Design Examples for the Eurocode 7 Workshop

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The ten geotechnical design examples, prepared for the International Workshop on the Evaluation of Eurocode 7 held in Trinity College Dublin on 31st March and 1st April 2005, are presented on the following pages. These design examples were circulated to the members of the committees involved in organising the Workshop: ERTC 10 - Evaluation of the Application of Eurocode 7, Geotechnet and TC23 – Limit State Design, before the Workshop and the members of these committees were asked to prepare solutions. The following instructions were given with the examples:

- *Please design all (or some) of the following ten examples to EN 1997-1 using your national annex, or Annex A if this is not available:*
    1. *Pad foundation with a central vertical load only*
    2. *Pad foundation with an inclined and an eccentric load*
    3. *Pile foundation*
    4. ~~*Cantilever retaining wall (with spread foundation)*~~
    5. ~~*Embedded retaining wall*~~
    6. *Anchored retaining wall*
    7. *Uplift of a deep basement*
    8. *Seepage around a retaining wall*
    9. *Slope stability*

- *For each design example, please state:*
    - *The determined design dimensions (e.g. foundation width)*
    - *The Design Approach (or Approaches) used*
    - *The partial factor values used and if taken from a national annex or EN 1997-1, Annex A*
    - *The analytical model used*
    - *The values adopted for any parameters that were not given in the example or provided in EN 1997-1*
    - *Any other design assumptions or comments*
    - *If and how the serviceability limit state has been considered*
    - *How the design dimensions obtained using EN 1997-1 compare to those that would be obtained using your current national standard for the design situation*
    - *Provide a brief evaluation of the EN 1997-1 design.*

Those submitting solutions were assured that no individuals would be identified when the results were presented.

A large number of solutions based on EN 1997-1 and national standards were received from 12 European countries and some solutions based on Japanese codes were received from Japan. The solutions received were summarised and evaluated at the Workshop by five reporters, who also prepared reports on their finding: one for the spread foundation examples (Scarpelli and Fruzzetti, 2005), one for the pile foundation examples (Frank, 2005), one for the retaining wall examples (Simpson, 2005), one for the examples to avoid hydraulic failure (Orr, 2005a), and one for the embankment on soft ground (Bergdahl, 2005).

In addition to the reports on the solutions received for the design examples, with evaluations of the solutions and explanations for the ranges of values received, the author has prepared a set of model solutions for the design examples (Orr, 2005b).

REFERENCES

Bergdahl, U. (2005) Embankment design according to Eurocode 7. A compilation of different solutions on Example 10– Road Embankment, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin, March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin

Frank, R. (2005) Evaluation of Eurocode 7 – Two pile foundation design examples, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin, March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin

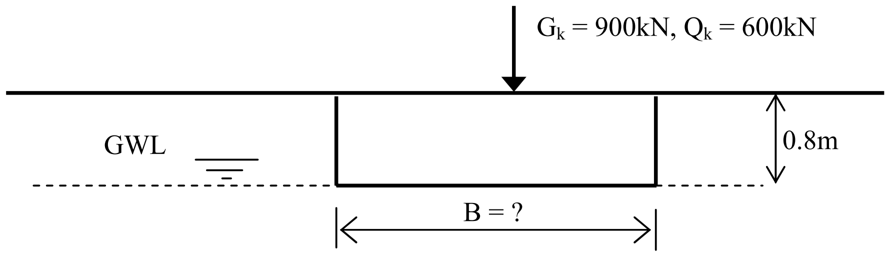
Orr, T.L.L. (2005a) Evaluation of Eurocode 7 - Uplift and Heave Designs, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin, March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin

Orr, T.L.L. (2005b) Model Solutions to Eurocode 7 Workshop Examples, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin, March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin

Scarpelli, G and Fruzzetti, V.M.E. (2005), Evaluation of Eurocode 7 – Spread Foundation design, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin, March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College Dublin

Simpson, B. (2005) Eurocode 7 Workshop – Retaining wall examples 5-7, *Proceedings of International Workshop on Evaluation of Eurocode 7*, Dublin March-April 2005, Department of Civil, Structural and Environmental Engineering, Trinity College, Dublin.

