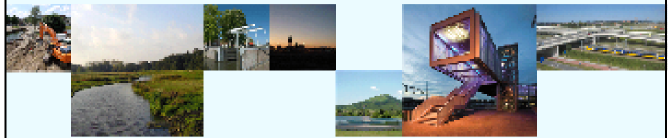
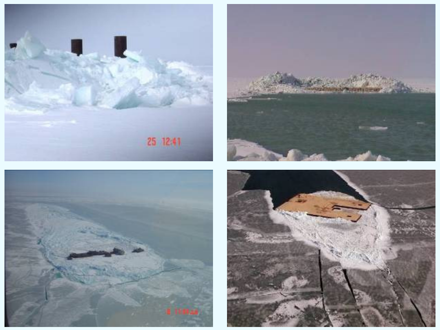
Arctic & Earthquake Engineering
KIVI NIRIA ALV Geotechniek 2013



Arny Lengkeek
Head of geotechnical
group Deventer

Part 1 - Arctic engineering



Arny Lengkeek
Floris Besseling
Coen Kuiper

Contents of presentation

- Introduction
- Project Artifical islands North Caspian Sea
  - Design of Perimeter wall
  - Ice loads and standards
- Project Yamal Russia
  - Design of Ice Protection Structures

Project North Caspian Sea

Civil design works Caspian Sea

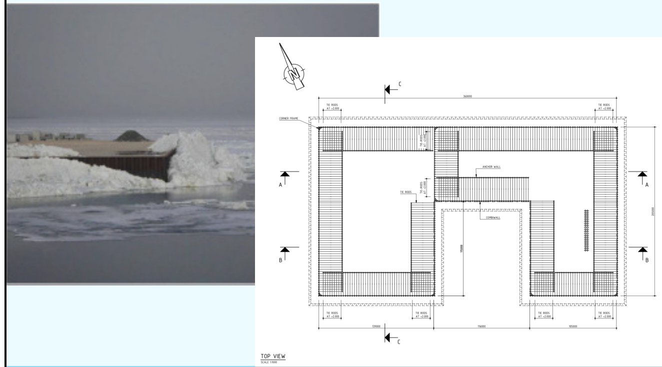
- civil design for manmade islands
- fully protected and semi protected islands

Facts and figures

- project start 1998
- W+B designed appr. 13 sites, man-made islands mostly
- exploration by mobile rig, submerged on berm, with active ice management and ice protection
- 2 major hubs with 40 year lifetime and manned, of which 1 is constructed (complex D)
- mulitple drilling / production islands, temporary manned
- appr. 10 sites constructed
- First oil 2013…

Design of island perimeter wall

Island layout – Combiwall design



Combiwall ice load performance

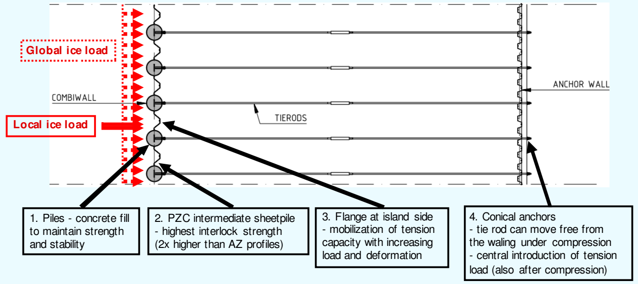
Measures taken for best ice load performance:
1. Combiwall pile with concrete fill
2. intermediate sheetpile with strong interlocks
3. Intermediate sheetpile flange at island-side
4. Conical anchors

Analysis performed:
- Plaxis 2D global ice load performance
- Plaxis 3D local ice load performance

Experience:
- Kashagan Complex D barrier heads

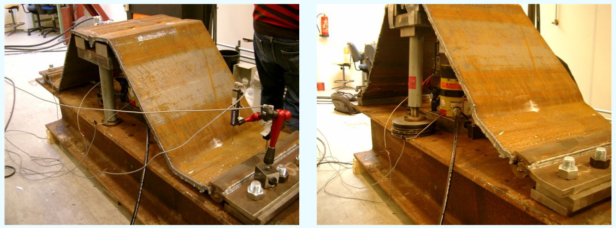
Combiwall ice load performance

Measures taken for best ice load performance:



