Design Examples using BS EN 1997-1

Introduction

A recent exercise[1] to compare design results using EN 1997-1 revealed a wide diversity of answers, attributable substantially to the use of different *geotechnical* analytical models for ground behaviour; there was only very limited UK input to this exercise.

You are now cordially invited to participate in a joint BGA/GeoTechNet[2]/BSI[3] exercise to design the same set of ten geotechnical problems; the primary aim is to see how UK geotechnical engineers interpret the new BS EN 1997-1[4]. ***Please note that individuals and their Companies will not be identified in any subsequent public communications of the results unless specifically requested by the participant.***

Guidance on the application of EN 1997-1 has been published[5] while guidance on BS EN 1997-1 already exists[6] with more expected shortly[7].

Design exercise**:**

Please design all (or some) of the following ten examples to BS EN 1997-1 (details given below):

1. Pad foundation with vertical load only
2. Pad foundation with an inclined and an eccentric load
3. Pile foundation designed from soil parameter values
4. Pile foundation designed from pile load tests
5. Cantilever gravity retaining wall
6. Embedded sheet pile retaining wall
7. Anchored sheet pile retaining wall
8. Uplift of a deep basement
9. Hydraulic heave
10. Road embankment

As the UK National Annex for BS EN 1997-1 has not yet been published and to limit the scope for misinterpretation from the use of different geotechnical formulae, participants are requested to do the following:

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[1] Under the auspices of ERTC 10, ISSMGE TC 23 and GeoTechNet, this design comparison exercise was examined at a Workshop in Dublin on 31 March and 1 April 2005. A publication on the outcome is expected in due course.
[2] GeoTechNet is an EU-funded geotechnical network, part of which aims to assist in the implementation of Eurocode 7 (see www.geotechnet.org).
[3] BSI is in the process of producing the UK National Annex for BS EN 1997-1.
[4] BS EN 1997-1: 2004 was published by BSI in December 2004.
[5] See Frank et al
[6] PP 1990:2004 *Structural Eurocodes. Guide to the Structural Eurocodes for students of structural design*. British Standards Institution, London
[7]ODPM (2005). *A Designers' Simple Guide to the use of Eurocode 7*. To be published.
CIRIA (2005). *EC7 - Implications for UK Practice*. To be published.

1. Use Design Approach 1 (DA1); please feel free also to try any of the other two Design Approaches if you wish[1].
2. Use the partial factor values given in Annex A of the Code.
3. Use the BS EN 1997-1 Annex D method to evaluate bearing capacities.
4. Treat surcharge as a variable load.
5. Use γ_m = 1.4 for the partial 'model' factor required when designing a pile from ground test results (Example 3).
6. *Wherever possible and particularly for the retaining wall Examples 5, 6 and 7, please present your results in tabular form, with as many intermediate calculations shown as possible; this will greatly aid the interpretation of differences in results between entries. Some additional requests specific to the three retaining wall Examples are given in Appendix A of this document.*

For each design example, please state**:**

- The determined design dimensions (e.g. foundation width).
- The geotechnical analytical model(s) used.
- The values adopted for any parameters that were not given in the example or provided in BS EN 1997-1.
- Any other design assumptions or comments.
- If and how the serviceability limit state has been considered. Again for the purposes of comparison of results, please use Annex F of BS EN 1997-1; you are welcome to comment on the use of this Annex if you wish to.
- How the design dimensions obtained using BS EN 1997-1 compare to those that would be obtained using your normal, in-house method or current BS Codes of Practice.

Queries:

Any questions about the designs should be sent to John Powell (email: powellj@bre.co.uk).