Example 1 - Pad Foundation with vertical load only



Soil: Stiff till - c_{uk} = 200kPa, c'_k = 0kPa, $\phi'_k = 35^o$, $\gamma = 22kN/m^3$, SPT N = 40, $m_{vk} = 0.015m^2/MN$

- **Design Situation**
  - Square pad foundation for a building, 0.8m embedment depth; groundwater level at base of foundation. The allowable settlement is 25mm
- **Ground Properties**
  - Overconsolidated glacial till, c_{uk} = 200kPa, c'_k = 0kPa, $\phi'_k = 35^o$, $\gamma = 22kN/m^3$, SPT N = 40, $m_{vk} = 0.015m^2/MN$
- **Characteristic values of actions**
  - permanent vertical load = 900kN + weight of foundation
  - variable vertical load = 600kN
  - concrete weight density = 24 kN/m^3
- **Require foundation width, B to satisfy both ULS and SLS**

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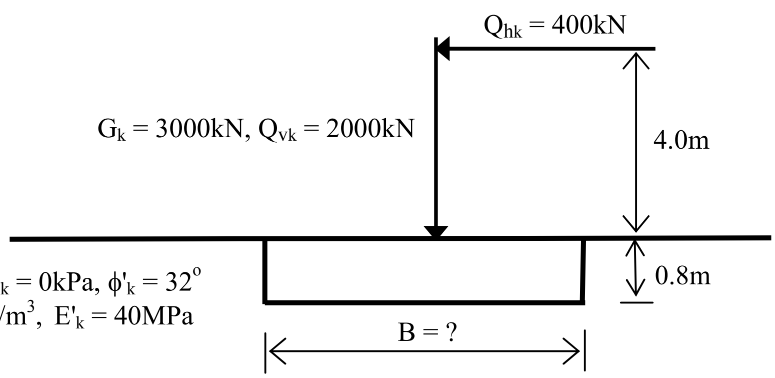
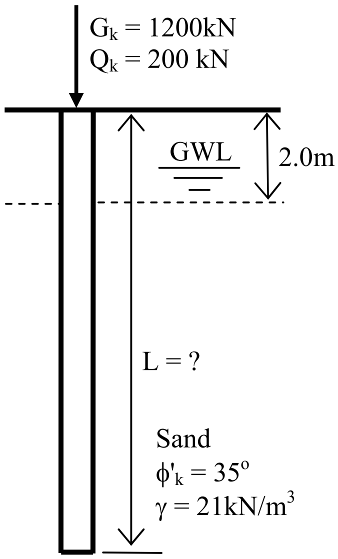
Example 2 – Pad Foundation with an inclined and eccentric load



Soil: Sand: c'_k = 0kPa, $\phi'_k = 32^o$
$\gamma = 20kN/m^3$, E'_k = 40MPa

- **Design situation:**
  - Isolated square pad foundation, 0.8m embedment depth, groundwater level at great depth. Allowable settlement is 25mm and maximum tilt is 1/2000
- **Soil conditions:**
  - Cohesionless sand, c'_k = 0, $\phi'_k = 32^o$, $\gamma = 20kN/m^3$, E'_k = 40MPa
- **Characteristic values of actions:**
  - Permanent vertical load G_k = 3000kN plus weight of pad foundation
  - Variable vertical load Q_{vk} = 2000kN (at top of foundation)
  - Permanent horizontal load = 0
  - Variable horizontal load Q_{hk} = 400kN at a height of 4m above the ground surface
  - Variable loads are independent of each other
- **Require width of foundation, B**