Combiwall ice load performance

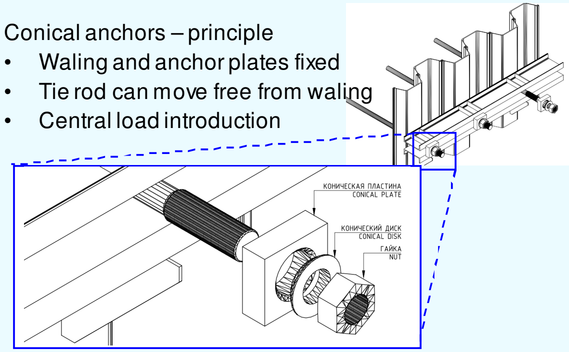
PZC sheetpile laboratory test:
- simulation of local ice load



Combiwall ice load performance

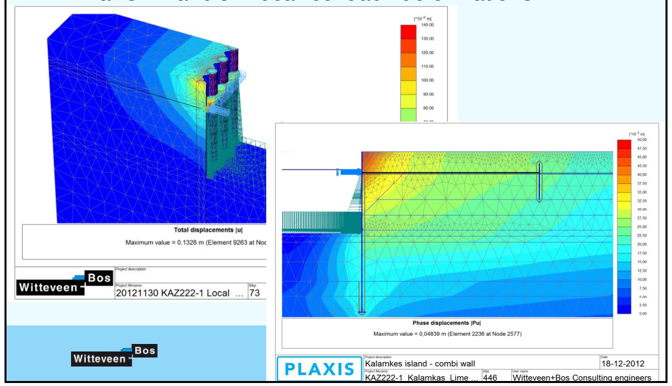
Conical anchors – principle

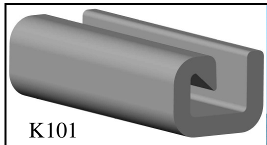
- Waling and anchor plates fixed
- Tie rod can move free from waling
- Central load introduction



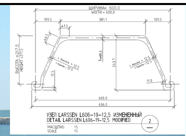
Combiwall ice load performance

Plaxis 2D and 3D local ice load - deformations

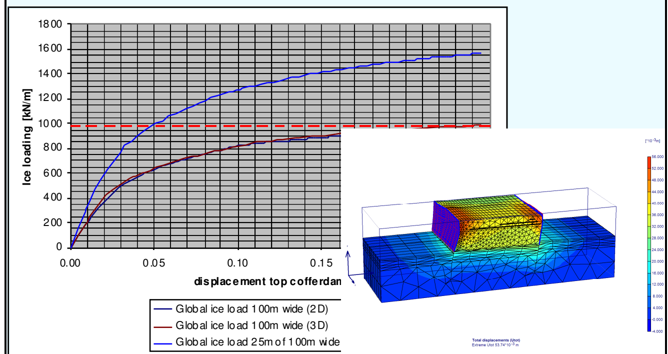




Strengthened Larssen 606m sheetpile and K101 interlock

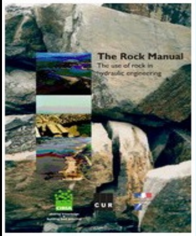


3D analysis cofferdam local and global ice load



Standards, manuals, research

- ISO Code 19906
- Rock Manual
- Field testing and data collection



Definitions of exposure level

- **consequence category:**
- **life-safety category:**
- **exposure level:**
- classification system used to define the requirements for a structure based on consideration of life-safety and of environmental and economic consequences of failure

Table 7-1 — Determination of exposure level

Life-safety category		Consequence category		
		C1 High consequence	C2 Medium consequence	C3 Low consequence
S1	Manned non-evacuated	L1	L1	L1
S2	Manned evacuated	L1	L2	L2
S3	Unmanned	L1	L2	L3

Reliability concept

- Ultimate limit state (ULS - ELIE)
- Abnormal (Accidental) limit state (ALS - ALIE)
- Serviceability limit state (SLS)
- Fatigue limit state (FLS)

ACTION	ANNUAL PROBABILITY OF EXCEEDANCE	LOAD FACTOR
EXTREME ENVIRONMENTAL	10^{-2}	1.35
ABNORMAL ENVIRONMENTAL	10^{-4}	1.00

EXPOSURE LEVEL	MAX ANNUAL FAILURE PROBABILITY
L1	1×10^{-5}
L2	1×10^{-4}
L3	1×10^{-3}

Design ice actions

- Ice scenarios (see table)
- Limiting mechanisms
- Ice failure modes
- Structural configuration
- Operation scenarios

Level ice	ice thickness	**First-year ridges**	surrounding level ice thickness
	drift speed		thickness of the consolidated layer
Rafted ice	total thickness		extent consolidated layer thicknesses
	extent of rafted ice areas		ridge length
	drift speed		maximum keel draft
	mean floe thickness		drift speed
	floe edge thickness	**Icebergs**	waterline length
	floe drift orientation relative to the structure		waterline width perpendicular to length
	floe speed		maximum height above waterline
Multi-year ridges	ridge spacing or frequency		maximum draft
	ridge orientation		depth of first contact with structure
	ridge length		mass
	maximum ridge sail height		local shape
	maximum ridge keel draft		drift orientation
	ridge keel geometry		drift speed