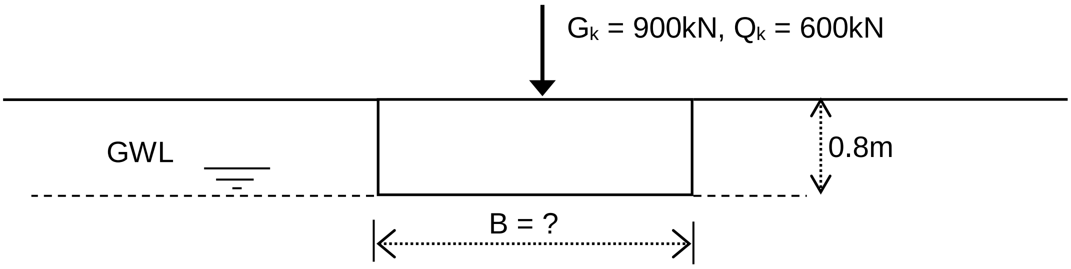
Completed calculations

Please send your results to John Powell at the above email address by **15 August 2005.**

It is hoped that, if a sufficiently extensive response is achieved, the results of the exercise will feature in a BGA meeting.

[1] While DA1 only is expected to be permitted for design in the UK, DA2 and DA3 may be required for design in other EU Member States.

Example 1 - Pad Foundation with vertical load only



Soil:
Stiff till - c_{uk} = 200kPa, c'_k = 0kPa, φ'_k = 35°,
γ_k = 22kN/m³, SPT N = 40, m_{vk} = 0.015m²/MN

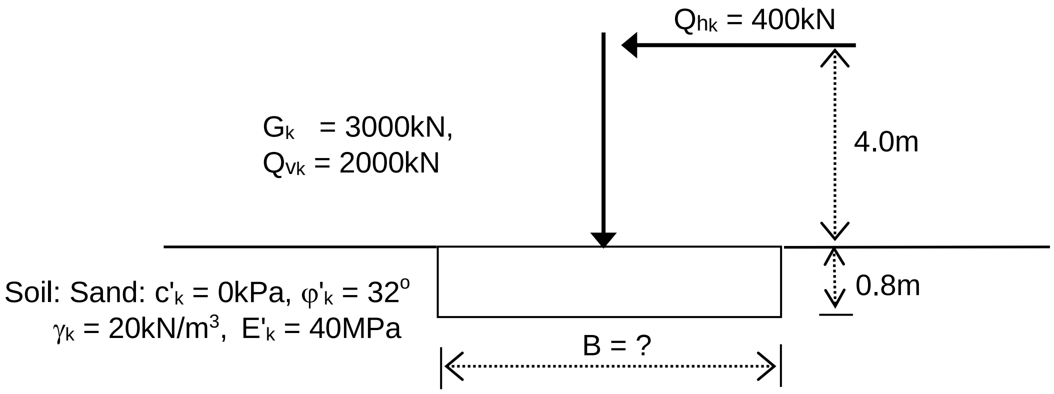
- Design Situation
  - Square pad foundation, 0.8m embedment depth; groundwater level at base of foundation. The allowable settlement is 25mm

- Characteristic values of ground properties
  - Overconsolidated glacial till, with the parameter values shown in the Figure.

- Characteristic values of actions
  - permanent vertical load = 900kN + weight of foundation
  - variable vertical load = 600kN
  - concrete weight density = 24 kN/m³

- **Require foundation width, B, to satisfy both ULS and SLS**

Example 2 – Pad Foundation with an inclined and eccentric load



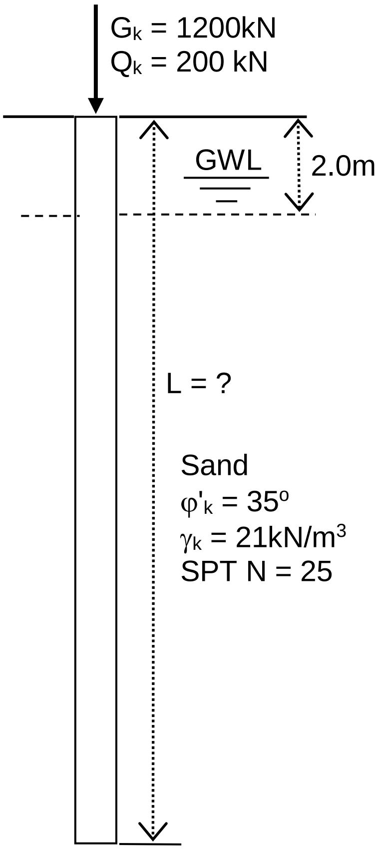
- Design situation:
  - Square foundation, 0.8m embedment depth, groundwater level at great depth. Allowable settlement is 25mm and maximum tilt is 1/2000