Example 3 – Pile Foundation designed from soil parameter values



- **Design situation**
  - Bored pile for a building, 600mm diameter
  - Groundwater level at depth of 2m below the ground surface
- **Soil conditions**
  - Sand: $c'_k = 0$, $\phi'_k = 35^o$, $\gamma = 21kN/m^3$
    SPT N = 25
- **Actions**
  - Characteristic permanent load G_k = 1200kN
  - Characteristic variable load Q_k = 200kN
  - Weight density of concrete = $24kN/m^3$
- **Require**
  - Pile length, L

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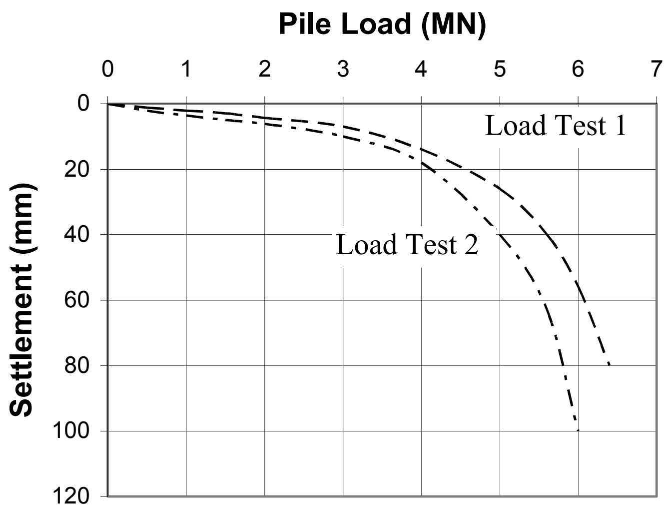
Example 4 – Pile Foundation designed from pile load tests

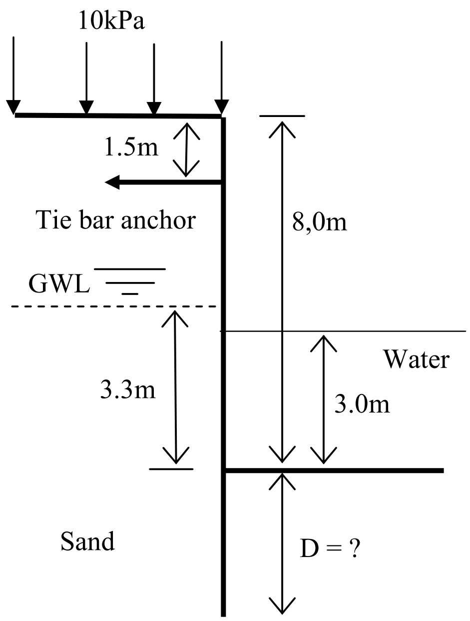
- **Design Situation**
  - Pile foundation, driven piles, pile diameter D = 0.4m and length = 15m. The building supported by the piles does not have the capacity to transfer the load from weak to strong piles. The allowable pile settlement is 10mm
- **Pile Resistance**
  - 2 static pile load test results provided on driven piles of same diameter and length as design piles. Piles were loaded beyond a settlement of 0.1D = 40mm to give the limit load.
- **Characteristic values of actions**
  - Permanent vertical load G_k = 20,000kN
  - Variable vertical load Q_k = 5,000kN
- **Require number of piles needed to satisfy both ULS and SLS**



