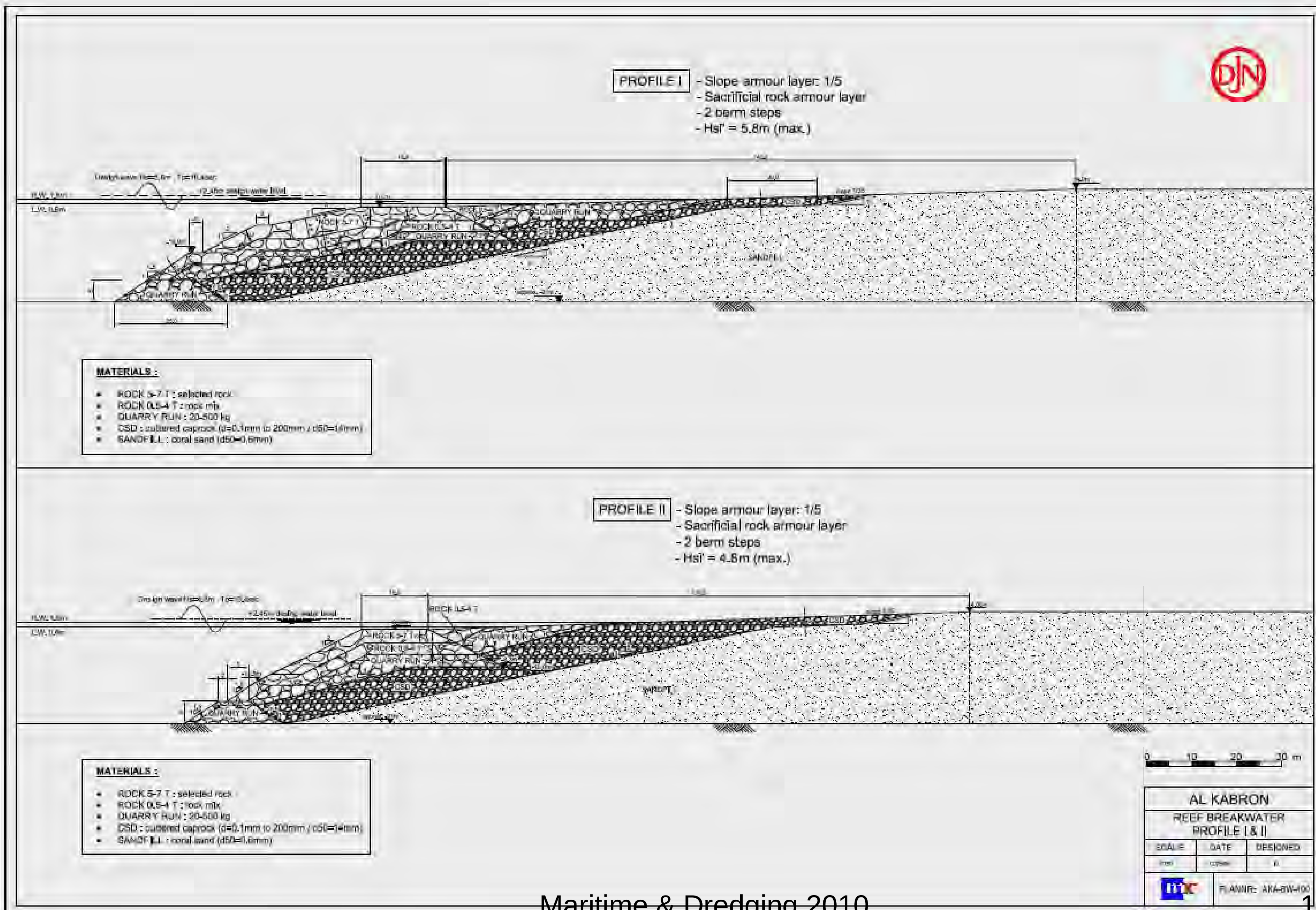
Dredgingdepth
Borrow area depths between 25 and 30 metres

Otherworks
Rock dumping: 3 million m³

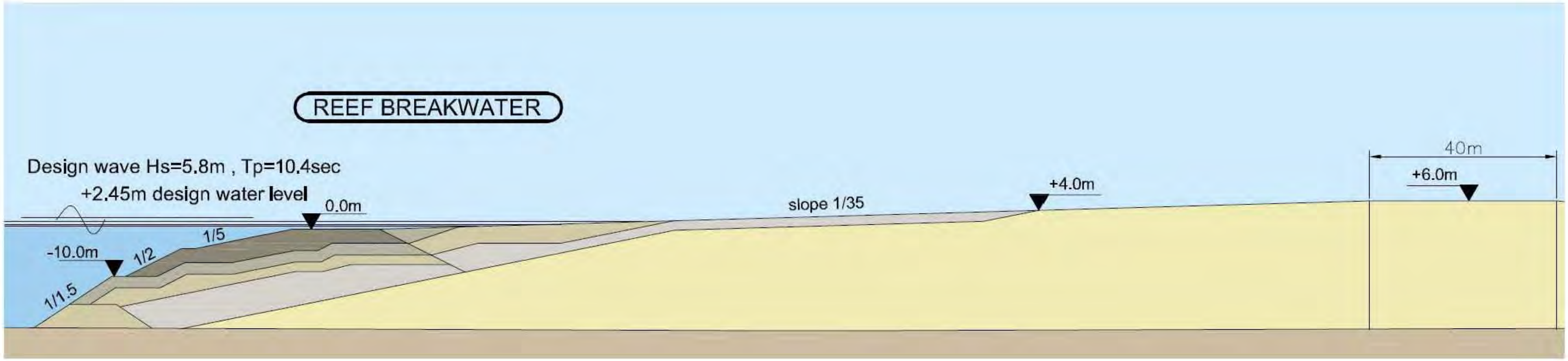
New Island Dedevelopment: Layout

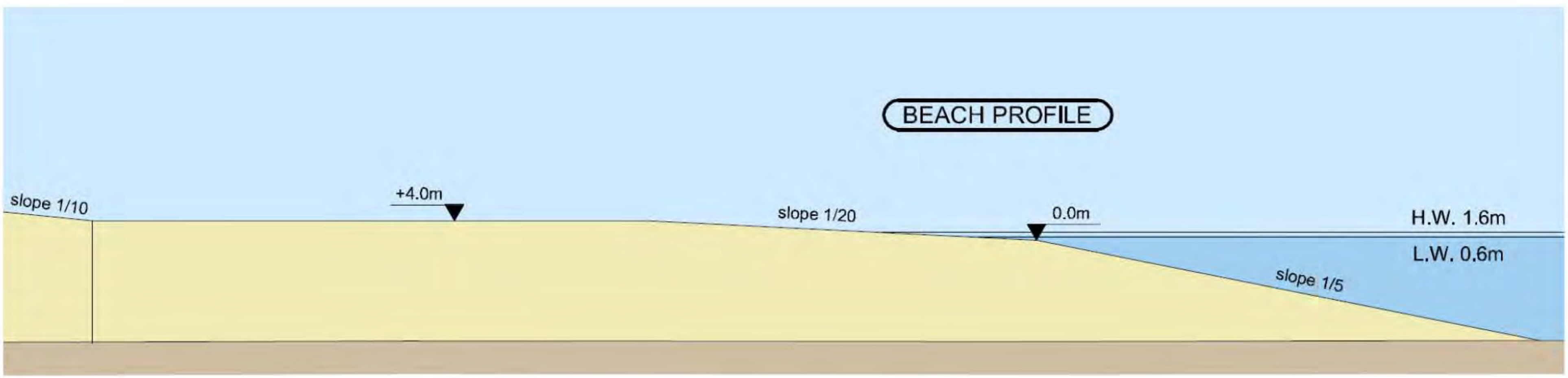


Engineering of Submerged “Reef” Breakwater

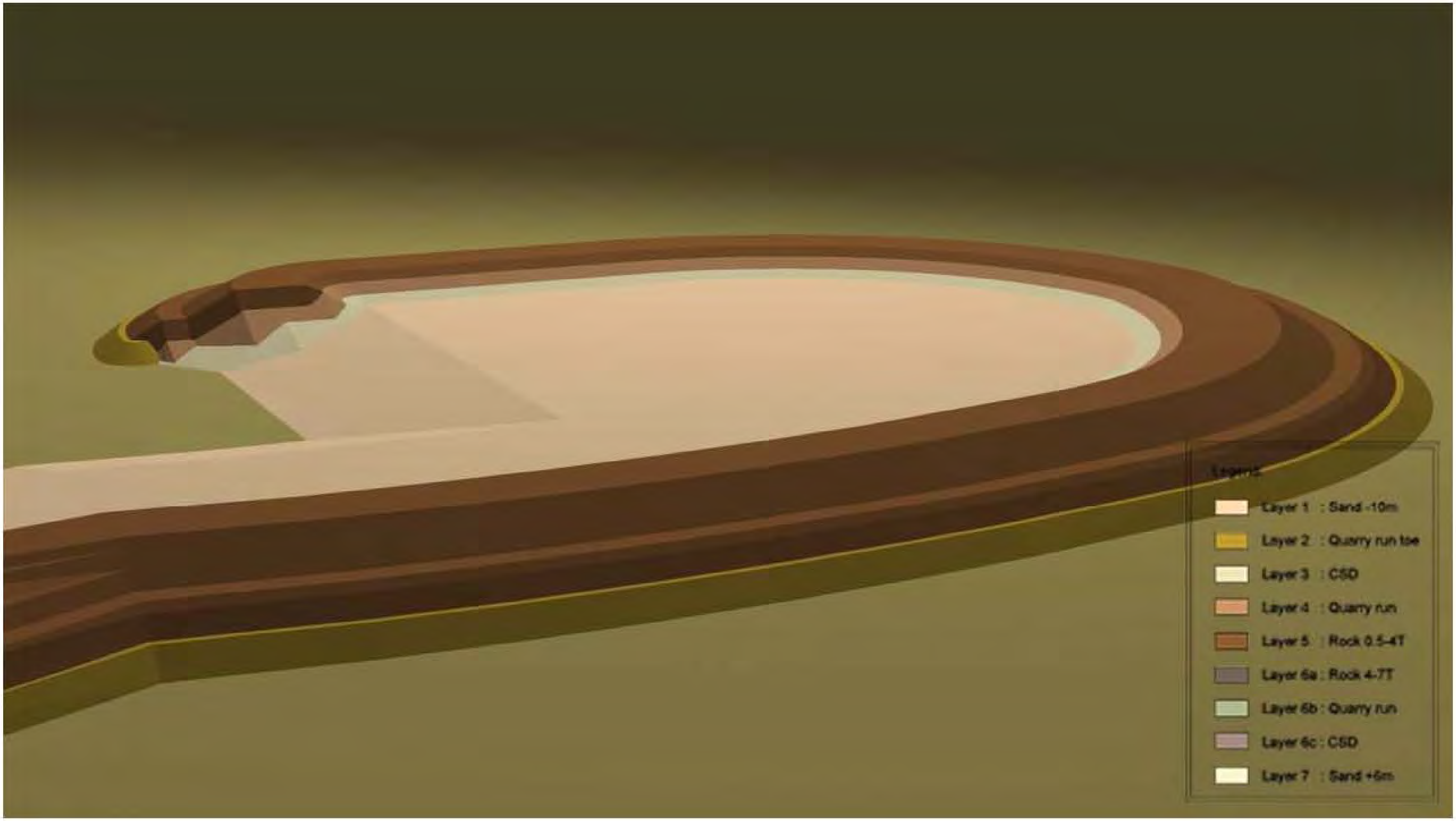


Submerged Shield Breakwater (New Island, Dubai)





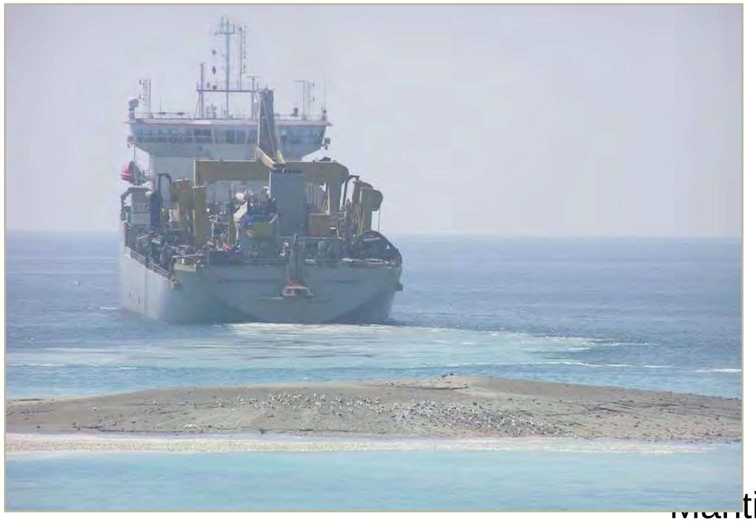
NID: Visualisation of Roundhead Structures

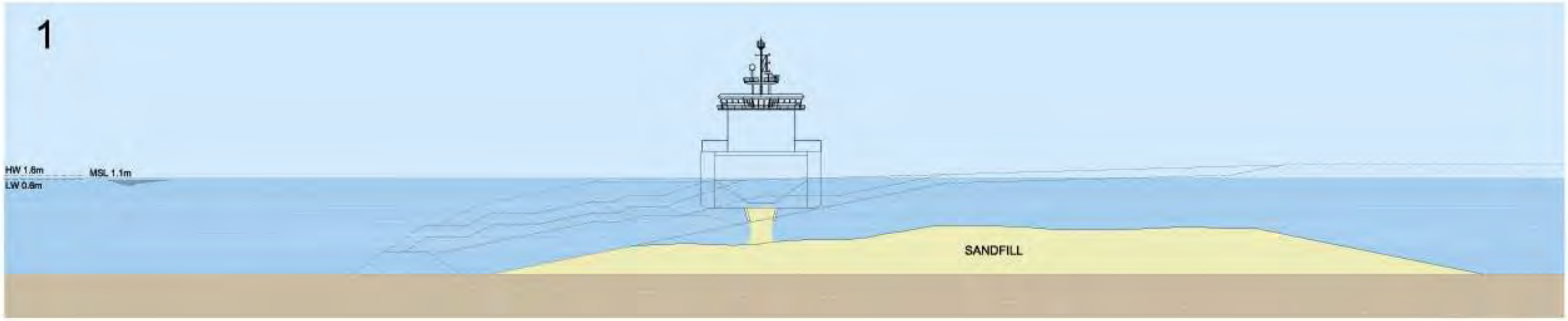


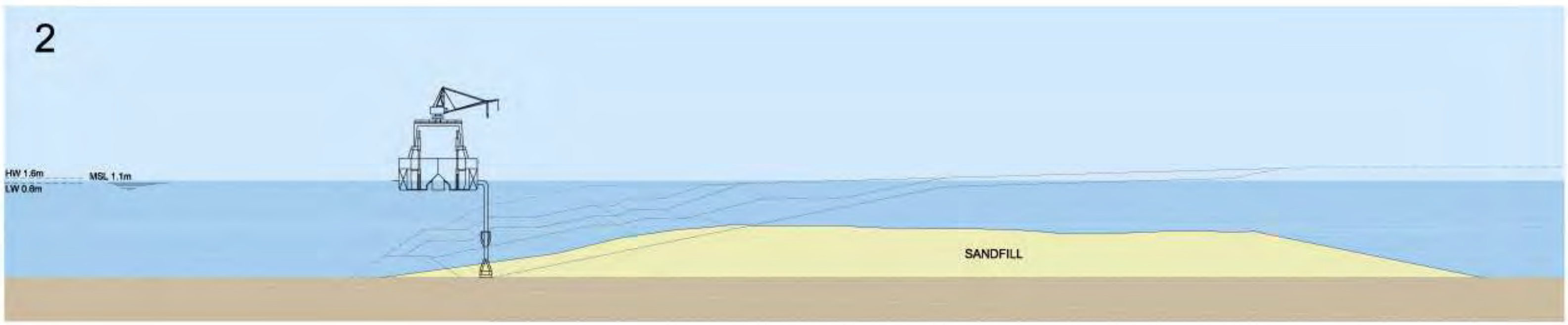
New Island Development (NID)