- Soil conditions:
  - Cohesionless sand, with the characteristic parameters shown in the Figure

- 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, to satisfy both ULS and SLS.**

Example 3 – Pile Foundation designed using soil parameter values



- Design situation
  - Bored pile, 600mm diameter
  - Groundwater level at depth of 2m below the ground surface
- Soil conditions
  Sand, with the characteristic parameter values shown in the Figure
- Characteristic values of Actions
  - Permanent load G_k = 1200kN
  - Variable load Q_k = 200kN
  - Weight density of concrete = 24kN/m^3
- **Require: pile length, L**

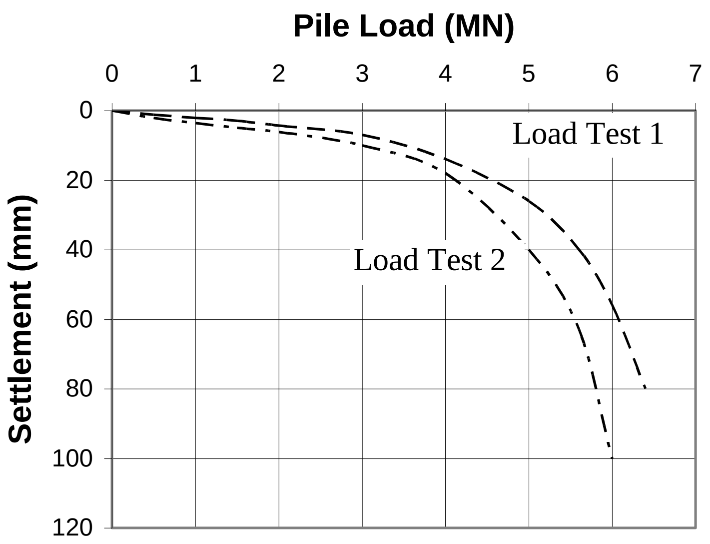
Example 4 – Pile Foundation designed from pile load tests

- Design Situation
  - Pile group foundation, driven piles, pile diameter D = 0.4m and length = 15m. The structure supported by the piles does not have the capacity to transfer the load from weak to strong piles. The allowable pile settlement is 10mm. IGNORE any pile group effect.

- 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

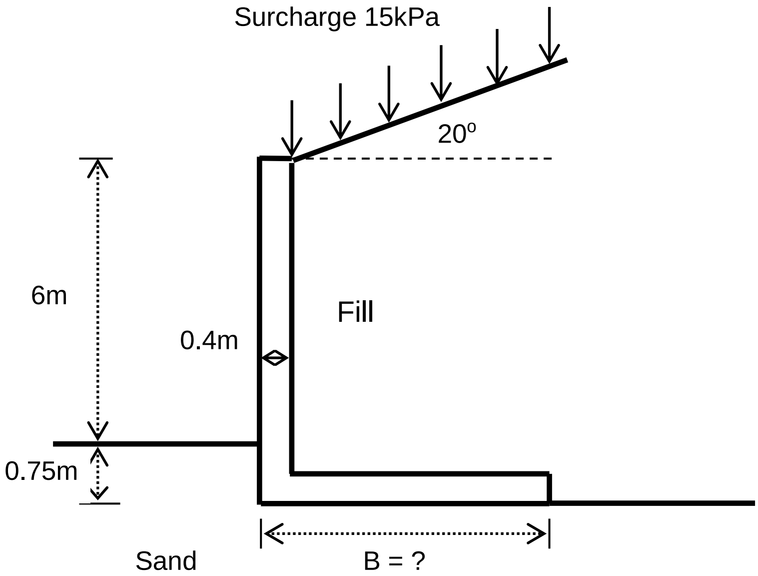
- **Require number of piles needed to satisfy both ULS and SLS**



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 5 – Cantilever Gravity Retaining Wall (see Appendix A)