Active Ice Management:

active processes used to alter the ice environment with the intent of reducing the frequency, severity or uncertainty of ice actions

Field testing and data collection

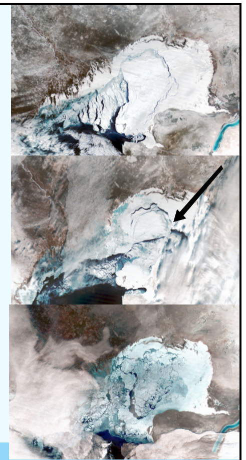
- meteorology
- oceanography
- geotechnical conditions
- ice conditions
  - ice thickness
  - ice drift
  - ice formations (type)
  - ice strength
  - ice structural interaction
  - seabed scours

Land fast ice or mobile ice

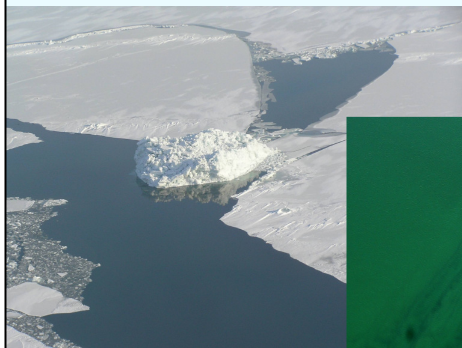
18 December 2002

22 December 2002

19 January 2003



Grounded stamukha in 8m water scour on seabed

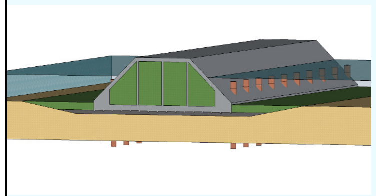


Strength testing on ice

Project Yamal Russia

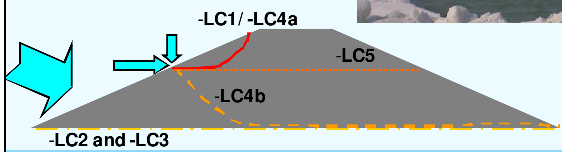
Design of IPS

- Ice Protection Structures:
- Breakwaters
- Caissons
- Piles
- …..

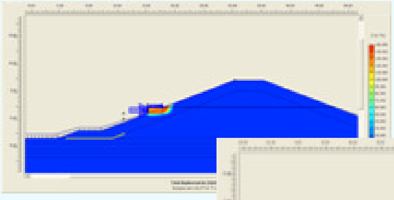


Failure modes breakwater

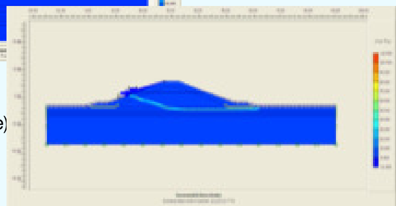
- Failure mechanisms, load cases
  - LC1: edge failure (local)
  - LC2+3: deep slide failure (global)
  - LC4: global slide failure (global)
  - LC5: decapitation (frozen cap)
- methodology
  - interaction scenarios and loads defined together with ice experts
  - simulation of ice and soil/rock in Plaxis (FEM)



Breakwater stability verification under ice loading

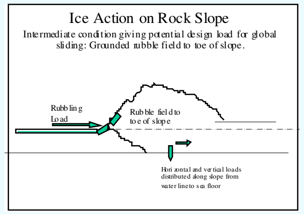


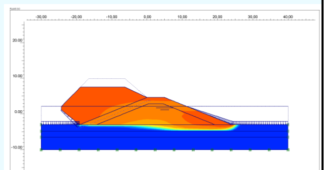
- local failure (acceptable?)