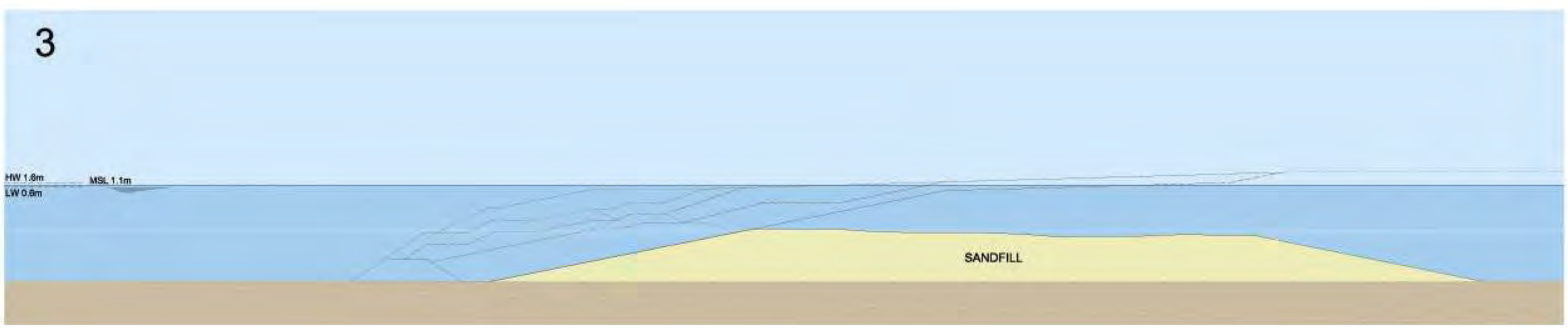
Equipment

- **TSHD Juan Sebastian De Elcano and Gerardus Mercator**
- **CSD J.F.J. De Nul**
- **2 split barges**
- **SSDV Pompei**
- **Positioning pontoon DN 121**
- **Rock transport barges DN 114, DN 115 and DN 116**
- **Split barge Verrazzano**

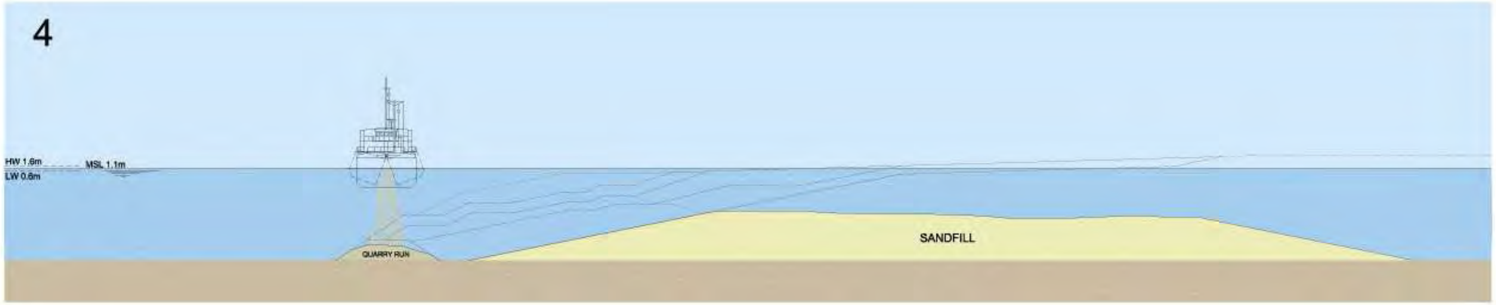



1
HW 1.6m
MSL 1.1m
LW 0.6m
SANDFILL

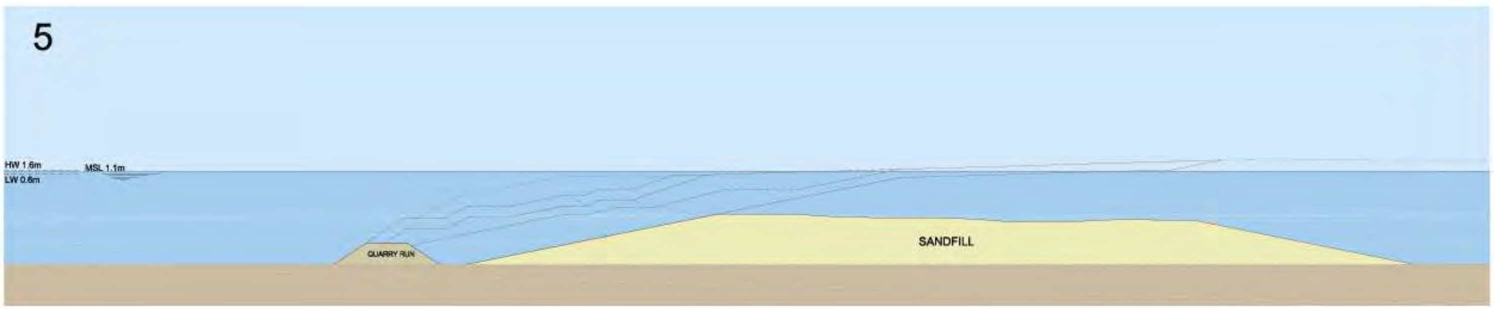

2
HW 1.6m
MSL 1.1m
LW 0.6m
SANDFILL


3
HW 1.6m
MSL 1.1m
LW 0.6m
SANDFILL

4


HW 1.6m
LW 0.6m
MSL 1.1m
QUARRY RUN
SANDFILL

5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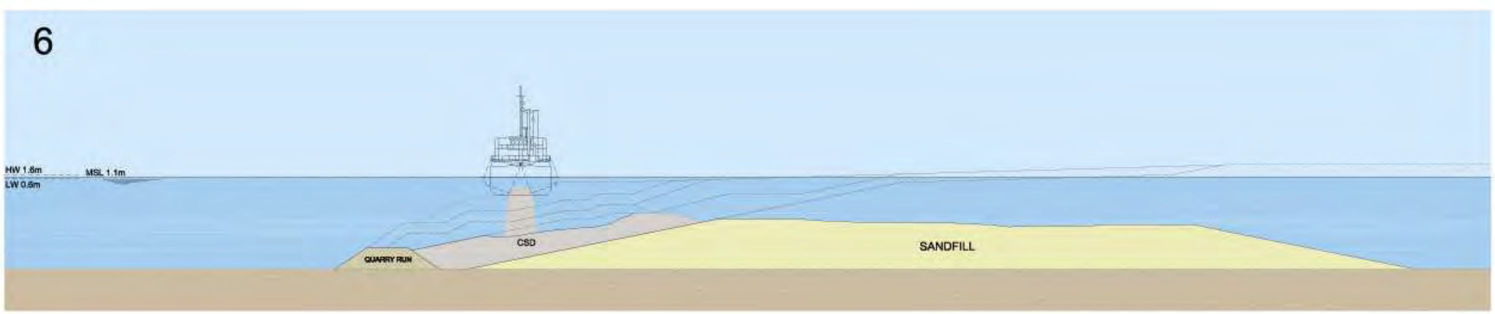
LW 0.6m
MSL 1.1m
QUARRY RUN
SANDFILL

6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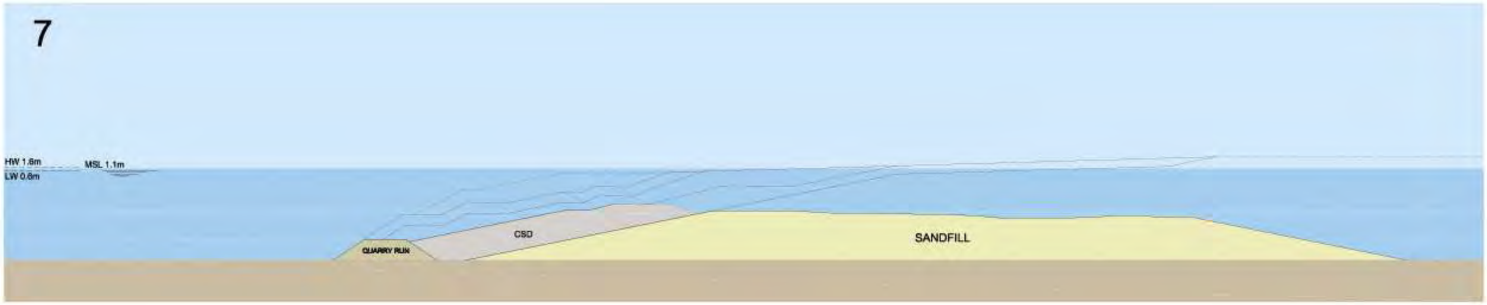
LW 0.6m
MSL 1.1m
CSD
QUARRY RUN
SANDFILL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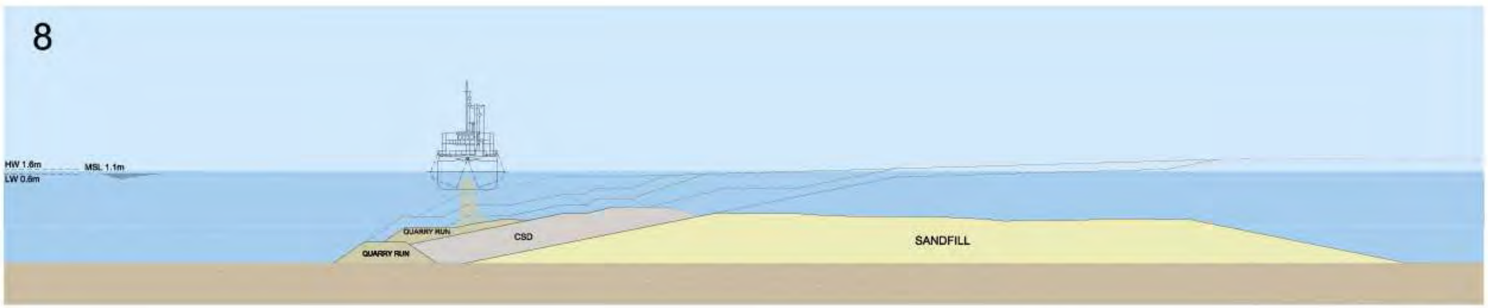
LW 0.6m
MSL 1.1m
QUARRY RUN
CSD
SANDFILL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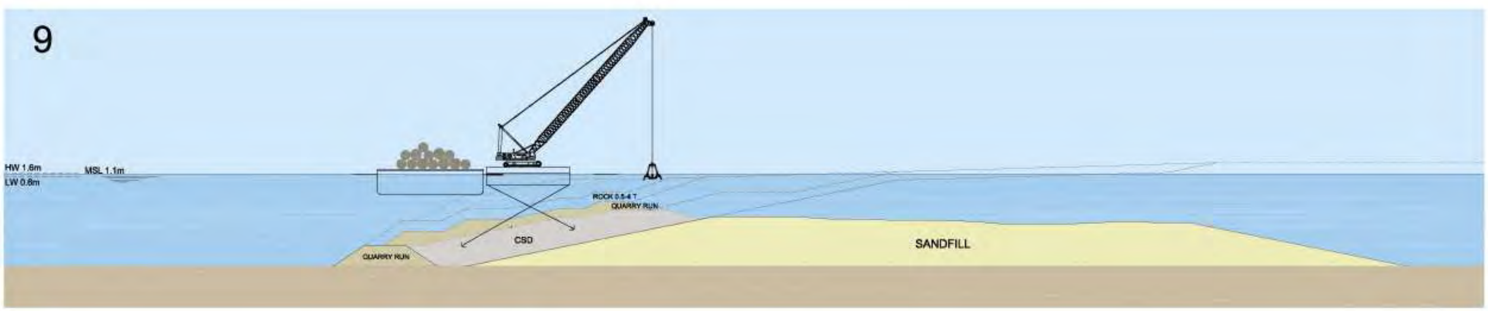
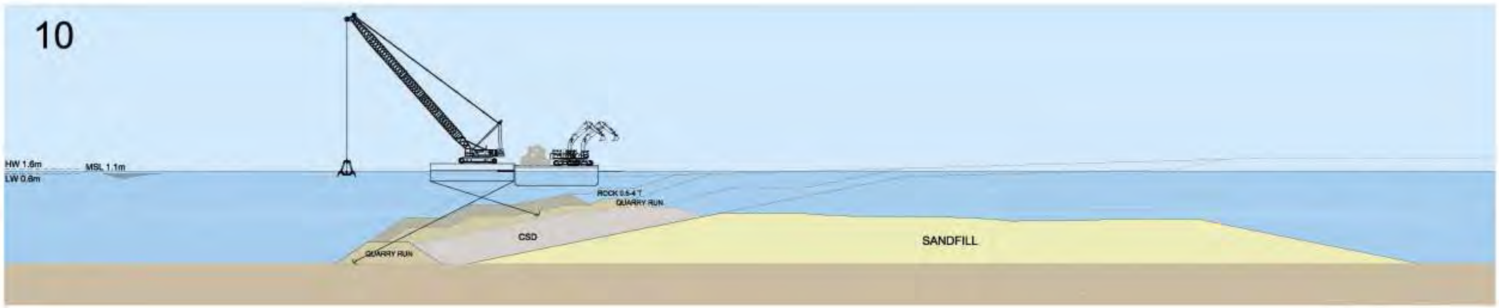
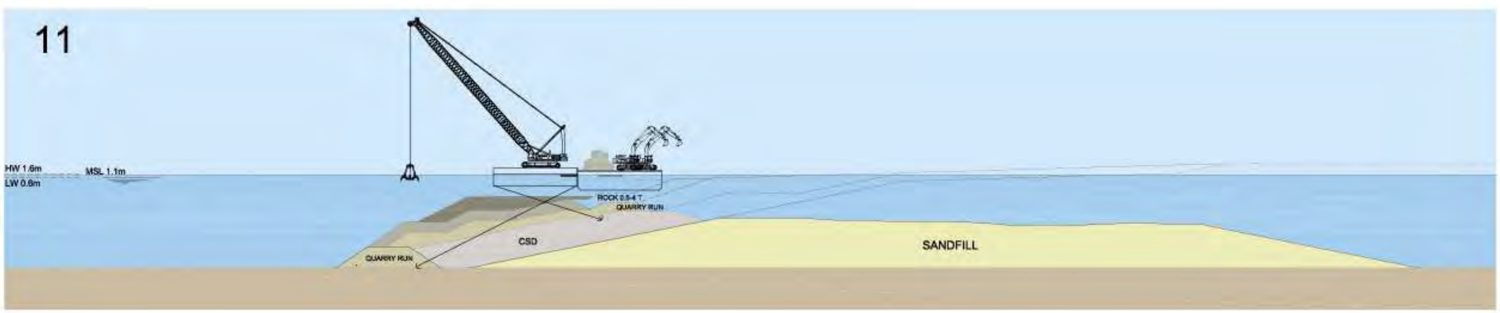
HW 1.6m
LW 0.6m
MSL 1.1m
QUARRY RUN
QUARRY RUN
CSD
SANDFILL


9
HW 1.6m
LW 0.6m
MSL 1.1m
ROCK 0.5-4 T
QUARRY RUN
CSD
QUARRY RUN
SANDFILL


SEA GLORY

NID in September 2008 (under construction)