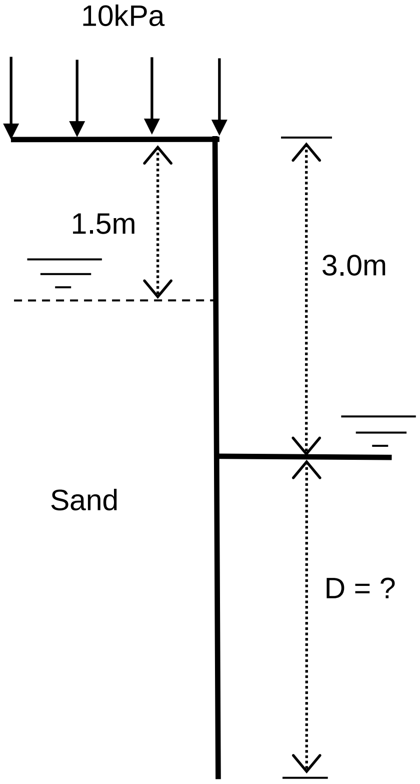


- Design situation
  - 6m high cantilever gravity retaining wall.
  - Wall and base thicknesses 0.40m.
  - Groundwater level is at depth below the base of the wall.
  - The wall is embedded 0.75m below ground level in front of the wall.
  - The ground behind the wall slopes upwards at 20°.

- Soil conditions
  - Sand beneath wall: $c'_k = 0$, $\varphi'_k = 34^o$, $\gamma_k = 19kN/m^3$.
  - Fill behind wall: $c'_k = 0$, $\varphi'_k = 38^o$, $\gamma_k = 20kN/m^3$.
- Characteristic values of actions
  - Characteristic surcharge behind wall 15kPa.

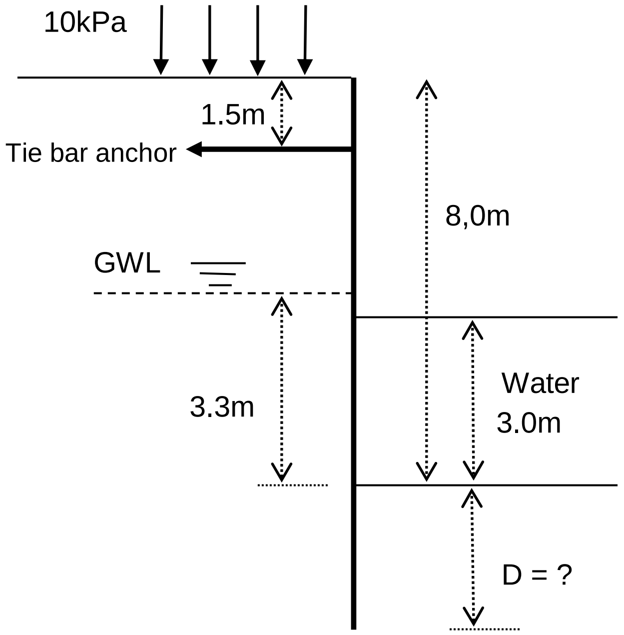
- **Require**
  - **Width of wall foundation, B.**
  - **Design shear force, S, and bending moment, M, in the wall.**

Example 6 – Embedded sheet pile retaining wall (see Appendix A)



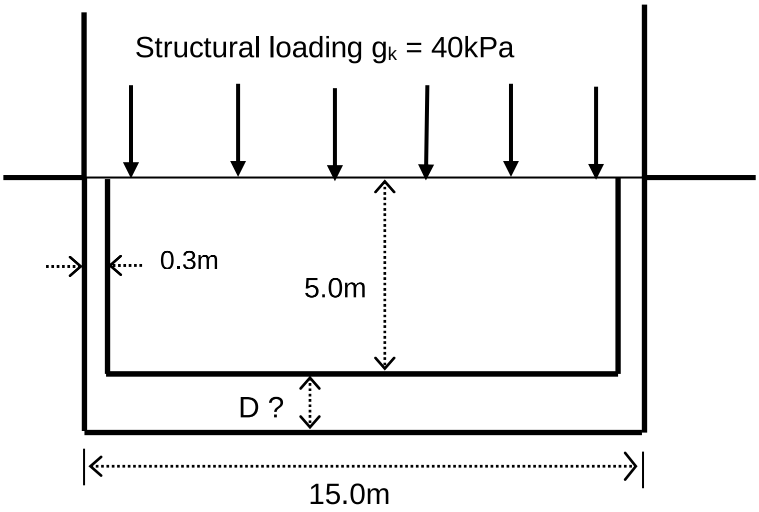
- Design situation
  - Embedded sheet pile retaining wall for a 3m deep excavation with a 10kPa surcharge on the surface behind the wall.
- Soil conditions
  - Sand: $c'_k = 0$, $\varphi'_k = 37^o$, $\gamma_k = 20kN/m^3$.
- Characteristic values of actions
  - Surcharge behind wall - 10kPa
  - Groundwater level at depth of 1.5m below ground surface behind wall and at the ground surface in front of wall
- **Require**
  - **Depth of wall embedment, D.**
  - **Design bending moment in the wall, M.**