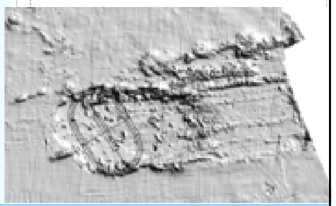


- global failure (not acceptable)

Global failure mode of trial berm



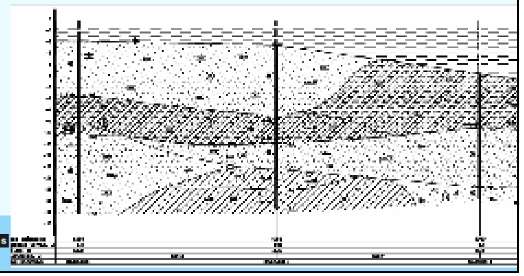




- height 6m
- footprint 30x60m
- seabed survey after actual failure

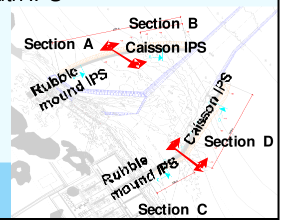
Два профиля, выбранные из разреза 22

- СК4966 (мелководье, разрез А,С)
  - ИГЭ -3 (песок) на -2 м БС
  - ИГЭ -6 на -6 м БС
  - ИГЭ -12 на -10 м БС
- СК4936 (глубокая вода, разрез B,D)
  - ИГЭ-4 (ил/глина) на -5 м БС
  - ИГЭ -2 на -10 м БС
  - ИГЭ -12 на -15 м БС

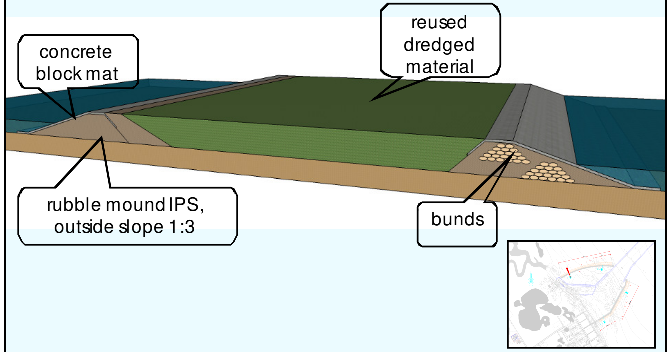


Selected concepts

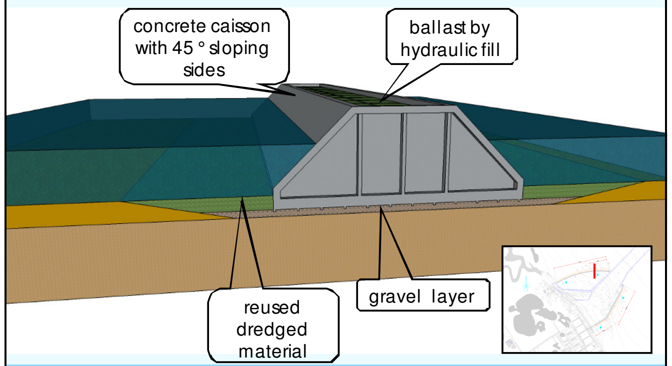
- Shallow section A+C: rubble mound IPS and reused dredged material
- Deep section B+D: two optimized prefab caisson IPS with sloping side walls
- Rubble mound construction on sandy layers
- Foundation level caisson IPS in dredged trench
- Piperack combined with south IPS



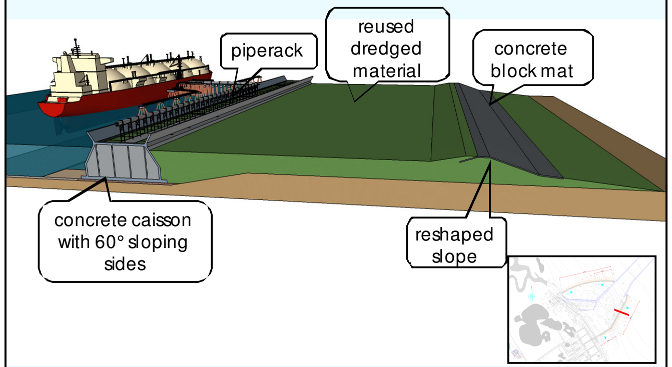
NW Section A



NE Section B



SE Section D



Ice parameters and loads (ISO19906)

- initial bending loads 0.1 to 0.4 MN/m
- rubbling load on rubble mound 0.8 to 1.5 MN/m
- rubbling load on caisson 0.9 to 1.3 MN/m

Table 1. Ice and ice rubble physical parameters

Parameter		
Ice unit weight γ_i	MN/m3	0.009
Ice elastic modulus	MN/m2	1864
Ice Poisson ratio	-	0.3
Ice rubble porosity e	-	0.3
Ice rubble internal friction angle φ_{ir}	º	40
Ice rubble cohesion	MN/m2	0.02