Pile Load Test Results

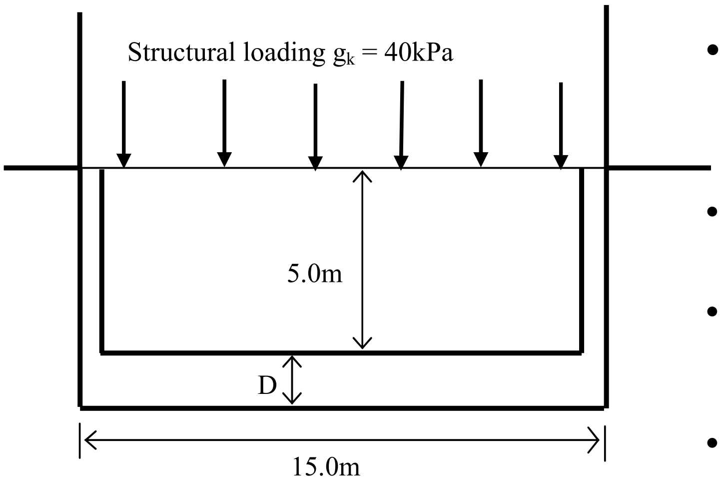
Load (MN)	Settlement Pile 1(mm)	Settlement Pile 2 (mm)
0	0	0
0.5	2.1	1.2
1.0	3.6	2.1
1.5	5.0	2.9
2.0	6.2	4.1
3.0	10.0	7.0
4.0	18.0	14.0
5.0	40.0	26.0
5.6	63.0	40.0
6.0	100.0	56.0
6.4		80.0

Example 7 – Anchored sheet pile quay wall



- **Design situation**
  - Anchored sheet pile retaining wall for an 8m high quay using a horizontal tie bar anchor as a permanent structure.
- **Soil conditions**
  - Gravelly sand - $\phi'_k = 35^o$, $\gamma = 18kN/m^3$ (above water table) and $20kN/m^3$ (below water table)
- **Actions**
  - Characteristic variable surcharge behind wall 10kPa
  - 3m depth of water in front of the wall and a tidal lag of 0.3m between the water in front of the wall and the water in the ground behind the wall.
- **Require**
  - Depth of wall embedment, D
  - Design bending moment, M in the wall

Example 8 – Uplift of a deep basement



- **Design situation**
  - Long structure, 15m wide, with a 5m deep basement
  - Groundwater level can rise to the ground surface
- **Soil Conditions**
  - Sand – $c'_k = 0$, $\phi'_k = 35^o$, $\gamma = 20kN/m^3$ (below water table)
- **Actions**
  - Characteristic structural loading g_k = 40kPa
  - Concrete weight density $\gamma = 24kN/m^3$
  - Wall thickness = 0.3m
- **Require**
  - Thickness of base slab, D for safety against uplift

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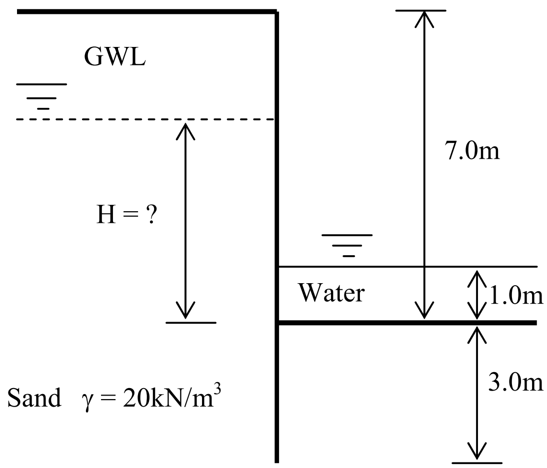
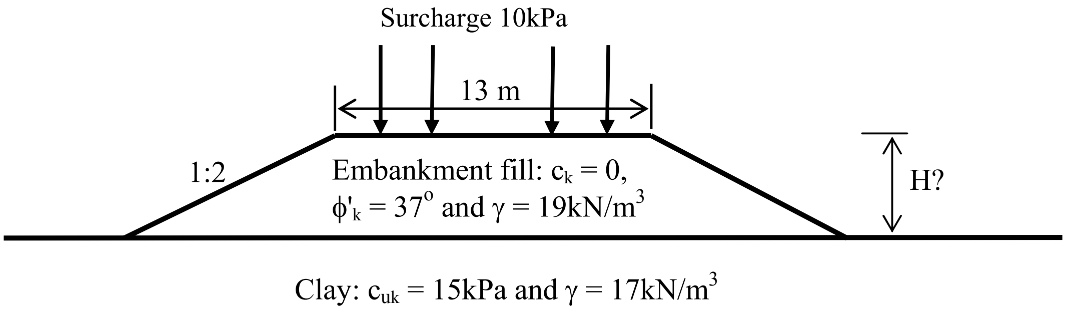
Example 9 – Failure by Hydraulic Heave



