New rules for swell load on foundations (floors and piles) in excavation (presentation of new SBRCURnet Recommendation C202)

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Content

- Approach of committee C202
- Literature study
- Engineering practice
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- Design rule for analytical calculations
- Conclusions and recommendations

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Research motivation

- Current design rule for swell load on piles in accordance with NEN 9997-1 (NEN 6743 - 1991) is very conservative
- Engineers uses various alternative calculation methods for swell load on piles and floors (for example Smits (2000) – Foundation Design book)
- Results swell investigation available: TUD – Korff (1999), Keijzers (2001), Schippers (2009) and COB-F210 (Sophia, 2002)
- Update CUR Recommendation 77 (2014) “Design rules for non reinforced underwater concrete slabs”

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Committee C202

- Members of CUR committee C202 are experts from clients, contractors, research institutes and engineering companies

- Participants C202: Rijkswaterstaat – GPO (chairman: Harry Dekker), Gemeentewerken Rotterdam, BAM Infraconsult, Volker InfraDesign, Ballast Nedam Engineering, Heijmans, Deltares, Grontmij Nederland, Kwast Consult, Witteveen+Bos, Fugro GeoServices, SBRCURnet en COB

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Approach C202

1. Literature study and research theoretical models
2. State of art engineering practice last 10 years
3. Comparative calculations analytical methods and FEM analyses (Plaxis 2D)
4. Expert meeting at info centre A4 Leiden (September 2013)
5. Proposal of analytical and FEM design rules and verification (some measurements)
6. Publishing recommendation C202

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Literature study

- Definition swell (C202): upwards vertical ground deformations (heave) in a construction pit by excavation with or without groundwater lowering
- 3 relevant mechanisms:
  - Instantaneous swell (s_{ini}), swelling direct during (short after) excavation
  - Primary swell, swelling by dissipation of water under pressure in time (s_{prim})
  - Secondary swell, swelling by creep (s_{sec})

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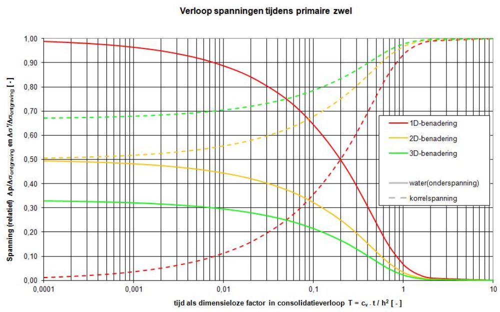
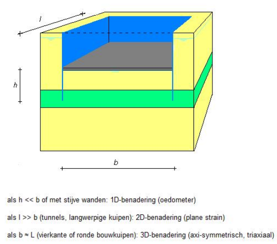
Literature study

- Swell load on floors:
  - Fixation deformations (moment of fixation and degree of consolidation)
  - Stiffness and shape construction pit (1D/2D/3D)





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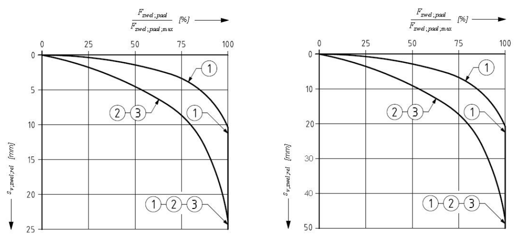
Literature study

- Swell load on foundation piles:
  - Fixation deformations (moment of fixation and degree of consolidation)
  - Stress state (vertical / horizontal) before and after excavation (stress distribution, contraction)
  - Pile - ground interaction (relative displacement)



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Literature study

- Swell load on foundation piles:
  - Pile installation effects (water under pressure, heave by pile driving)
  - Calculation methods based on CPT (NEN 9997-1, swell load), horizontal effective stresses (skin friction) or undrained shear strength:
    - $F_{swell;pile} = O_{pile} \cdot \alpha_{z;1} \cdot q_{c;1} \cdot \Delta h$
    - $F_{swell;pile} = O_{pile} \cdot \sigma'_{v;t} \cdot K_0 \cdot \tan\delta \cdot \Delta h$
    - $F_{swell;pile} = O_{pile} \cdot a \cdot c_u \cdot \Delta h$ (a ≈ 0,5 à 0,6)