10
HW 1.6m
LW 0.8m
MSL 1.1m
ROCK 0.5-4 T
QUARRY RUN
CSD
QUARRY RUN
SANDFILL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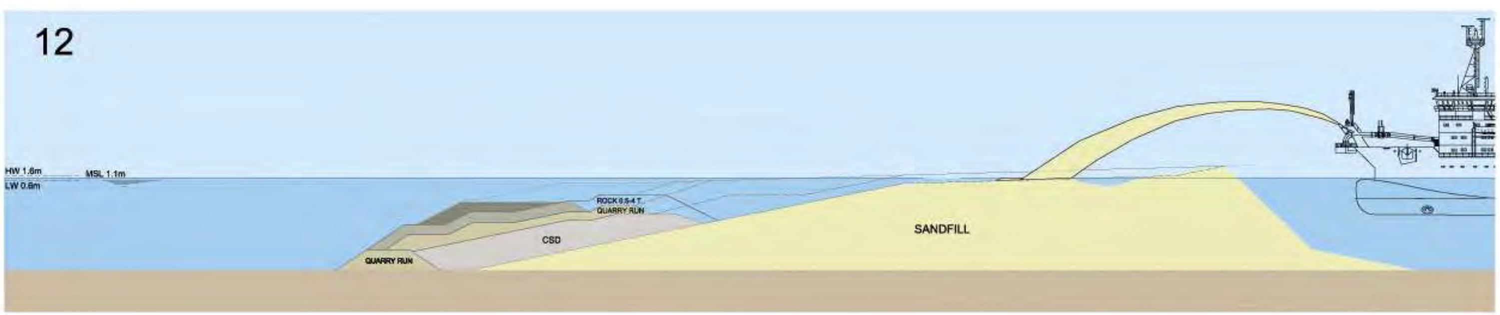
LW 0.8m
MSL 1.1m
ROCK 0.5-4 T
QUARRY RUN
CSD
QUARRY RUN
SANDFILL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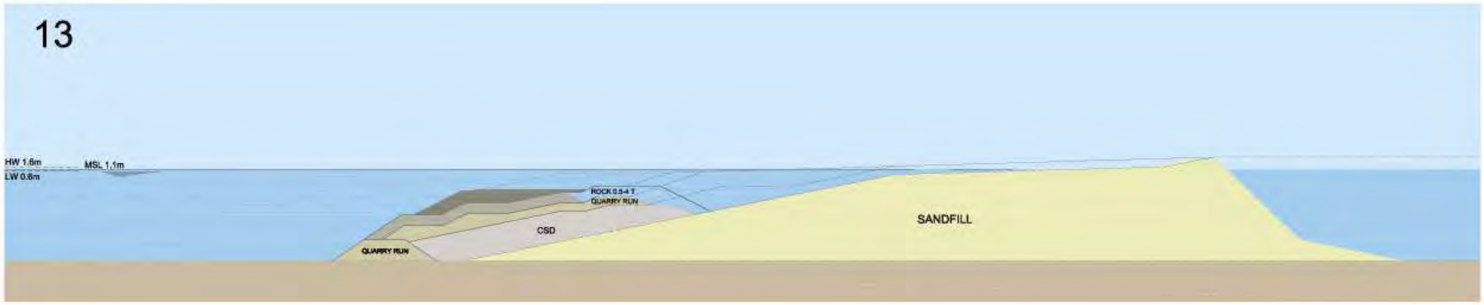
LW 0.8m
MSL 1.1m
ROCK 0.5-4 T
QUARRY RUN
CSD
QUARRY RUN
SANDFILL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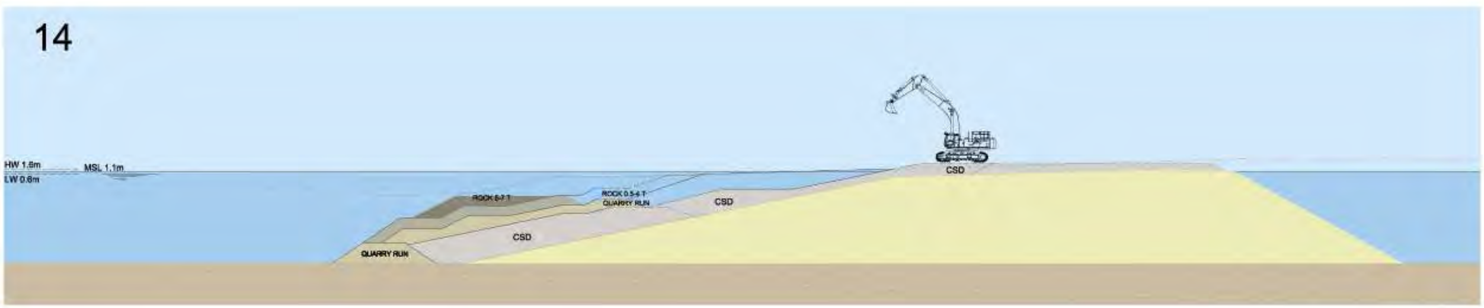
HW 1.6m
MSL 1.1m
LW 0.6m
ROCK 0.5-4 T
QUARRY RUN
CSD
SANDFILL
QUARRY RUN


14
HW 1.6m
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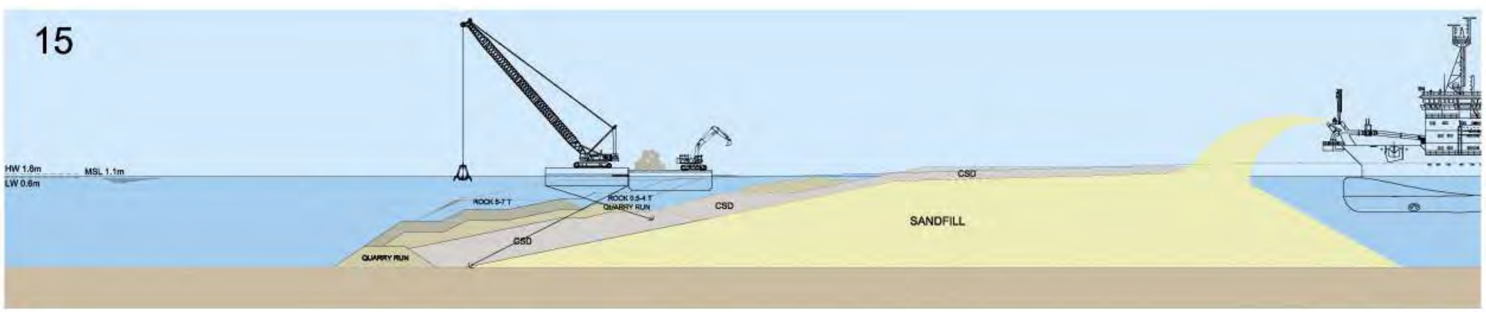
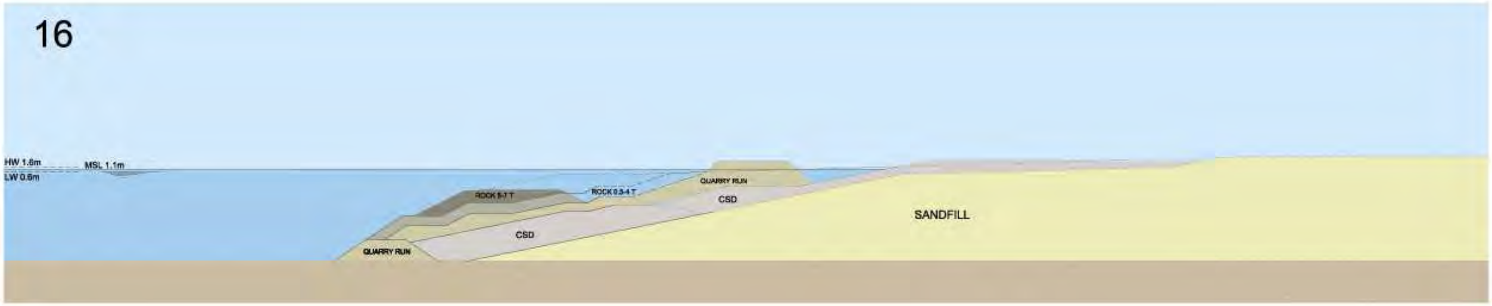
LW 0.6m
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
CSD
CSD
QUARRY RUN


15
HW 1.6m
MSL 1.1m
LW 0.6m
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
CSD
CSD
SANDFILL
QUARRY RUN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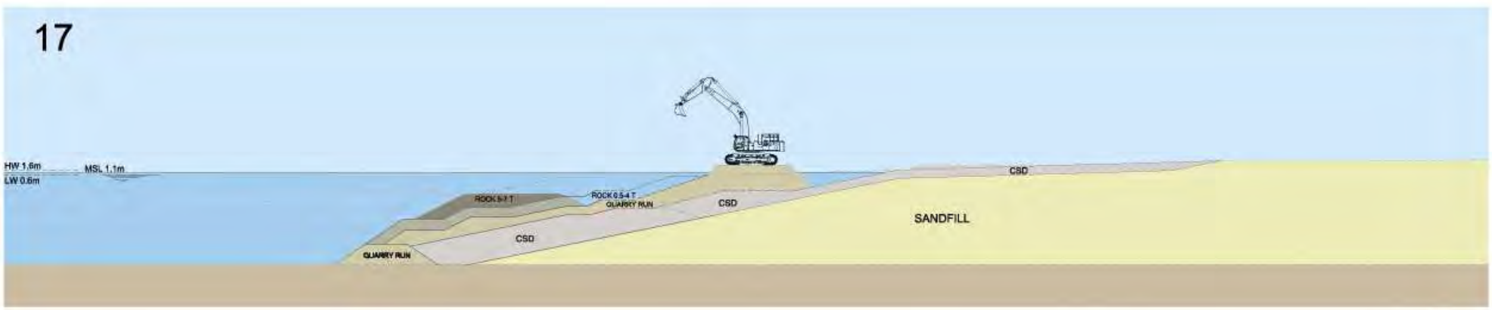
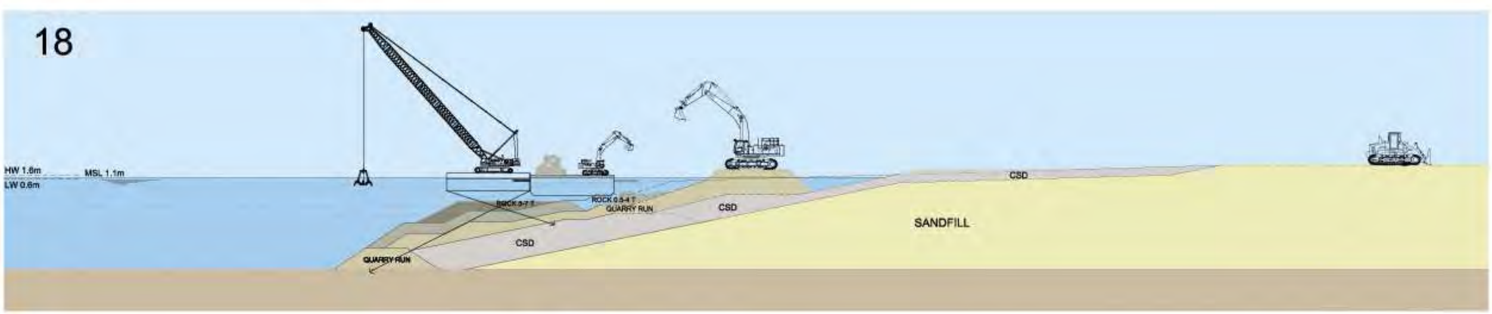
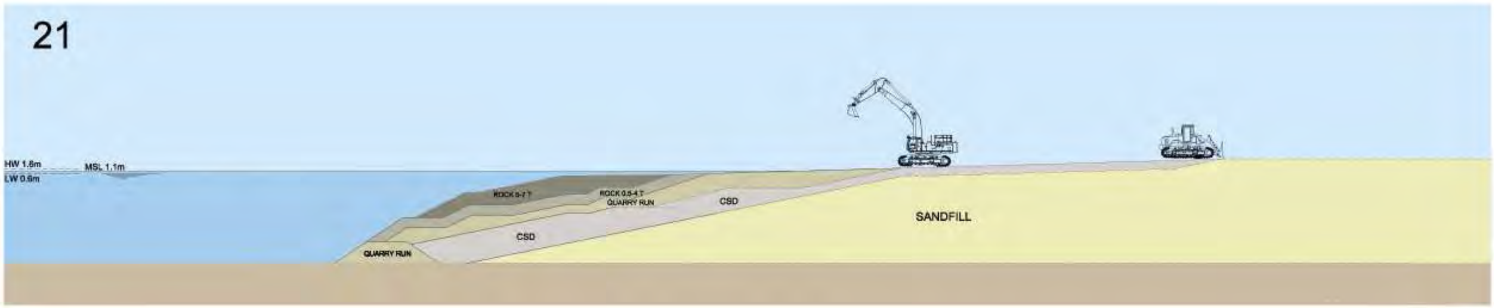
HW 1.6m
MSL 1.1m
LW 0.6m
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
CSD
SANDFILL
QUARRY RUN


17
HW 1.6m
MSL 1.1m
LW 0.6m
CSD
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
SANDFILL
CSD
QUARRY RUN


18
HW 1.6m
MSL 1.1m
LW 0.6m
CSD
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
SANDFILL
CSD
QUARRY RUN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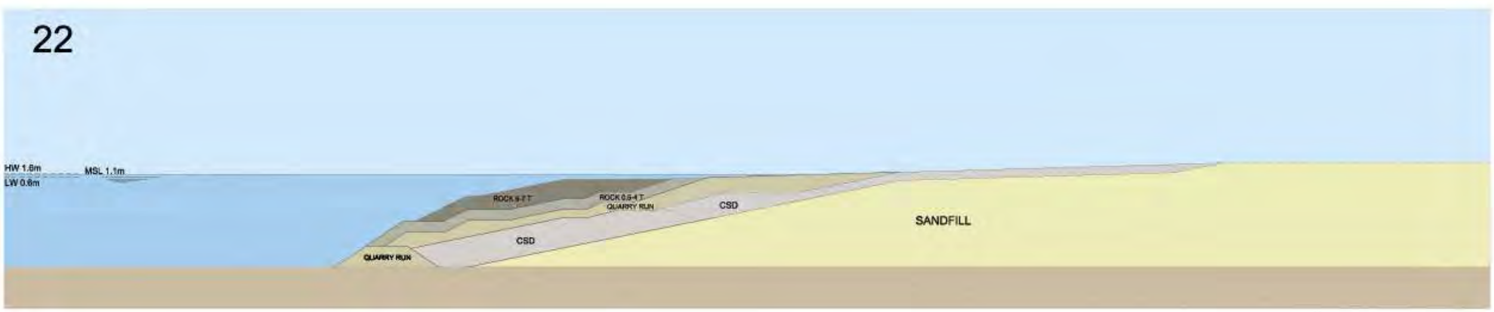
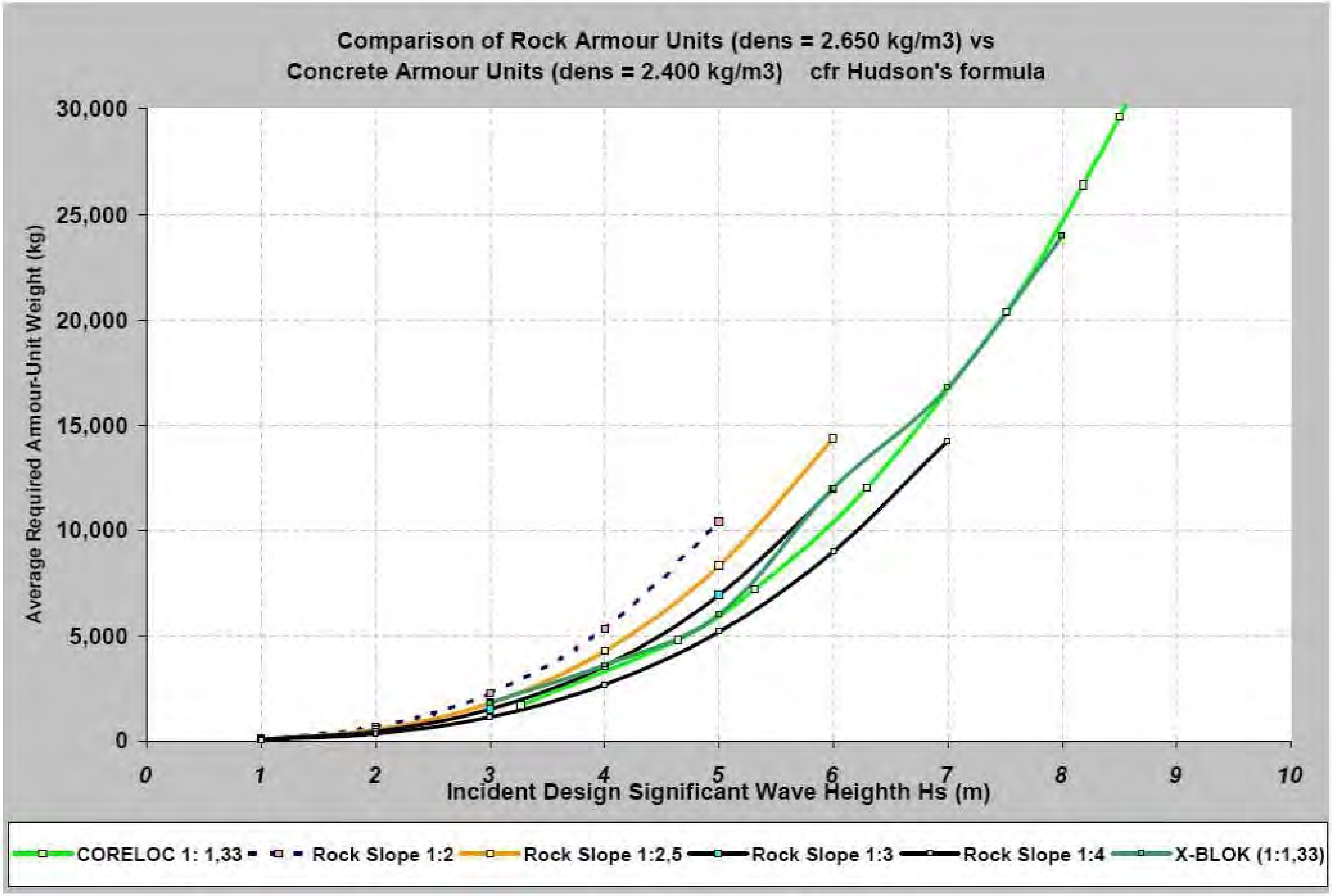
HW 1.8m
LW 0.6m
MSL 1.1m
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
CSD
QUARRY RUN
SANDFILL

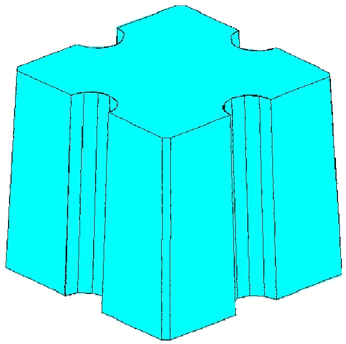

22
HW 1.8m
LW 0.6m
MSL 1.1m
ROCK 5-7 T
ROCK 0.5-4 T
QUARRY RUN
CSD
CSD
QUARRY RUN
SANDFILL

New Island Development: June 2009

Errors in rubble-Mound Breakwaters NOT to make !