Table 2. Ice strength parameters

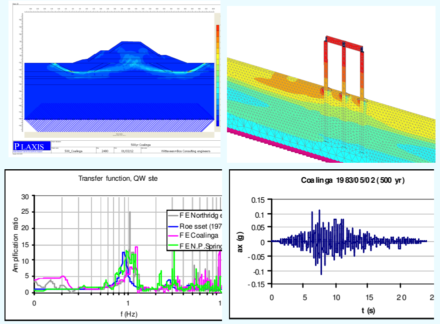
Parameter		
Ice pressure averaged over nominal area for 2.4 m ice thickness p_g	MPa	0.974
Ice pressure averaged over nominal area for 0.6 m ice thickness p_g	MPa	1.232
Ice bending strength upper limit (applied for stage 1 slope actions) σ_f	MPa	0.900
Ice bending strength (applied for stage 2 slope actions) σ_f	MPa	0.750

Table 3. Friction coefficients

Parameter		
Ice-ice friction coefficient μ_i	-	0.05
Ice-smooth concrete friction coefficient μ_{ic}	-	0.1
Ice-rock fill friction coefficient μ_{ir}	-	0.5
Rubble-seabed friction angle δ_{rs}	º	20

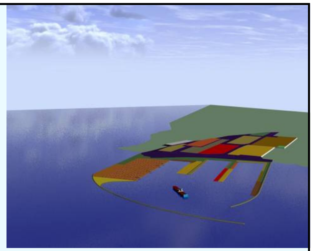

Спасибо за внимание - Вопросы
Witteveen + Bos
tel 0570 69 79 11
fax 0570 69 73 44
www.witteveenbos.nl
Deventer
Almere
Amsterdam
Breda
Den Haag
Heerenveen
Maastricht
Rotterdam
België (Antwerpen)
Indonesië (Jakarta)
Kazachstan (Aktau, Almaty, Atyrau)
Letland (Riga)
Rusland (St. Petersburg)
Vietnam (Ho Chi Minh City)

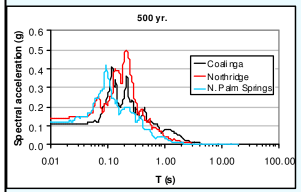
Part 2 - Earthquake engineering

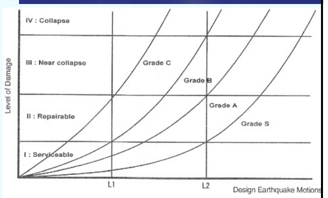


Arny Lengkeek
Carolina Sigaran
Floris Besseling

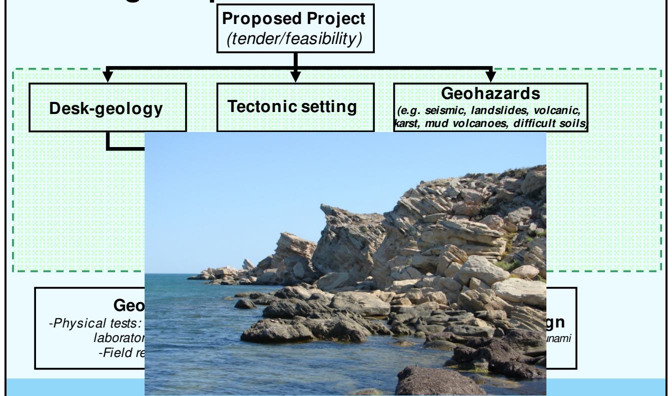
Contents



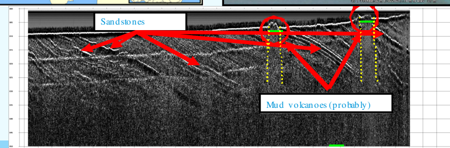




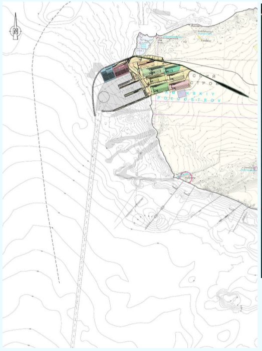
Geological quick-scan



Site location: Taman Port, Russia



Site location: Taman Port, Russia



Witteveen+Bos 7 February 2013 5

Geological quick-scan

Proposed Project
(tender/feasibility)

- **Desk-geology**
- **Tectonic setting**
- **Geohazards** *(e.g. seismic, landslides, volcanic, karst, mud volcanoes, difficult soils)*

Recommendations for *SoW* and geotechnical design

- **Geomodels**
  - *-Physical tests: in situ (BH, SPT, CPT), laboratory, geophysics;*
  - *-Field reconnaisance*
- **Seismic assessment for design**
  - *Liquefaction, ground deformation, landslides, tsunami*

Witteveen+Bos 7 February 2013 6

Seismic assessment for design (performance-based)