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Engineering practice

- Selection of 10 representative cases:
  - Parking garage Ossenmarkt Groningen (1998)
  - Tunnel Oude Rijn A4 Leiden (2011)
  - Underground museum Assen (2011)
  - Railway tunnel Delft (2013)
  - Polder construction Haak om Leeuwarden (2013)
  - Sophia railway tunnel Papendrecht (2003)
  - Fehmarnbelt tunnel D-DK (2013)
  - Station Vijzelgracht NZ-lijn Amsterdam (2013)
  - Station Ceintuurbaan NZ-lijn Amsterdam (2013)
  - Tunnel Sluiskil (2013)

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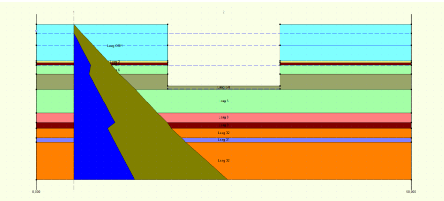
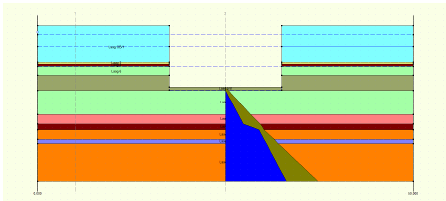
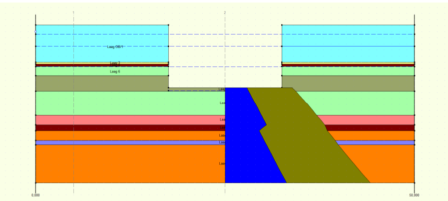
Engineering practice

Case tunnel Delft - Stress state before/after excavation



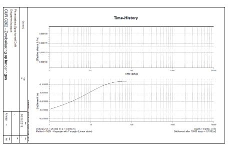


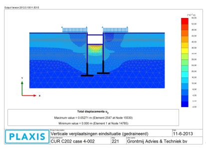


Engineering practice

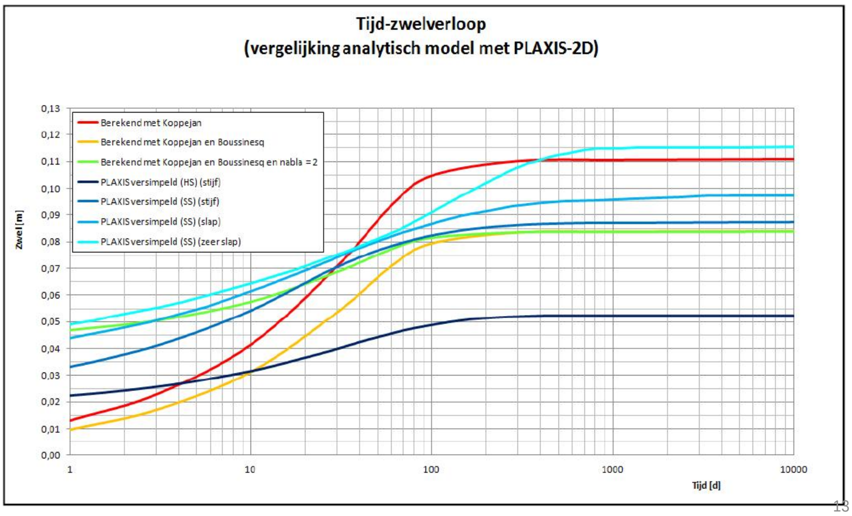
Conclusions swell load on floors and piles:

- Calculation methods floors: analytical 1D based on compression theory (D-Settlement – model Koppejan/Terzaghi or NEN-Bjerrum) or 2D ground – construction interaction (Plaxis 2D – HS(s)-model)
- Calculation methods piles: horizontal effective stresses (calculation sheet without construction interaction) or Plaxis 2D (with construction interaction)