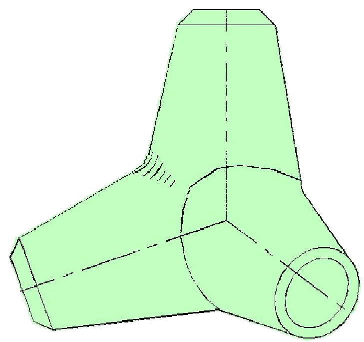

Comparison of Rock Armour Units (dens = 2.650 kg/m3) vs
Concrete Armour Units (dens = 2.400 kg/m3) cfr Hudson's formula
Average Required Armour-Unit Weight (kg)
30,000
25,000
20,000
15,000
10,000
5,000
0
0
1
2
3
4
5
6
7
8
9
10
Incident Design Significant Wave Heighth Hs (m)
CORELOC 1: 1,33
Rock Slope 1:2
Rock Slope 1:2,5
Rock Slope 1:3
Rock Slope 1:4
X-BLOK (1:1,33)

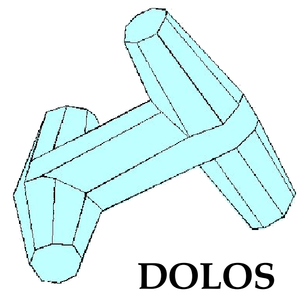
Armouring of Breakwaters with Concrete Armour Units, CAU's



ANTIFER CUBE

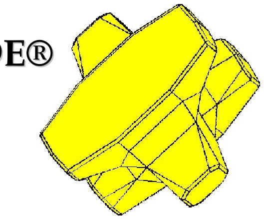
TETRAPOD

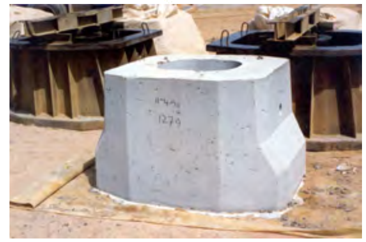




DOLOS

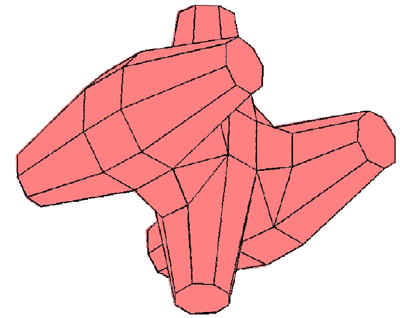
ACCROPODE®



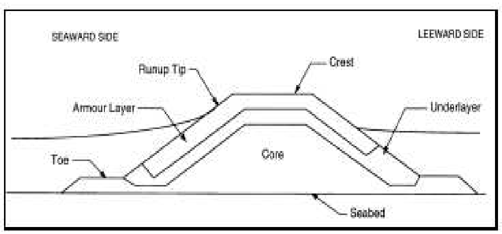


HARO

CORE-LOC™



Xbloc



$$W = \frac{w_r H^3}{K_D (S_r - 1)^3 \cot\theta}$$

Type of Armour Block	TETRAPOD	ANTIFER CUBE	HARO	ACCROPODE ®	CORE-LOC™
Number of Layers	2	2	2	1	1
Armour Slope H/V	3/2	3/2	3/2	4/3	4/3
Porosity %	50	45	51 - 53	52	60
Breaking Waves Kd	7*	9*	13,8	12	16
% Damage	5	5	0,5	0	0
Concrete Volume per m² of Slope	0.35 Hs	0.38 Hs	0.27 Hs	0.2 Hs	0.18 Hs
Relative Quantity of Concrete	1.9	2.0	1.3	1.0	0.9

CAU's

Type	Layers	History	Void Percentage	Concrete percentage
Antifer Cube	2	Developed in 1972 Sogreah (Fr)	45%	55%
Tetrapod	2	Developed in 1950 Sogreah	50%	50%
Dolos	2	Developed in 1970 (SA)	60%	40%
Accropode I	1	Developed in 1980 Sogreah	50%	50%
Accropode II	1	Developed in 1994 Sogreah	55%	45 %
Core-Loc	1	Developed in 2000 USACE & commercialised by Sogreah	60%	40%
Xbloc	1	Developed in 2004 DMC (Nl)	60%	40%

Placement-rythms of CAU's in Breakwaters

cyclus time for different CAU's:

Type	2,50 m3, 6 ton		5,00 m3, 12 ton		10,00 m3, 24 ton	
	[sec]	[min]	[sec]	[min]	[sec]	[min]
Kubus	150	2,50	200	3,33	250	4,17
Tetrapod	200	3,33	250	4,17	300	5,00
Accropod	250	4,17	300	5,00	375	6,25

Hourly productions at 3.000 working seconds per hour:

Type	2,50 m3, 6 ton	5,00 m3, 12 ton	10,00 m3, 24 ton
	[pcs/hr]	[pcs/hr]	[pcs/hr]
Kubus	20,00	15,00	12,00
Tetrapod	15,00	12,00	10,00
Accropod	12,00	10,00	8,00

Port of Rades: Armouring with Accropode I

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SOGREAH CONSULTANTS

ACCROPODE™

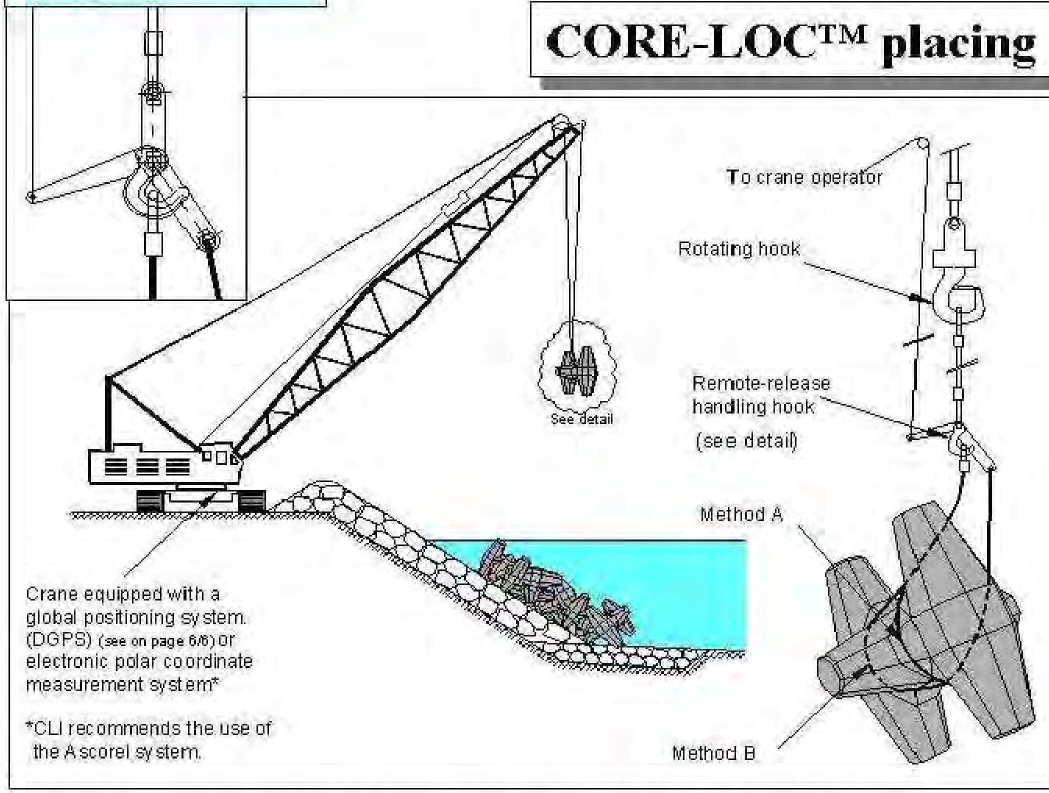
Shed Armouring Units (Limassol Marina)

Port of Zeebrugge: Sand retention breakwaters armoured with HARO’s

C L I
CORE-LOC™ International

CORE-LOC™ placing

Remote-release handling
Hook detail



Filter layer requirements: W/15 to W/7 (where W is the CORE-LOC™ unit weight)
Filter layer tolerances: C/6 (where C is the unit height)

Single-layer
CORE-LOC™ armouring

CORE-LOC® is a trademark of the US Army Corps of Engineers USA

CORE-LOC® est une marque déposée par l'US Army Corps of Engineers USA

SOGREAH CONSULTANTS

CORE-LOC®

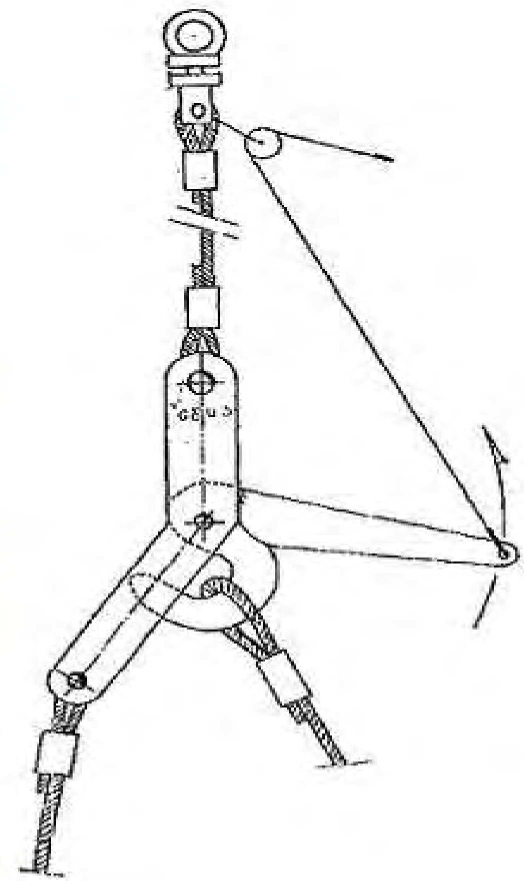
ACCROPODE™ is a trademark of SOGREAH - France

SOGREAH CONSULTANTS

ACCROPODE™

ACCROPODE™ est une marque déposée par SOGREAH - France

ACCROPODE™ is a trademark of SOGREAH - France



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ACCROPODE™

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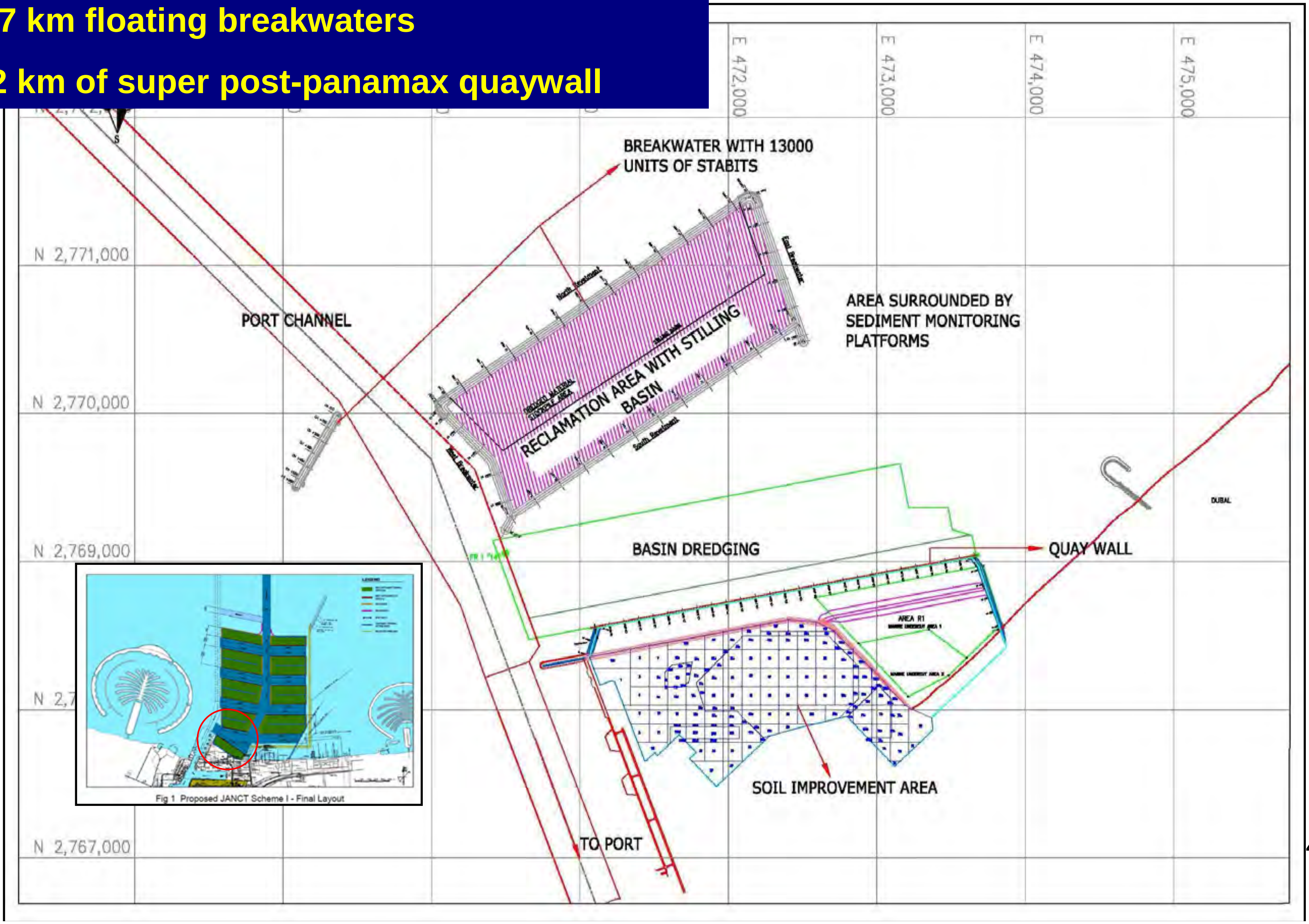
SOGREAH CONSULTANTS

ACCROPODE™

Key Figures:

- **23 Mm3 of dredging**
- **9 km of rubble-mound breakwaters**
- **1,7 km floating breakwaters**
- **2,2 km of super post-panamax quaywall**