- **Design situation**
  - Seepage around an embedded sheet pile retaining wall
- **Soil conditions**
  - $\gamma = 20kN/m^3$
- **Actions**
  - Groundwater level 1.0m above ground surface in front of wall
- **Require**
  - Maximum height, H of water behind wall above ground surface in front of the wall to ensure safety against hydraulic heave

Example 10 – Road Embankment



- **Design Situation**
  - A road embankment is to be constructed over soft clay. Embankment is 13m wide at the top and has side slopes at 1:2 (26.6^o)
- **Soil conditions**
  - Fill for embankment: Granular soil $c'_k = 0$, $\phi'_k = 37^o$, $\gamma = 19kN/m^3$
  - Soil beneath embankment: Clay $c_{uk} = 15kPa$, $\gamma = 17kN/m^3$
- **Characteristic values of actions**
  - Traffic load on embankment: $q_k = 10kPa$
- **Require**
  - Maximum height, H of embankment

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Second Questionnaire for the implementation of EC 7-1

Please complete this questionnaire before 2 October 2006

Selection of design approaches and partial factors

in ...... ?

Geotechnical application	Design Approach DA 1	Design Approach DA 2[1)]	Design Approach DA 2*[2)]	Design Approach DA 3
Example 2: Pad foundation – verification of ground bearing capacity	Comb. 1: $\gamma_{G;unfav}^{3)}$ = ? ; $\gamma_{G,fav}^{4)}$= ?; Comb. 2: γ_G= 1,0 ; γ_Q= ? ; $\gamma_{\varphi'}$= ? ; $\gamma_{c'}$= ?, γ_{cu}= ?;	$\gamma_{G;unfav}^{3)}$ = ? ; $\gamma_{G,fav}^{4)}$= ? ; γ_Q= ? ; $\gamma_{R;v}$ = ?	$\gamma_{G;unfav}^{3)}$ = ? ; $\gamma_{G,fav}^{4)}$ = ?; γ_Q= ? $\gamma_{R;v}$ = ?;	$\gamma_{\varphi'}$= ? ; $\gamma_{c'}$= ?, γ_{cu}= ?; From the structure: $\gamma_{G;unfav}^{3)}$ = ? ; $\gamma_{G,fav}^{4)}$= ? ; γ_Q= ?
Example 2: Pad foundation – verification of sliding resistance	Comb. 1: $\gamma_{G;unfav}$= ? ; $\gamma_{G,fav}$= ? γ_Q= ?; Comb. 2: γ_G= 1,0 ; γ_Q= ? ; $\gamma_{\varphi'}$= ?	$\gamma_{G;unfav}$= ? $\gamma_{G,fav}$= ? ; γ_Q= ? $\gamma_{R;h}$ = ?	$\gamma_{G;unfav}$= ? $\gamma_{G,fav}$= ? ;γ_Q= ? $\gamma_{R;h}$ = ?	$\gamma_{\varphi'}$= ? From the structure: $\gamma_{G;unfav}$= ? ;$\gamma_{G,fav}$= ? ;γ_Q= ?
Example 3: pile foundation – design of the pile length from soil parameter values	Comb. 1: $\gamma_{G;unfav}$= ? ; γ_Q= ?; γ_b= ? ; γ_s= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ? Comb. 2: γ_G= 1,0 ; γ_Q= ? ; γ_b= ? ; γ_s= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ?	$\gamma_{G;unfav}$= ?; γ_Q= ? ; γ_b= ? ; γ_s= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ?	$\gamma_{G;unfav}$= ?; γ_Q= ? ; γ_b= ? ; γ_s= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ?	$\gamma_{\varphi'}$= ? From the structure: $\gamma_{G;unfav}$= ? ;γ_Q= ?; γ_R = ?
Example 4: pile foundation – determination of the number of piles from pile load tests	Comb. 1: $\gamma_{G;unfav}$= ?; γ_Q= ?; γ_t= ? ; $\gamma_R^{3)}$ = ? Comb. 2: γ_G= 1,0 ; γ_Q= ? ; γ_t= ? ; $\gamma_R^{3)}$ =	$\gamma_{G;unfav}$= ? ; γ_Q= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ?	$\gamma_{G;unfav}$= ? ; γ_Q= ? ; γ_t= ? ; $\gamma_R^{3)}$ = ?	Is it not possible to use DA 3 with pile load tests!
Example 7: anchored sheet pile quay wall – design of embedment depth without anchor design without check of vertical equilibrium	Comb. 1: $\gamma_{G;unfav}$= ? ;$\gamma_{G;fav}$= ? ;γ_Q= ? Comb. 2: $\gamma_{\varphi'}$= ? ; γ_G= 1,0 ; γ_Q= ?	$\gamma_{G;unfav}$= ? ;$\gamma_{G;fav}$= ? ;γ_Q= ? $\gamma_{R;e}$ = ?		$\gamma_{\varphi'}$= ? ; From the structure: $\gamma_{G;unfav}$= ? ;$\gamma_{G,fav}$= ? ;γ_Q= ?