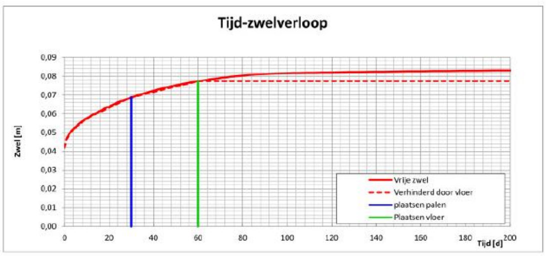


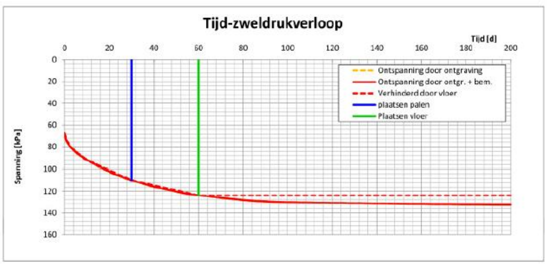


Results analytical en numerical calculations



Results analytical en numerical calculations





Results analytical en numerical calculations

Tabel 5.19 Vergelijking berekende zwelkracht in paal met analytische en numerieke modellen – case Spoortunnel Delft

reken- model	omschrijving variant	$\tau_{zwel;gem}$ [kPa]	$F_{t;zwel;max}$ [kN]	$s_{v;t=30d}$ [m]	$F_{t;zwel;interactie}$ [kN]
analytisch	initiële spanningstoestand ($\alpha_{z;zand}$ = 0,02, $\alpha_{z;klei/veen}$ = 0,05)	66,1	291		268
q_c-methode	initiële spanningstoestand ($\alpha_{z;zand}$ = 0,01, $\alpha_{z;klei/veen}$ = 0,02)	28,3	124	0,069	114
	lineaire ontgravingsreductie ($\alpha_{z;zand}$ = 0,01, $\alpha_{z;klei/veen}$ = 0,02)	3,2	14		13
	wortel ontgravingsred. ($\alpha_{z;zand}$ = 0,01, $\alpha_{z;klei/veen}$ = 0,02)	**9,4**	**41**		**38**
analytisch	initiële spanningstoestand (K_0.tanδ = 0,25)	33,1	145		133
slipmethode	initiële spanningstoestand (K_0.tanδ·$OCR^{0,5}$ = 0,29	38,4	169		155
	initiële spanningstoestand (K.tanδ = 0,35)	46,3	204		188
	lineaire ontgravingsreductie (K_0.tanδ = 0,25)	3,9	17		16
	lineaire ontgravingsreductie (K_0.tanδ·$OCR^{0,5}$ = 0,29	4,5	20	0,069	18
	lineaire ontgravingsreductie (K.tanδ = 0,35)	5,5	24		22
	wortel ontgravingsreductie (K_0.tanδ = 0,25)	11,3	50		46
	wortel ontgravingsreductie (K_0.tanδ·$OCR^{0,5}$ = 0,29	13,1	58		53
	wortel ontgravingsreductie (K_0.tanδ = 0,35)	**15,8**	**70**		**64**
	wortel ontgravingsreductie (K_p.tanδ)	32,9	145		133
numeriek	met R_{int} = 1,0 (rigid)	28,8	127	0,070	106
	met R_{int} = 0,3	**15,4**	**67**		**55**

Results analytical en numerical calculations

Tabel 5.19 Vergelijking berekende zwelkracht in paal met analytische en numerieke modellen – case Sluiskil