Jebel Ali New Container Terminal Phase 1



Jebel Ali New Container Terminal Extension

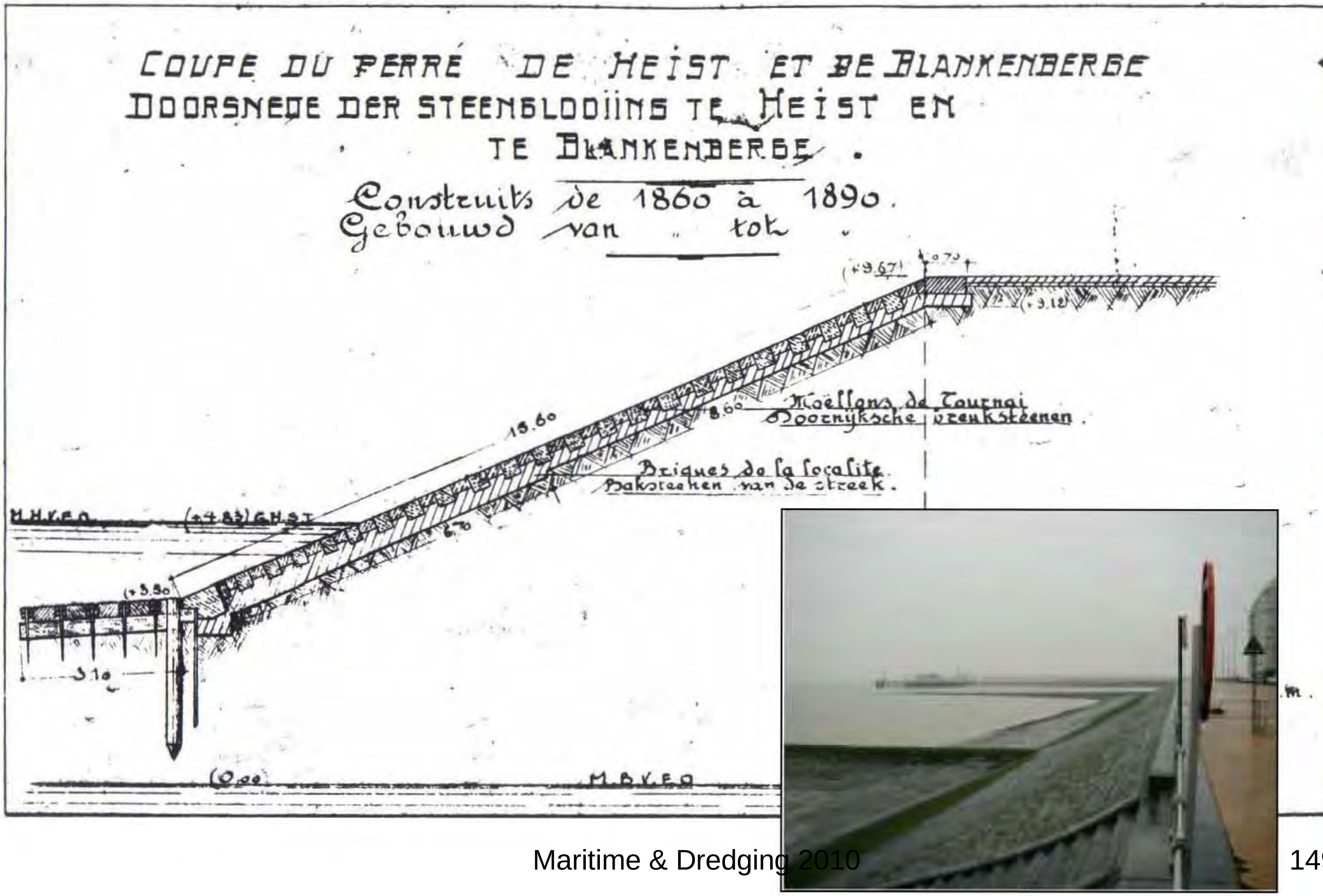
Jebel Ali New Container Terminal Extension

Container Port Jebel Ali, Dubai

Container Port Jebel Ali, Dubai

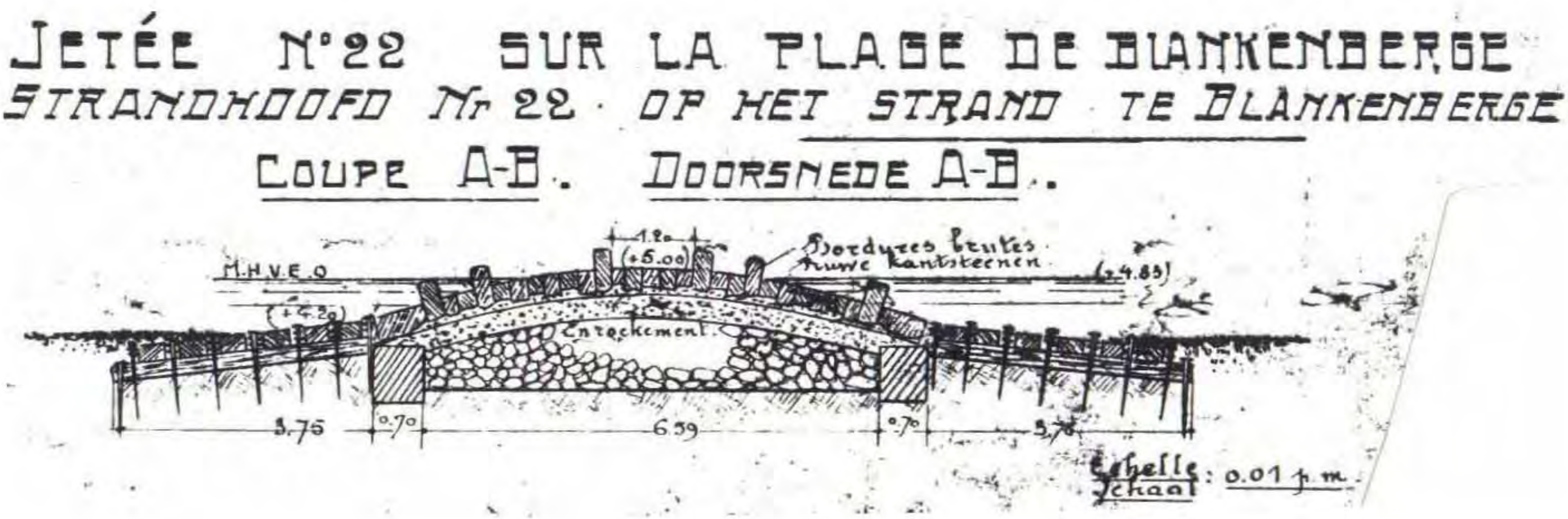
Armouring with 11 ton Stabit CAU's

Sea-defence works: sea-dikes



Sea-dike, Bredene (Belgium)

Coastal protection structures: groynes



Coastal groyne , Ostend (Belgium)

Groyne Fields, Cadzand

Concrete in Waterfront Engineering.

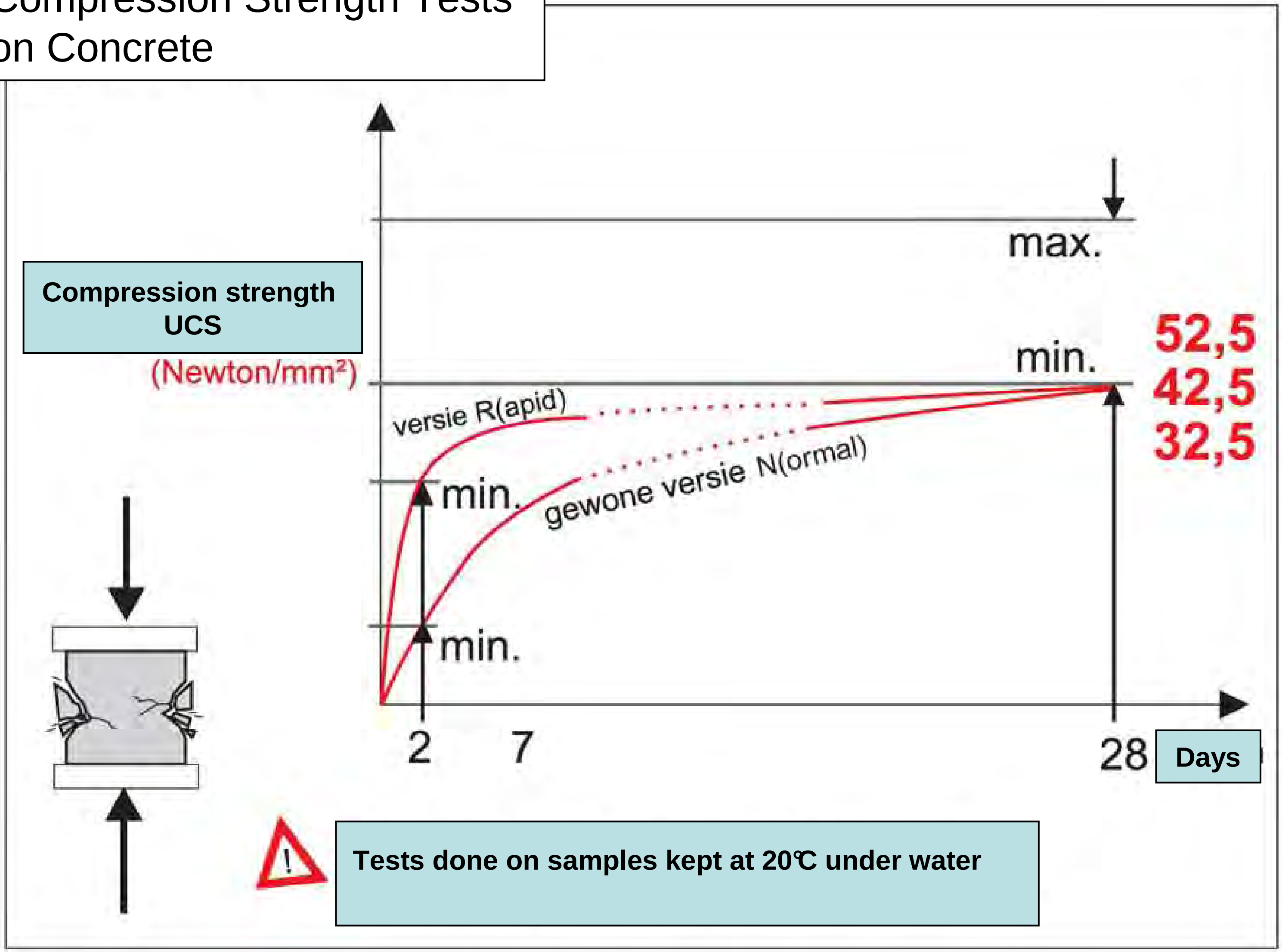
Challenges:

- **limited sustainability (> 100 years ?)**
- **sensitive to sulphate weathering (sea-water environment)**
- **reinforcement corrosion**
- **….**

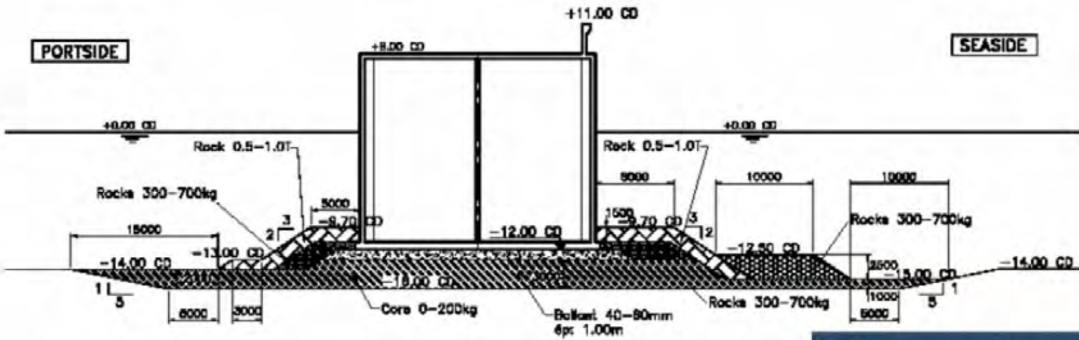
Concrete for Waterfront structures: High Sulfate Resisting (HSR) Concrete

- **Granulates : 0/4, 4/16, 16/32 or 4/32: grades in mm ranges @ 750 l/m3**
- **Sand: Rhine-sand @ 400 l/m3**
- **water : water/cement factor = 0,4**
- **Low-Alkali Cement (either or not self-compacting):**
  - **Lean Concrete**
    - **C15 (ca 100 kg Cement/m3): workfloor, …**
    - **C20 : blinding support**
  - **Rich Concrete**
    - **C30 : precasting**
    - **C40 (ca 400 kg Cement/m3)**
- **Cement- containing additives:**
  - **micro-silicates: to improve durability**
  - **fly-ash : as a (cheap) substitute for cement**
  - **colloïds : to make concrete hydrophobic**
- **Additives to influence hardening:**
  - **Slow-down: when concrete-plant is remote**
  - **Accelerators: when formworks have to be removed swiftly**
  - **Mix e.g. Glenium (BASF): first slow-down, then accelerated**
- **Reinforcement:**
  - **fibre-glass (improves tensile strength)**
  - **steel with active cathodic protection**
  - **epoxy- coated steel**
  - **stainless steel**

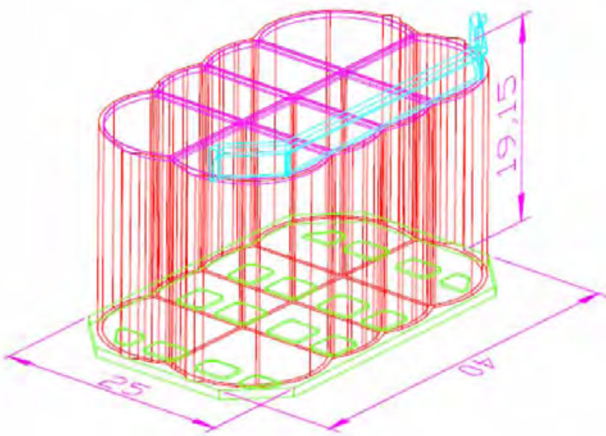
Compression Strength Tests on Concrete



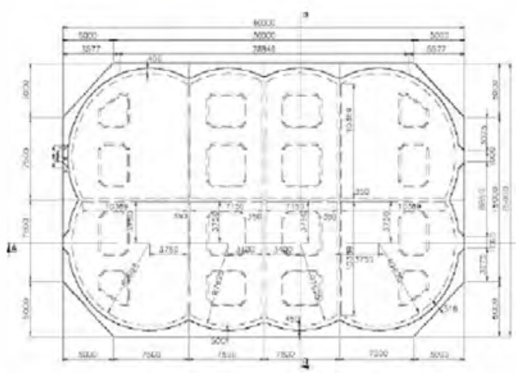
Concrete Caissons for Breakwaters or Quaywalls

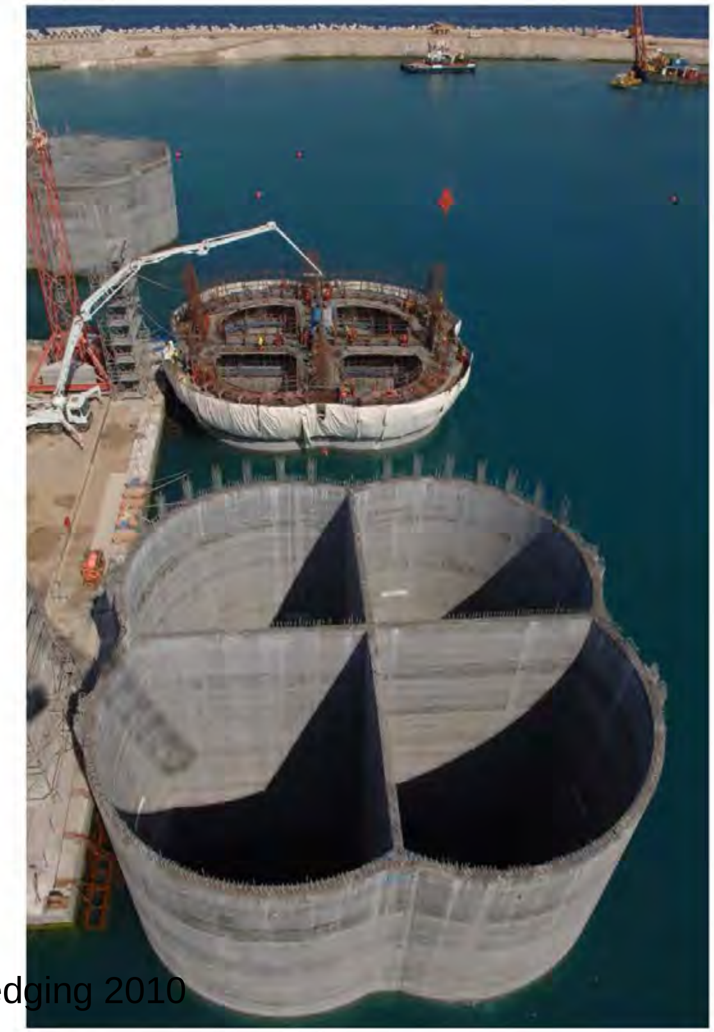


+11.00 CD
PORTSIDE
SEASIDE
+8.00 CD
+0.00 CD
Rock 0.5–1.0T
Rocks 300–700kg
5000
15000
10000
-14.00 CD
-13.00 CD
-12.00 CD
-12.50 CD
-15.00 CD
Core 0–200kg
Ballast 40–80mm
Rocks 300–700kg
6000
3000
1000