- ***National Code and/or International specifications***
  e.g. EC8, IBC-NEHRP, PIANC, ASTM, API
- ***Site-specific seismic hazard***
  e.g. PSHA, DSHA

Earthquake loads
e.g. operating, contingency levels (OLE, CLE, ULE)

- **Pseudostatic** ***("simplified")***
  → ***Stability*** *(inertial forces: threshold limits)*
- **Displacement-based** ***(Newmark, "simplified dynamic")***
  → *-**Formal analysis** (time histories)* ***or*** *-**Simplified approaches** (empirical relations, design charts)*
  → ***Deformation*** *(displacements, threshold limits)*
- **Site response (*"dynamic"*):**
  - -Equivalent linear
  - -Nonlinear
  - *(e.g. FEM/FDM)*

  → ***-Permanent deformations Stresses/ductility -Stability***

Witteveen+Bos 7 February 2013 7

Site response (*"dynamic"*)

Selection criteria:
-Magnitud, distance,
-PGA,
-Focal mechanism,
-Site class,
-Qualitative match target spectrum,
-Scaling factor,
-Variability

- **Input:**
  - Geotechnical characterization
  - "n" seismic records *(corrected, filtered, scaled)*
- **Approaches:**
  - Equivalent linear *(e.g. Shake, Matlab)*
  - Nonlinear *(e.g. Plaxis)*
- **Outputs**, e.g.:
  - Site response *(t- f- domain)*
  - *Deformations*
  - *Stresses/ductility*
  - *Stability*

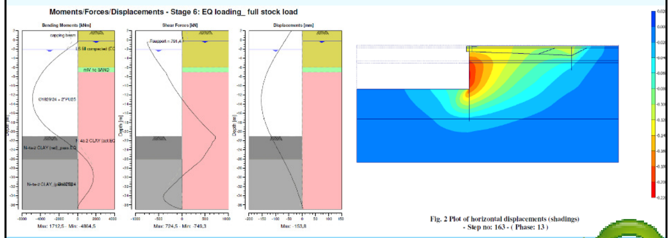
*-**Discretization:***
$\Delta l \approx \lambda/5$; $\lambda = v_s/f$
*-**Calibration:***
Lateral boundaries

Witteveen+Bos 7 February 2013 8

Pseudostatic: QW Taman Port, Russia

- Deltares-sheetpiling (winkler model)
- Plaxis (FEM)

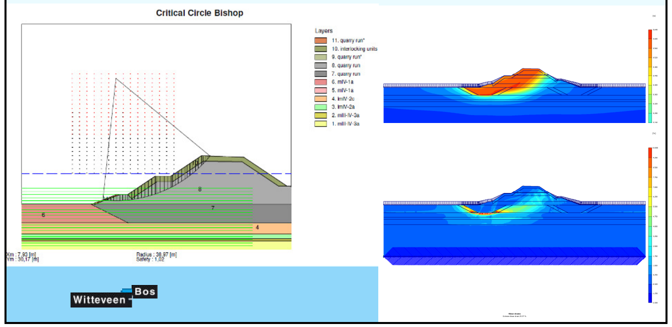
•12 quays
•Lengths: 400-1187 m
•Total length: 9355 m



Pseudostatic: BW Taman Port, Russia

- Deltares-Stability (Slip circle)
- Plaxis (FEM)

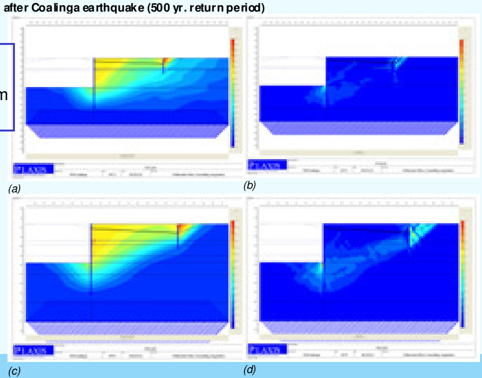
•6 sections
•Total length: 7500 m



Dynamic: QW Taman, Russia

Total displacements and total strains from front wall from quay 2 (a, b) and quay 9 (c, d) after Coalinga earthquake (500 yr. return period)

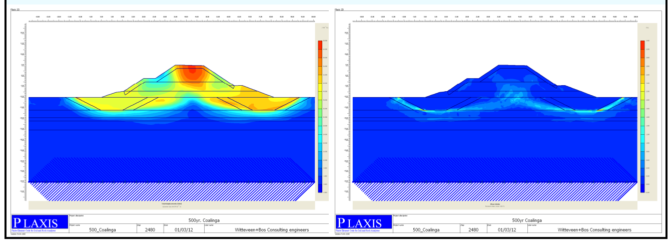
•12 quays
•Lengths: 400-1187 m
•Total length: 9355 m