Example 7 – Anchored sheet pile quay wall (see Appendix A)



- Design situation
  - Anchored sheet pile retaining wall for an 8m high quay using a horizontal tie bar anchor.
- Soil conditions
  - Gravelly sand - $\varphi'_k = 35^o$, γ_k = 18kN/m^3 (above water table) and 20kN/m^3 (below water table).
- Characteristic values of actions
  - 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



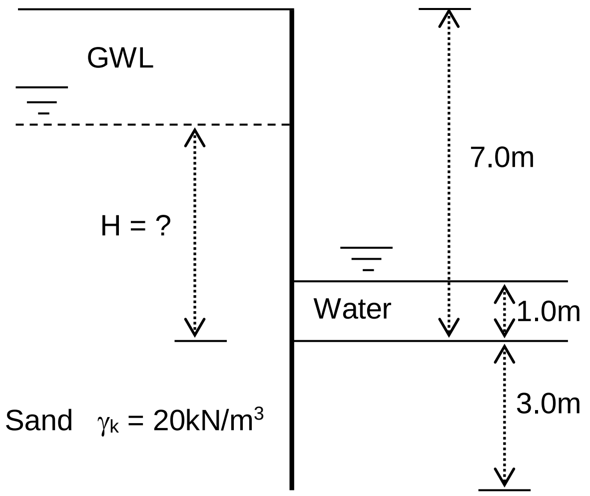
- Design situation
  - Long structure, 15m wide, with a 5m deep basement.
  - Groundwater level can rise to the ground surface.
  - Wall thickness = 0.3m.

- Soil Conditions
  - Sand - $c'_k = 0$, $\varphi'_k = 35^o$, $\gamma_k = 20kN/m^3$ (below water table).

- Characteristic values of actions
  - Permanent structural loading G_k = 40kPa.
  - Concrete weight density γ = $24kN/m^3$.

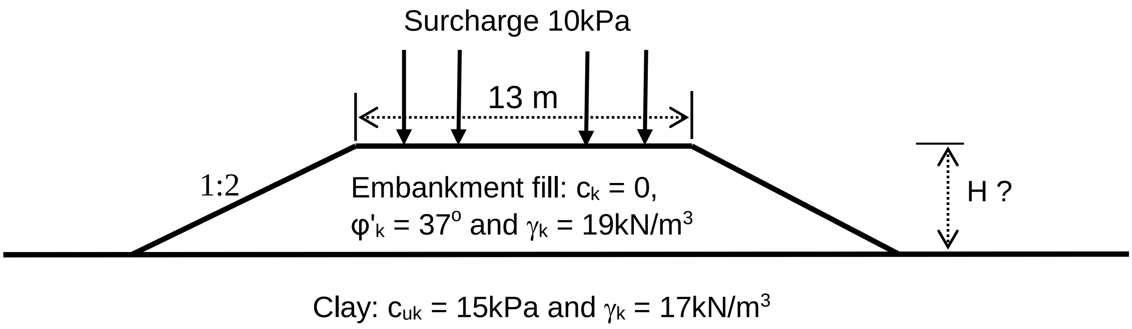
- **Require**
  - **Thickness of base slab, D, for safety against uplift.**

Example 9 – Failure by Hydraulic Heave



- Design situation
  - Seepage around an embedded sheet pile retaining wall.
- Soil conditions
  - γ_k = 20kN/m^3.
- Characteristic values of 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 $c'_k = 0$, $\varphi'_k = 37^o$, $\gamma_k = 19kN/m^3$.
  - Soil beneath embankment: Clay $c_{uk} = 15kPa$, $\gamma_k = 17kN/m^3$.