19.15
25
40





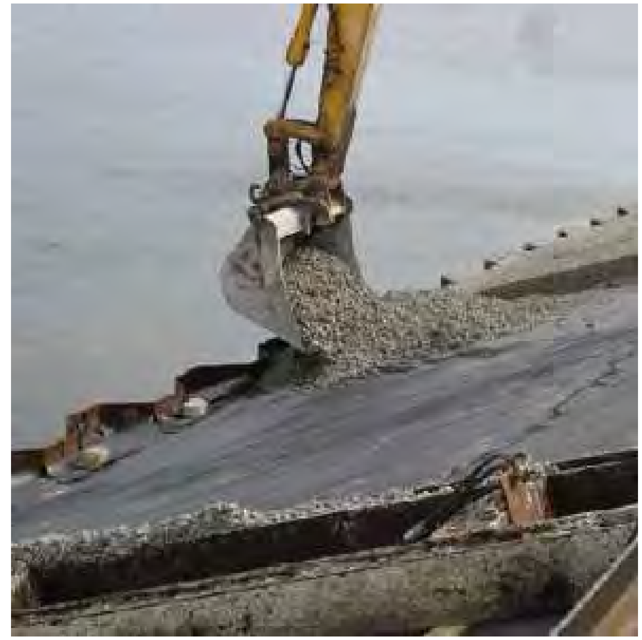
Dry-docks used for caisson-construction

Colloïdal Concrete (info cfr Interbeton):

- **open structure**
- **closed structure**

Hydromix is een merknaam van Interbeton

Cfr www.heidelbergcement.com

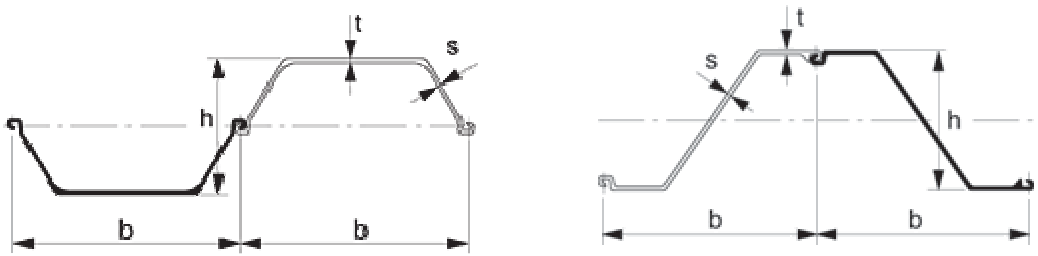


Characteristics:

- UCS = 7 N/mm2
- ρ = 1750 kg /m3
- k = 2.10^{-4} to $2 . 10^{-7}$ m/sec

Underwater Concrete with closed structure (cfr Hydromix)

Sheetpile Walls : U- orf Z- profiles



Choice of profile depends upon:

- **Ultimate soil/water load (horizontal soil pressure): U-profile has a stronger bending moment, Z-profile is more economic**
- **Type of Soil :**
  - **Resistant Soils (e.g. qc > 2 MPa or SPT > 15)with difficult driveability: U profile preferred (= stronger)**
  - **Soft soils with good driveability: Z-profile preferred because more cost-effective (relative to kg of steel)**

Accelerated Low-water Corrosion in Oxygen-rich water environment (top part & splash zone):

Protection by:

- **Overwidth on steel : corrosion = ca 0,10mm/year**
- **Coatings (epoxy) …but risks of damage during driving**
- **Cathodic protection, either passive with sacrificial Zn-anodes (1kg/m2 exposed), either active, with DC**

Application of sheet-piles in cofferdams

Double sheet-pile wall, Blankenberge (Belgium)

Combi-Walls:

Combination of deeper tubes (stability) with shallow U-profiled sheetpiles (soil/water retention)

Bouw van de 2de Sluis te Evergem: Buispalen en Combi-walls

New lock-chamber at Evergem-Lock on Canal Ghent-Terneuzen

Combiwall in Danish Quay-Wall , Albert I dock, Zeebrugge, Belgium

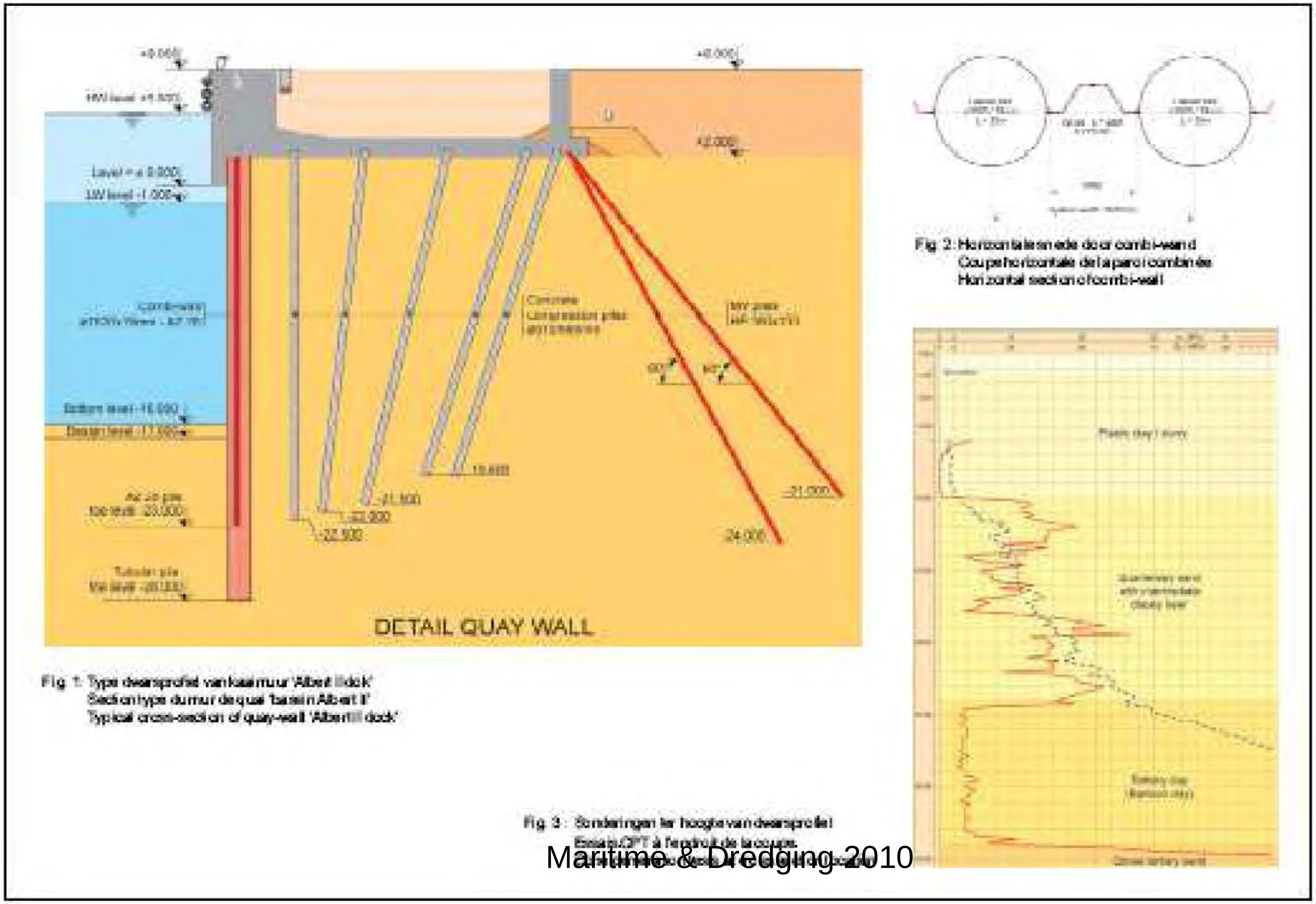
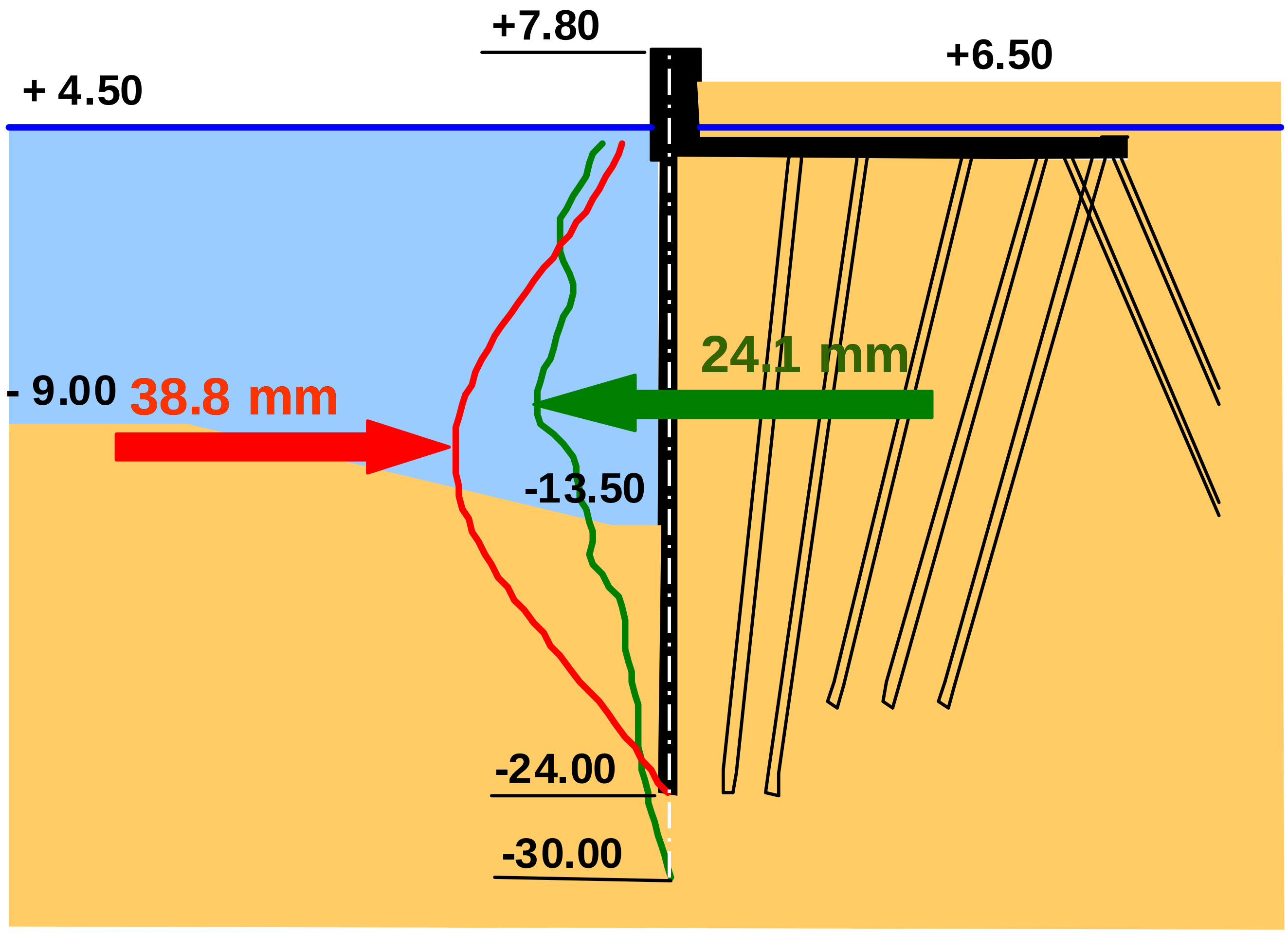


Fig. 1: Type dwarsprofiel van kaaimuur 'Albert II dok'
Section type du mur de quai 'bassin Albert II'
Typical cross-section of quay-wall 'Albert II dock'

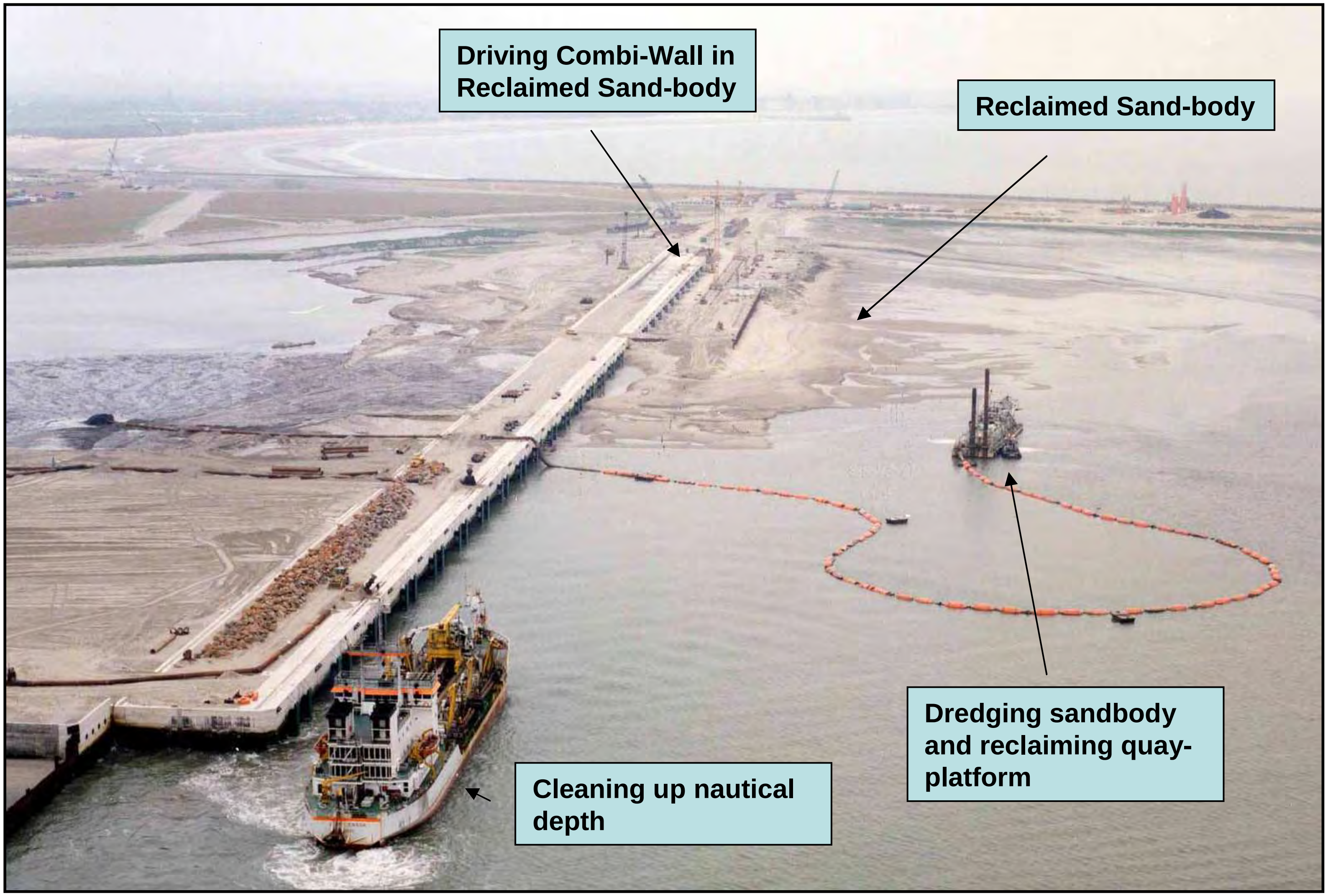
Fig. 2: Horizontale snede door combi-wand
Coupe horizontale de la paroi combinée
Horizontal section of combi-wall