Dynamic: BW Taman, Russia

- Lower displacements then for pseudostatic
- Displacements in both directions
- Soil improvement at toe is effective

•6 sections
•Total length: 7500 m

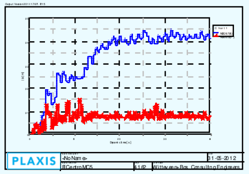


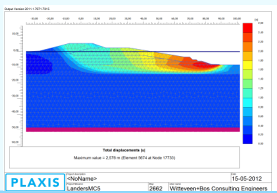
Nonlinear: Dike Kapuk-Naga, Indonesia

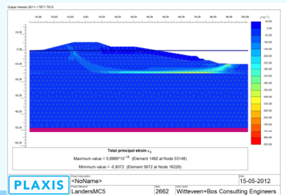
- design of three offshore islands
- dredging plans (50 million m^3 reclamation)

Dynamic: Dike Kapuk-Naga, Indonesia

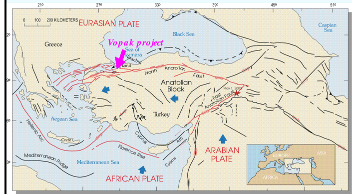
- Displacements
- FoS
- Shear strains
- Liquefaction potential



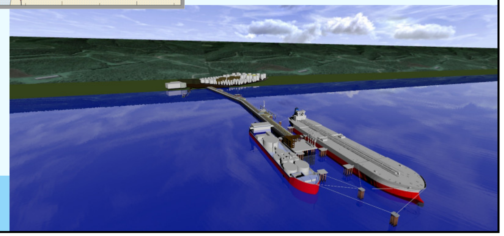




Seismic soil-structure interaction



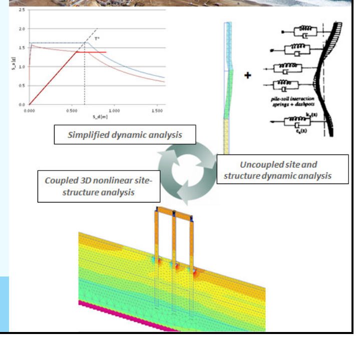
- Sea of Marmara, Turkey
- Basic design
- Oil and chemical jetty, LNG tanks
- 30 m soft soil (class E)



Jetty's

- MSc thesis Floris Besseling
- Soil – Structure interaction
- Performance based seismic design

(focus on displacements and ductility)

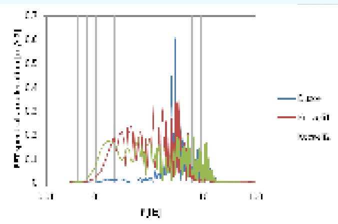


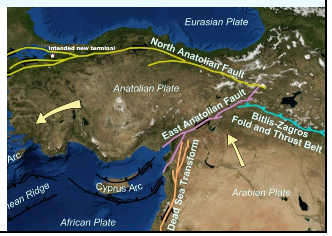
Witteveen+Bos

7 February 2013 17

Thesis project

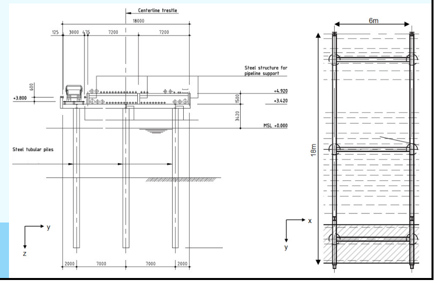
- Jetty structure for transfer of oil and chemicals (high risk structure)
- High seismicity area (L1 EQ $a_{peakbedrock}$ = 0.7g, L2 EQ $a_{peakbedrock}$ =1.02g)
- Izmit 1999 earthquake, Mw = 7.6, 17,000 fatalities, 43,000 injured, 120,000 buildings damaged





Case study project

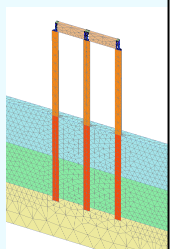
- Concrete deck with steel tubular piles
- Soft soil deposit (20 m. depth, two clay layers) overlying dense sand, overlying bedrock
- Typical situation of large end-bearing shafts
- Structural model, high deck stiffness and plastic hinge locations