- Characteristic values of actions
  - Traffic load on embankment: $q_k = 10kPa$.

- **Require**
  - **Maximum height, H, of embankment.**

Appendix A – Requests for the three retaining wall Examples

To ensure that any possible mis-interpretations of the Code are minimised, please conform to the following:

1. Values of K_a and K_p should be taken from the charts in BS EN 1997-1 Annex C

2. Example 5

   - The characteristic value of the angle of sliding resistance on the interface between wall and concrete under the base should be taken as 30º.

   - The weight density of concrete should be taken as 25 kN/m^3.

   - It should be assumed that the surcharge might extend up to the wall (i.e. for calculating bending moments in the wall), *or* might stop behind the heel of the wall, not surcharging the heel (i.e. for calculating stability).

3. Example 6

   - The wall is a permanent structure.

4. Example 7

   - The wall is a permanent structure.

   - The length of the wall is to be the minimum allowable.

5. Tabular results

To assist in comparing and interpreting results, please tabulate your design calculations as illustrated for Example 7 in the table below:

	Method: **1 - Limit equilibrium;** **2 - Soil-structure interaction to obtain redistribution of active pressures**						
	1	1	1	2	2	2	2
Design approach:	DA1-C2[1]	DA1-C1	BS8002	DA1-C2	DA1-C2	DA1-C1	DA1-C2
Sand							
γ (kN/m³)	18 & 20	18 & 20	18 & 20	18 & 20	18 & 20	18 & 20	18 & 20
φ'ₖ (°) (c'ₖ = 0)	35	35	35	35	35	35	35
γ(φ)□	1.25	1	1.2	1.25	1.25	1	1.25
φ'd (°)	29.3	35.0	30.3	29.3	29.3	35.0	29.3
δ/φ active	0.6667	0.6667	0.75	0.6667	0.6667	0.6667	0.6667
δ/φ passive	0.6667	0.6667	0.75	0.6667	0.6667	0.6667	0.6667
Ka	0.29	0.23	0.28	0.29	0.29	0.23	0.29
γ (on Ka or active pressure)	1	1	1	1	1	1	1
Ka(d)	0.29	0.23	0.28	0.29	0.29	0.23	0.29
Kp	4.43	6.51	4.87	4.43	4.43	6.51	4.43
γ (on Kp or passive pressure)	1	1	1	1	1	1	1
Kp(d)	4.43	6.51	4.87	4.43	4.43	6.51	4.43
Overdig (m)	0.5	0.5	0.5	0.5	0.5	0.5	0
Surcharge (k) (kPa)	10	10	10	10	10	10	10
γ (surcharge)	1.3	1.1	1	1.3	1.3	1.1	1.3
Surcharge (d) (kPa)	13	11	10	13	13	11	13
Embedment (m)	**3.74**	**2.65**	**3.43**	**3.5**	**3.4**	**3.4**	**2.8**
Bending moment (kNm/m)	333.5	218.9	298.7	257.5	257.9	153.9	224.1
γ (BM)	1	1.35	1	1	1	1.35	1
Design bending moment (kNm/m)	**333.5**	**295.515**	**298.7**	**257.5**	**257.9**	**207.765**	**224.1**
Strut force (kN/m)	130.7	92.15	117.9	151.5	151.05	103.62	137.01
γ (SF)	1	1.35	1	1	1	1.35	1
Design strut force (kN/m)	**130.7**	**124.4025**	**117.9**	**151.5**	**151.05**	**139.887**	**137.01**
Young's modulus (MPa)				10+2z	10+2z	10+2z	10+2z
Anchor stiffness (kN/mm)				10	10	10	10
Bending stiffness EI (kNm2/m)				100000	100000	100000	100000

[1] DA1 - Design Approach 1
C1 - Combination 1 etc.