Fig. 3: Sonderingen ter hoogte van dwarsprofiel
Essais CPT à l'endroit de la coupe

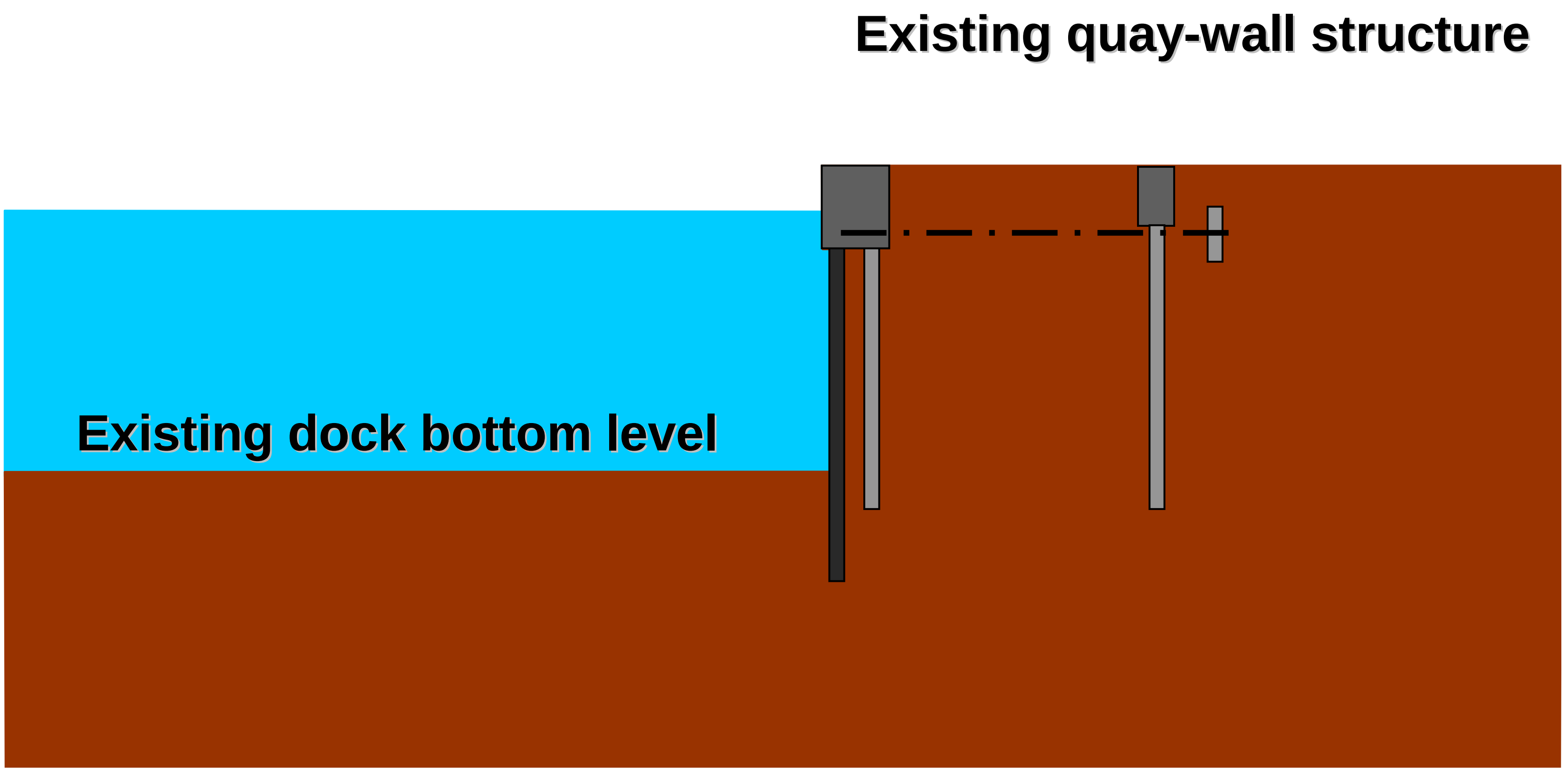
Monitoring : inclinometers (3/4)



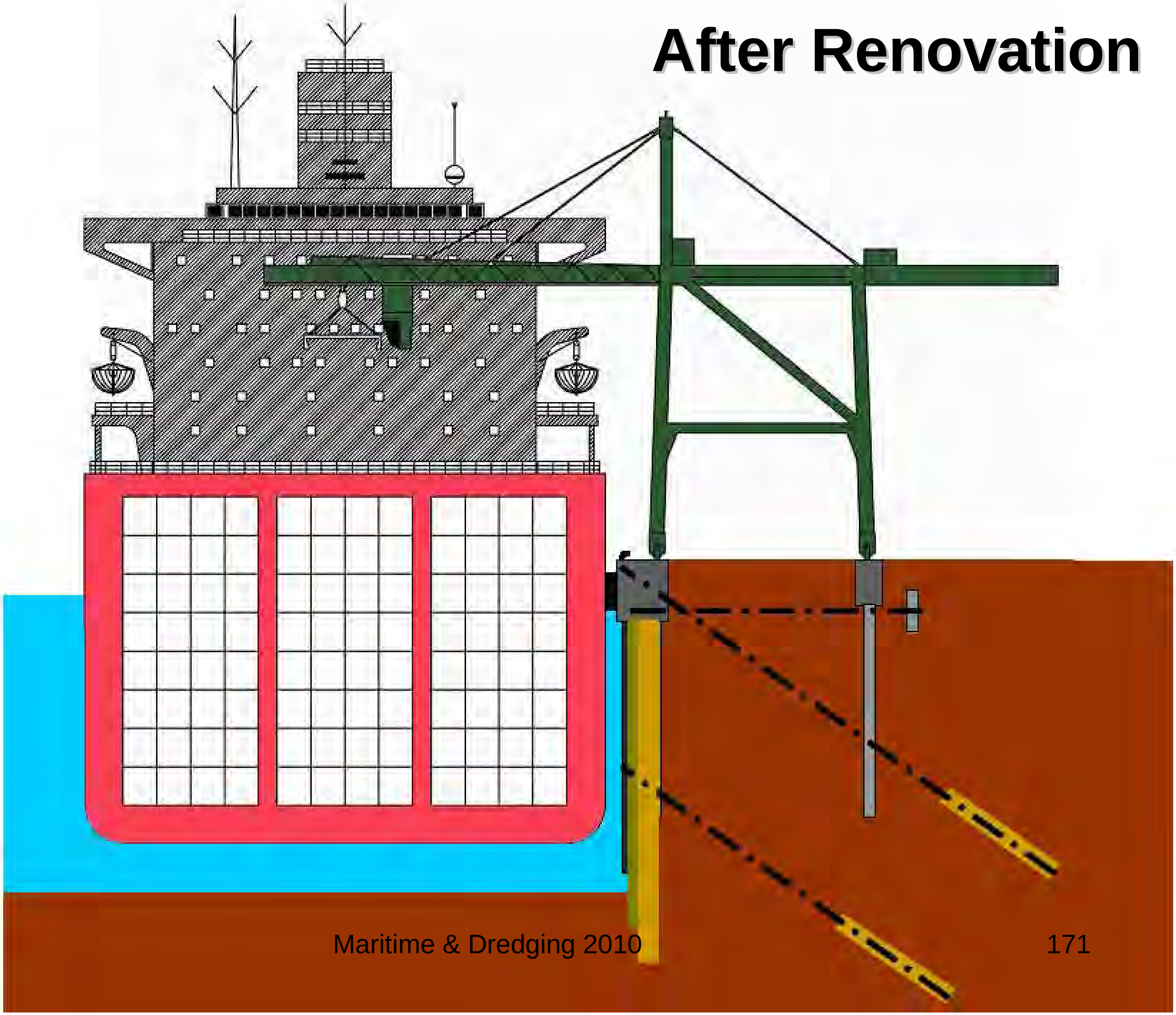
Construction of Albert II-Dok Quay-Wall (Zeebrugge)



Renovation of Quaywalss in the port of Ghent, Belgium



After Renovation



Sheetpiles in Waterfront Engineering: flexible, cheap, but…
Accelerated Low Water Corrosion (ALWC)

What ?

- In the tidal range and splash zone and to ca 1 to 2m under the LW-line, bacteria are agglutinated to the steel causing an acid-corrosion: the result is a strongly accelerated corrosion and oxydation of the steel.
- Normally, a corrosion of 0,08mm to 0,17 mm/year/wet surface is to be considered
- ALWC corrodes up to 0,3mm to 2mm/year/wet surface !

Solutions?

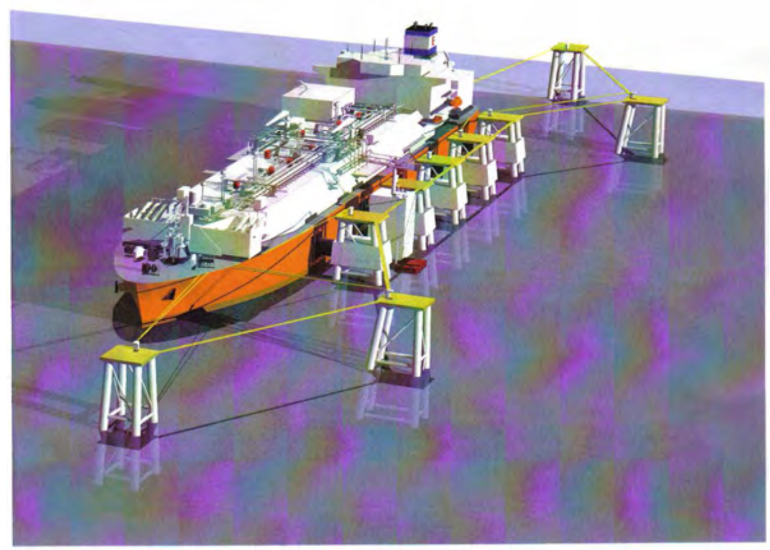
- Cathodic Protection with sacrificial (Zn) anodes
- Epoxy-coatings
- Calcium Carbonate/ Mg - hydroxyde coating

Concrete Tube-Piles or Steel Tube-Piles (fully or partially filled with (reinforced) concrete) for breasting Dolphins, Mooring Dolphins

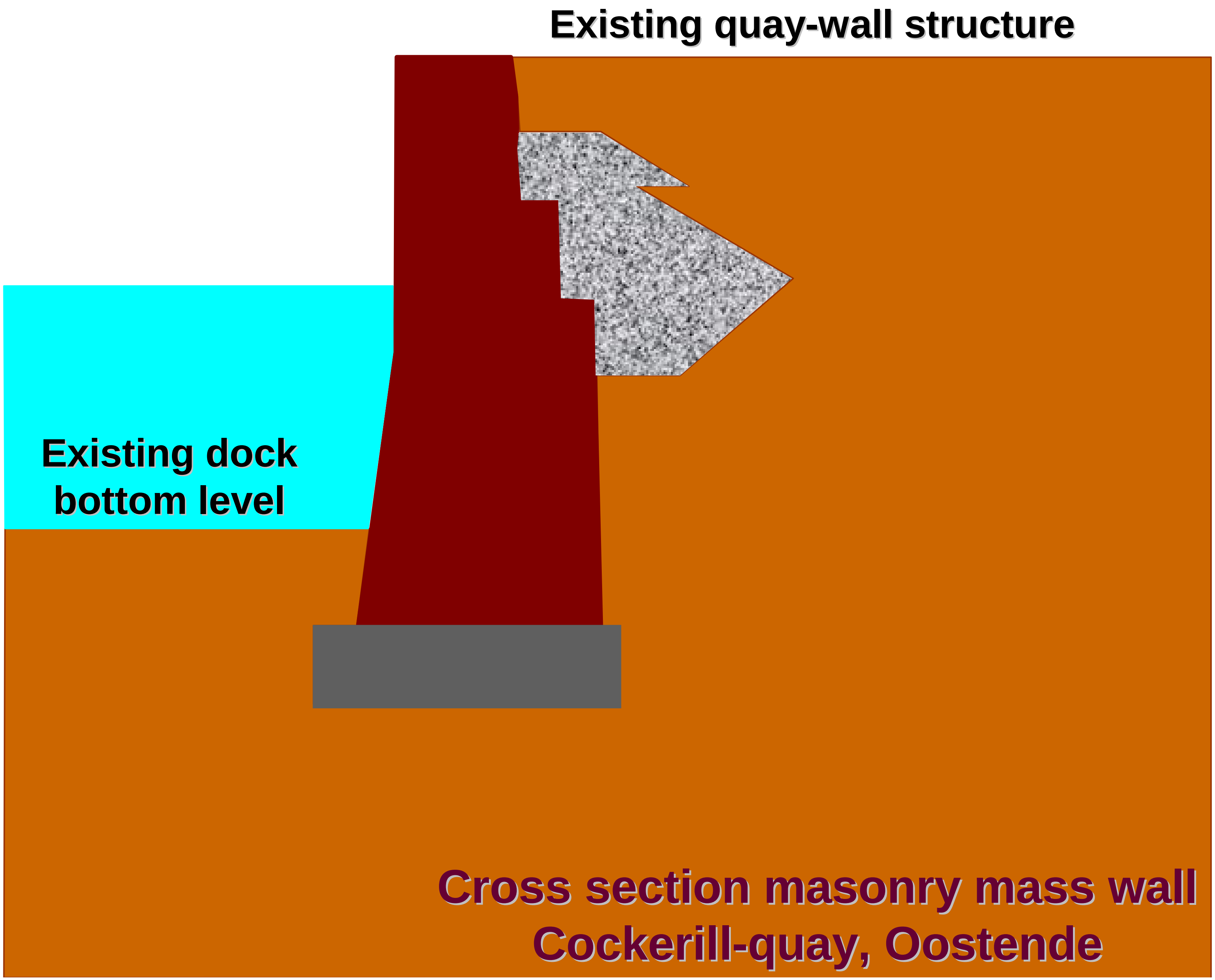
Steel Tube-Piles: choice is determined by steel-quality, i.e. the Flow-limit of the steel.

Generally, it appears to be more cost-effective to use lighter tube-piles with a high-quality steel (instead of larger tube-piles, with lower steel-quality).