reken- model	omschrijving variant	$\tau_{zwel;gem}$ [kPa]	$F_{t;zwel;max}$ [kN]	$s_{v;t=45d}$ [m]	$F_{t;zwel;interactie}$ [kN]
analytisch	initiële spanningstoestand ($\alpha_{z;klei}$ = 0,05)	195,5	983		590
q_c-methode	initiële spanningstoestand ($\alpha_{z;klei}$ = 0,03)	112,5	566	0,034	374
	lineaire ontgravingsreductie ($\alpha_{z;klei}$ = 0,03)	23,4	118		78
	wortel ontgravingsreductie ($\alpha_{z;klei}$ = 0,03)	**49,5**	**249**		**164**
analytisch	initiële spanningstoestand (K_0.tanδ = 0,25)	43,2	217		143
slipmethode	initiële spanningstoestand (K_0.tanδ.$OCR^{0,5}$ = 0,35)	60,5	304		201
	lineaire ontgravingsreductie (K_0.tanδ = 0,25)	19,4	47		31
	lineaire ontgravingsreductie (K_0.tanδ.$OCR^{0,5}$ = 0,35)	13,0	65	0,034	43
	wortel ontgravingsreductie (K_0.tanδ = 0,25)	19,4	98		65
	wortel ontgravingsreductie (K_0.tanδ.$OCR^{0,5}$ = 0,35)	27,2	137		90
	wortel ontgravingsreductie (K_p.tanδ)	**50,6**	**254**		**168**
analytisch	initiële spanningstoestand (α = 0,60)	80,6	406		268
c_u-methode	lineaire ontgravingsreductie (α = 0,60)	20,1	101	0,034	67
	wortel ontgravingsreductie (α = 0,60)	39,3	201		133
	wortel ontgravingsreductie (α = 0,60)	**48,3**	**243**		**160**
numeriek	met R_{int} = 0,3 (paalgroep) x factor (K_p/K_0 = 2,9)	31,0	157 (122)	0,030	**151** (99)
MC	met R_{int} = 0,3 (enkele paal) x factor (K_p/K_0 = 2,9)	49,0	**246**	0,030	99
numeriek	met R_{int} = 0,3 (paalgroep) x factor (K_p/K_0 = 2,9)	29,9	154 (125)	0,034	**128** (102)
SS	met R_{int} = 0,3 (enkele paal) x factor (K_p/K_0 = 2,9)	40,6	**203**	0,032	87

Design rule for analytical calculations

Steps for analytical calculations (piles and floors):

- step 1: ground profile, soil parameters, initial stress situation and structural elements
- step 2: construction phases with moments of fixation piles and floor
- step 3: unload and loading by excavation and / or dewatering
- step 4: calculation undisturbed swell and swell load on the floor
- step 5: calculation swell load on the piles/wall and verify the tension pile/wall capacity (groundwater pressure + swell load)

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Design rule for analytical calculations

Steps for analytical calculations (piles and floors):

- step 4: calculation undisturbed swell

$$s(t)_{corr} = \left(1 - \frac{1}{\eta}\right) \cdot s_{end} + \frac{1}{\eta} \cdot s(t) = \frac{1}{2} \cdot s_{end} + \frac{1}{2} \cdot s(t)$$

- step 4: calculation swell load on the floor

$$\sigma_{swell;floor} = \frac{1}{2} \cdot \Delta\sigma_{\text{excavation}} \cdot (1 - U)$$

$$q_{Ek} = \sigma_{water} + \sigma_{swell\,;\,floor} - \sigma_{eg} - \sigma_{rb}$$

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Design rule for analytical calculations

Steps for analytical calculations (piles and floors):
- step 5: calculation swell load single pile / wall

$$F_{swell;pile} = O_{pile} \cdot \sigma'_{v;t} \cdot K \cdot \tan\delta \cdot \Delta h$$

- Normal consolidated soils: $K \cdot \tan\delta = 0{,}35 \cdot \left(\frac{\sigma'_{v;0}}{\sigma'_{v;t}}\right)^{0{,}5}$

- Overconsolidated peat, clay and loam layers: $K \cdot \tan\delta = 0{,}60 \cdot \left(\frac{\sigma'_{v;0}}{\sigma'_{v;t}}\right)^{0{,}5}$

- Overconsolidated sand layers: $K \cdot \tan\delta = 1{,}20 \cdot \left(\frac{\sigma'_{v;0}}{\sigma'_{v;t}}\right)^{0{,}5}$

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Conclusions and recommendations

Conclusions:
- The calculation method for swell load on foundations based on NEN 9997-1 is to conservative and isn't in accordance with engineering practice
- Based on the results of literature study, engineering practice and comparative calculations an analytical calculation (safe) method is determined and an advanced FEM - Plaxis 2D - (optimized) method

Recommendations:
- The observational method for swell load on foundations can be very useful for optimization
- Measurements of undisturbed swell and swell load on piles and floors is needed for further validation of the calculations methods
- Fundamental research for unloading ground conditions (theory of Skempton) is recommended

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Grontmij Kwast Consult Geotechnische Advisering en Innovaties

New rules for swell load on foundations (floors and piles) in excavation is soon available at:
www.sbrcurnet.nl

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