Witteveen+Bos

Contents

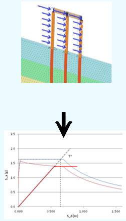
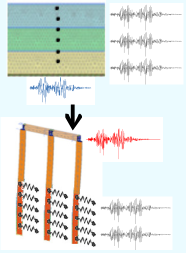
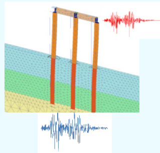
- Case study project
- Seismic/dynamic jetty analysis
  - Simplified dynamic analysis
    - Pushover analysis and laterally loaded piles
  - Uncoupled dynamic analysis
  - Coupled dynamic analysis
  - Comparison of uncoupled/coupled results
- Conclusions



Witteveen+Bos

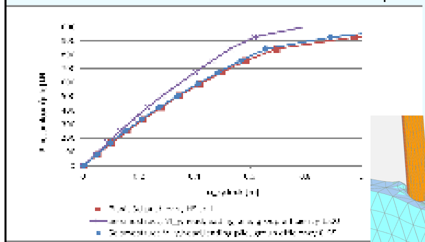
7 February 2013 20

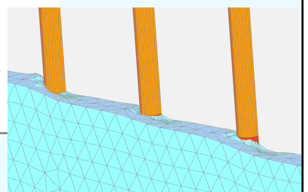
Seismic/dynamic jetty analysis methods

Simplified dynamic analysis	Uncoupled dynamic analysis	Coupled dynamic analysis
		
u_{max}, M_{max}	u(t), M(t), $u_{residual}$	u(t),M(t), $u_{residual}$

Pushover analysis and laterally loaded piles

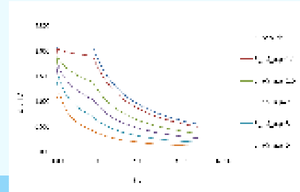
- Literature: Reese and van Ympe and NCHRP Report 461
- Plaxis3D as a tool to establish equivalent Winkler foundations

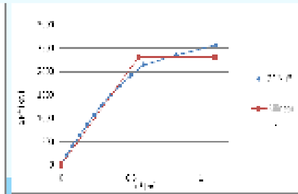




Simplified dynamic analysis

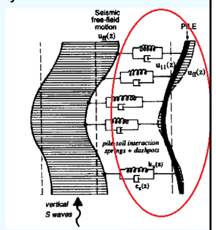
- N2 - Single mode capacity spectrum method, Fajfar (2000)
- Pushover curve to determine capacity and estimate fundamental frequency
- Transformation to equivalent SDOF system
- Response spectrum approach (displacement demand)





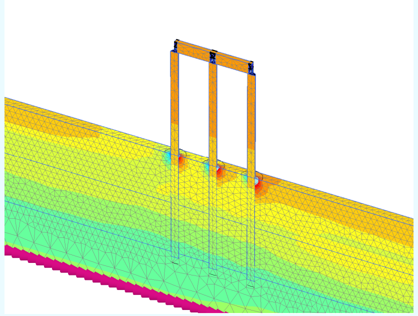
Uncoupled dynamic analysis

- Input from free field site response at levels along the pile
- Structure dynamic analysis with structural model
- Near field lateral interaction covered by non-linear p-y springs
  - Static p-y spring stiffness
  - Added viscous dashpots



Coupled dynamic analysis

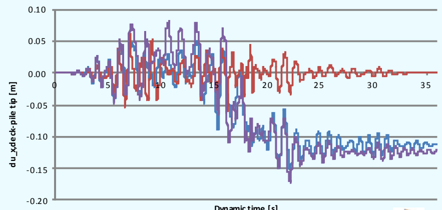
- Dynamic analysis of slice of soil including the jetty structure



Witteveen+Bos 7 February 2013 25

Comparison results dynamic analysis

- Similar results for uncoupled and coupled dynamic analysis
- Residual displacements can only be determined by non-linear site response analysis (Plaxis)



Witteveen+Bos 7 February 2013 27

Coupled dynamic analysis

- Aspects of preliminary model calibration:
  - Pushover analysis
    - Structure modelling, interfaces etc..
    - Soil parameters and constitutive modelling
    - Group effects (soil slice thickness, 2.5*D)
  - Free field dynamic analysis
    - Mesh element size (<1.00 m)
    - Boundary disturbances and dynamic viscous boundaries (soil slice width, 300 m)
    - Soil parameters (incl. damping) and constitutive modelling
- Computational demands
  - Duration of a single run: 2 days
  - Model calibration: weeks

Witteveen+Bos 7 February 2013 26

Summary

Earthquake loads

Seismic ground response (1D Shake, 2D Plaxis)

Liquefaction potential

Seismic stability (Pseudostatic, Newmark, Plaxis)

Structure response and soil-structure interaction (Response spectrum+pushover, Uncoupled and coupled dynamic analysis)

Witteveen+Bos 7 February 2013 28