Geotechnical application	Design Approach DA 1	Design Approach DA 2[1)]	Design Approach DA 2*[2)]	Design Approach DA 3
Example 8: verification of uplift of a deep basement	$\gamma_{G;stb}$ = ? ; $\gamma_{G;dst}$ = ? $\gamma_{Q;dst}$ = ? for friction on the walls: a): partial factors of Table A.16 (γ_{φ}= ?) or b): friction as a stabilising action using $\gamma_{G;stb}$ = ?			
Example 9: verification of failure by hydraulic heave	verification using eq. ...? (2.9a or 2.9b?); $\gamma_{G;stb}$ = ? ; $\gamma_{G;dst}$ = ? $\gamma_{Q;dst}$ = ?			
Example 10: road embankment – determination of the maximum height using the slope stability as criterion	Comb. 1: $\gamma_{G;unfav}$= ? ;$\gamma_{G,fav}$= ? ;γ_Q= ? Comb. 2: γ_G= 1,0 ; γ_Q= ? $\gamma_{\varphi'}$= ? ; $\gamma_{c'}$= ?, γ_{cu}= ?;	γ_G= ? ; γ_Q= ?; $\gamma_{R;e}$ = ?		$\gamma_{\varphi'}$= ? ; $\gamma_{c'}$= ?, γ_{cu}= ?; $\gamma_{R;e}$= ? From the structure: $\gamma_{G;unfav}$= ? ;$\gamma_{G,fav}$= ? ;γ_Q= ?

1) The partial factors are applied to the actions at the beginning of the verification and the calculation is performed with design values of actions

2) The verification is performed using characteristic values of actions and partial factors are applied to the characteristic values of the effects of actions (and the characteristic values of the resistance of the ground) at the end of the verification when the inequality for the ultimate limit state is checked.

3) $\gamma_{G;unfav}$: partial factor for permanent unfavourable actions or effects of actions

4) $\gamma_{G,fav}$: partial factor for permanent favourable actions or effects of actions

5) γ_R: is a model factor here!

Additional questions:

- In Table A.4 of EN 1997-1 a partial factor on weight density of γ_γ = 1.0 is recommended. Do you have design situations or verifications where you use a factor of $\gamma_\gamma \neq 1.0$? No.... Yes, in ....