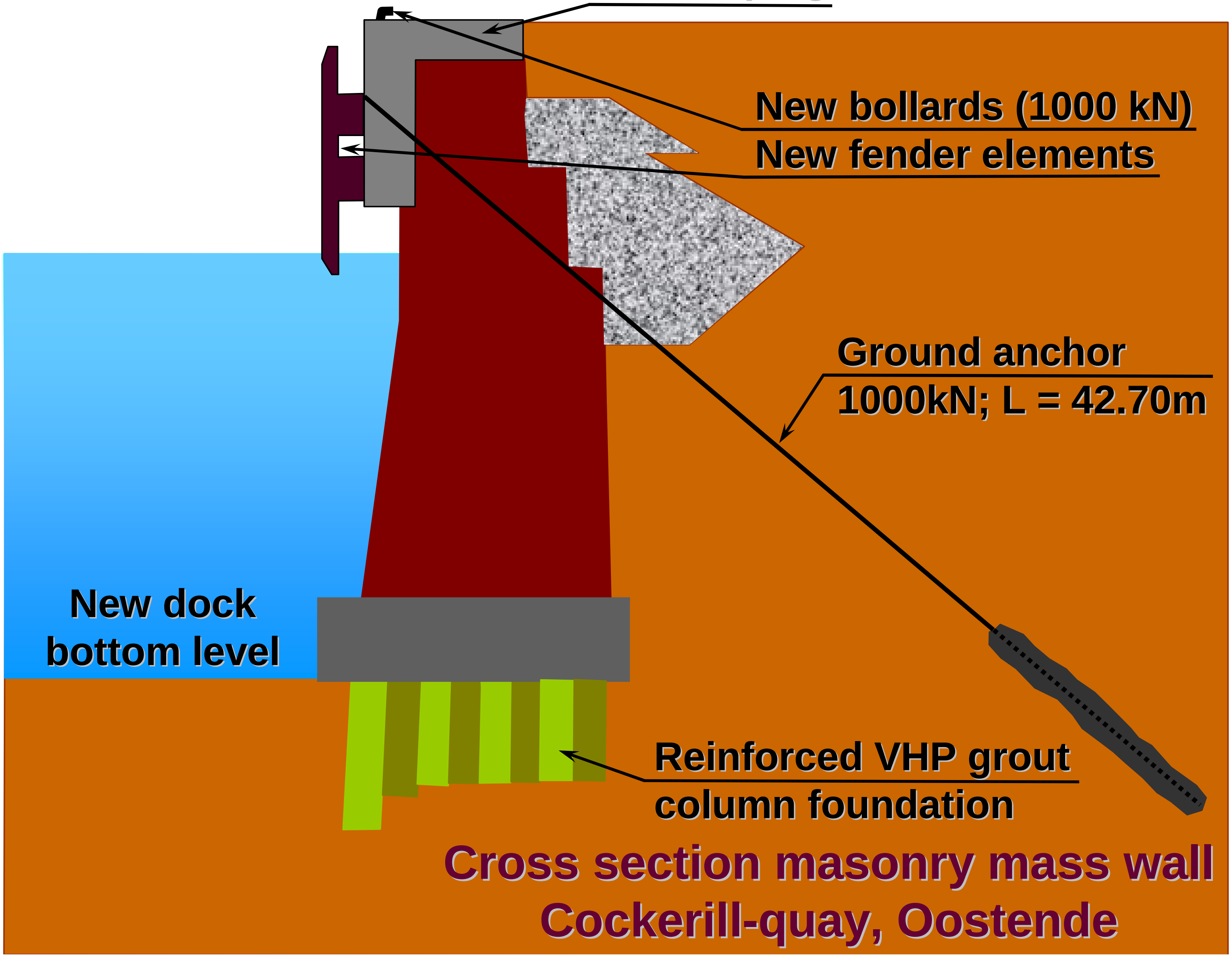
Dimensions are engineered via bending moments, driving depth (geotechnics,…),…



Massive gravity quay-walls

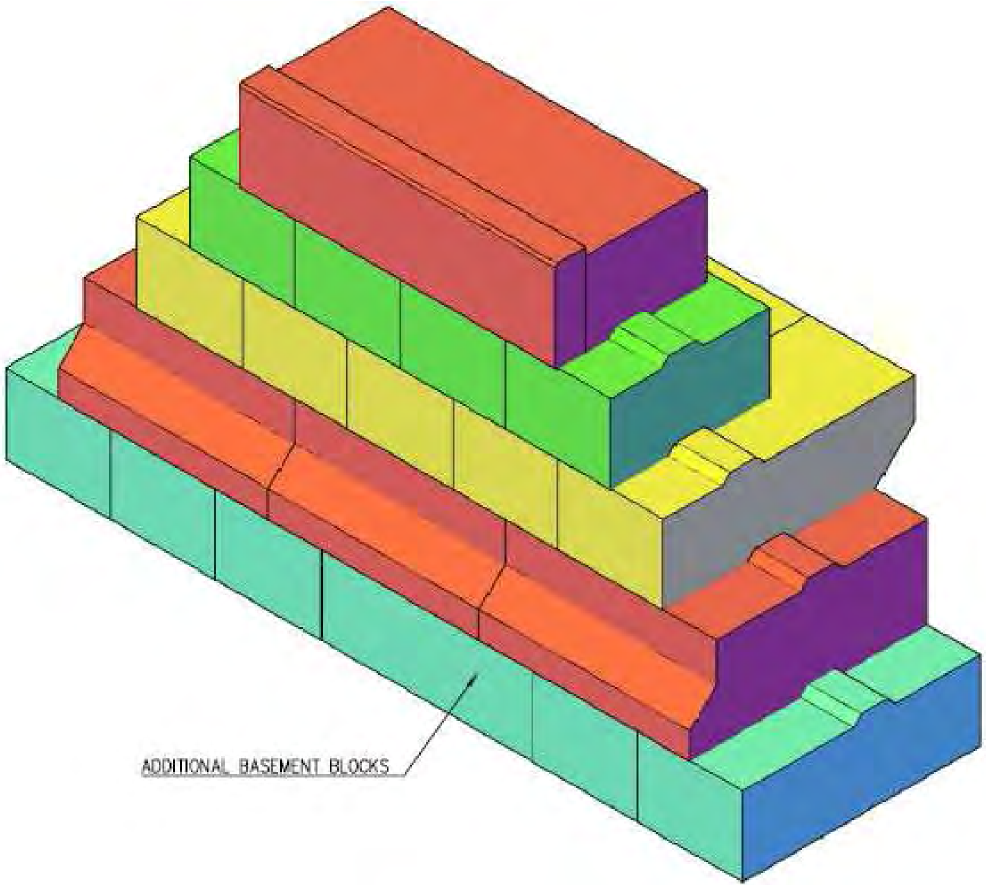


After renovation , Port of Klaipeda, Lit

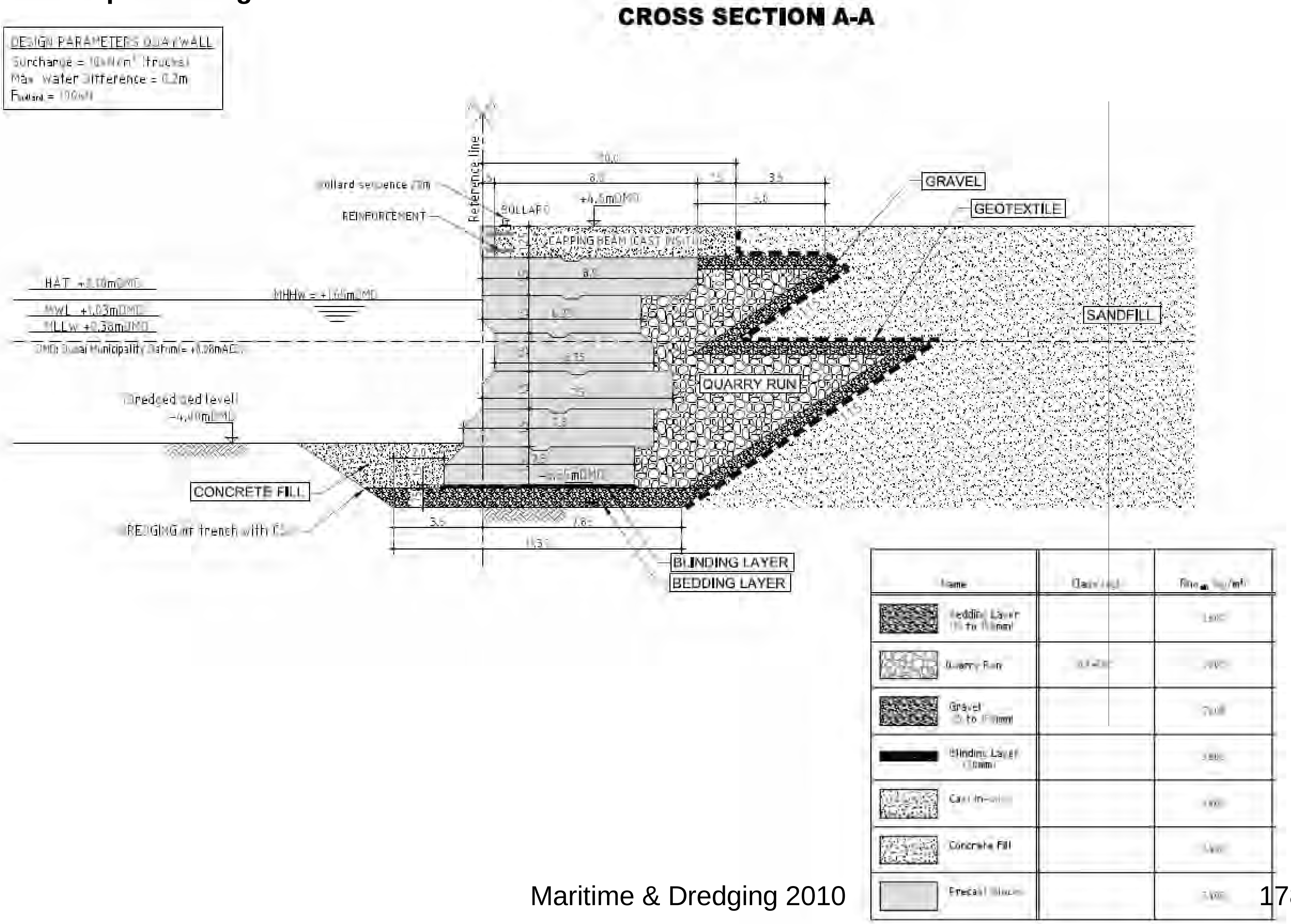


IMPACT RECONSTRUCTION

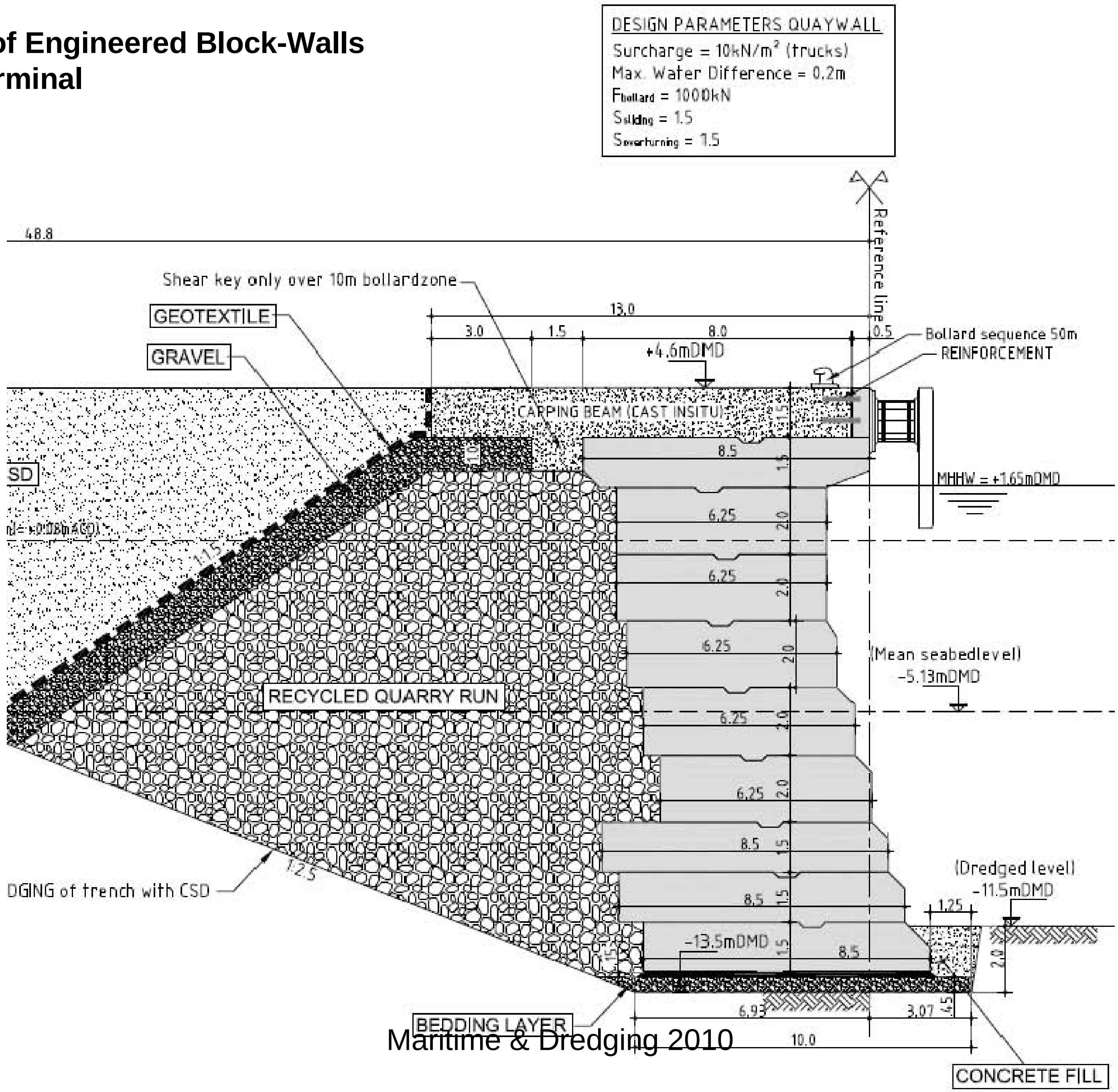
Gravity Quaywalls, constituted of Concrete Blocks, Cove Canal, UAE



Examples of Engineered Block-Walls



Examples of Engineered Block-Walls
, Cruise Terminal



Palm Cove Canal, UAE:

More than 12 km of qua-wall constructed with 25 to 32 ton unreinforced concrete blocks

Course-1: 4-side mould.

Overview Precast Yard

Course-1: casting 2-side mould

Overview Precast Yard

Mould C2

Lifting Course-2 block

Mould C3

Placing course-2 block.


Formwork Course-4B, Precast Front Panel. Casting position..


Course-4B "Precast Front Panel": Lifting block out of mould.


Formwork Course-4B, Precast Front Panel. Open position after removing block.


Course-4B "Precast Front Panel": Stockpile & GFRP-bars for connection with C4A.


Course-4B "Precast Front Panel": Placing blocks at Quay Wall.


Mould Course-4A


Course-4B "Precast Front Panel": Side view with mould Course-4A


Pontoon Corner

Return corner section-1

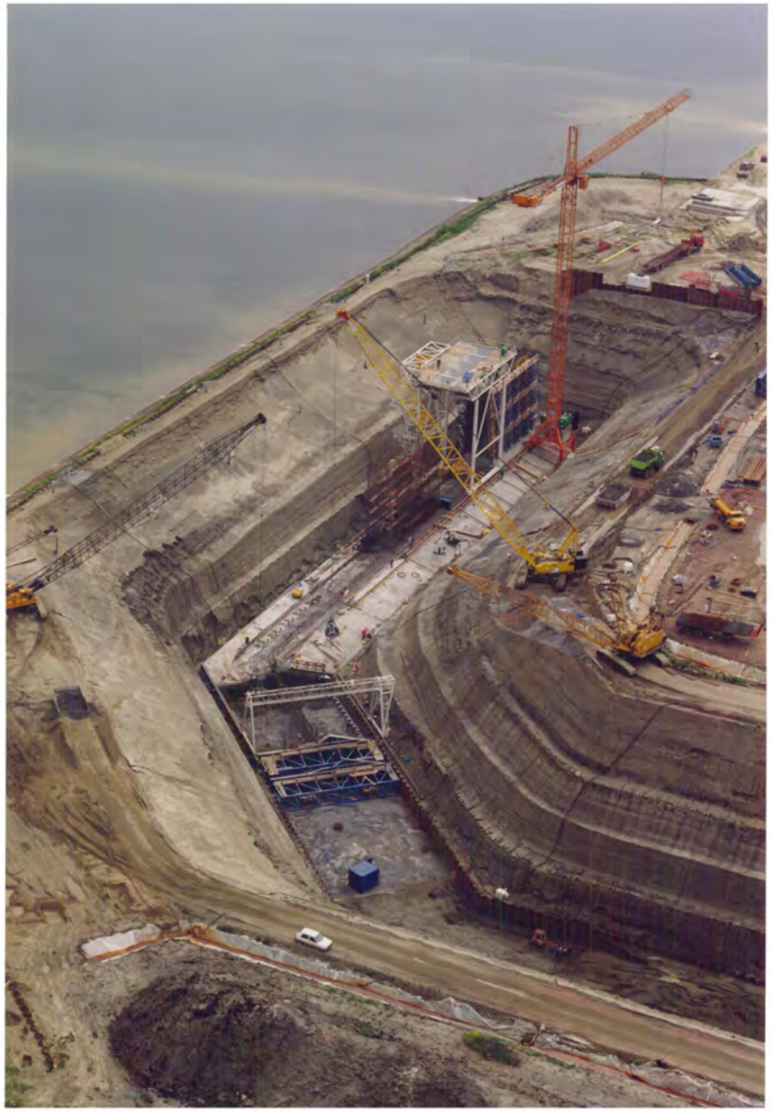
Insitu casted "Pontoon-Corner" after completion

Massive Gravity Wall cast in-situ: example of Verrebroeck-Dock, Port of Antwerp

Fixed Formwork in corners

Sliding formwork

Verrebroeck-Dock: Port of Antwerp



Controlled Inundation Area at Kruibeke Bazel Rupelmonde (KBR), River Scheldt: construction of dewatering sluices

KBR at LW

KBR at HW

KBR at extreme HW