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8-10 Stukeley Street

Basement Impact Assessment Audit

For

London Borough of Camden

Project Number: 12336-28
Revision: F1

June 2016

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Project Number	12336-28
Project Name	8-10 Stukeley Street
Planning Reference	2015/7028/P

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Appendix

1.0 NON-TECHNICAL SUMMARY

1.1. CampbellReith was instructed by London Borough of Camden, (LBC) to carry out an audit on the Basement Impact Assessment submitted as part of the Planning Submission documentation for 8-10 Stukeley Street, London WC2B 5LB (planning reference 2015/7028/P). The basement is considered to fall within Category B as defined by the Terms of Reference.

1.2. The Audit reviewed the Basement Impact Assessment for potential impact on land stability and local ground and surface water conditions arising from basement development in accordance with LBC's policies and technical procedures.

1.3. CampbellReith was able to access LBC's Planning Portal and gain access to the latest revision of submitted documentation and reviewed it against an agreed audit check list.

1.4. The BIA and Structural Strategy Report (SSR) have been prepared by an established firm of engineering consultants using individuals who possess suitable qualifications.

1.5. The BIA has confirmed that the proposed basement will be founded in the area where the Made Ground is anticipated to meet the Lynch Hill Gravel below and that the excavation should be deepened if necessary to ensure a suitable bearing is utilised.

1.6. A draft Audit report was issued to the consultants who prepared the BIA and as part of the response to the queries raised, an updated BIA was submitted, along with the Hydrogeology & Land Stability Report produced by Maund Geo-Consulting. This was further supplemented by email correspondence and further calculations relating to retaining wall design and the ground movement assessment. The following audit report relates the updated BIA and this supplementary information.

1.7. A desk study in accordance with GSD Appendix G1 is included for the proposed development.

1.8. The BIA indicated retaining walls and foundations are to be formed by RC underpinning methods and a structural methodology statement is presented, including construction sequence, temporary works requirements and recommendations for contractors.

1.9. The ground investigation and groundwater monitoring indicates that groundwater is at a level of between 5.03m and 5.90m BGL. The BIA notes that further monitoring will be carried out prior to construction and conservative allowances for a rise in groundwater levels have been made within the BIA.

1.10. It is accepted that there are no hydrological concerns with respect to the development proposals impacting the surrounding area.

1.11. It is accepted there are no issues with slope stability affecting the surrounding area.

1.12. Calculations in relation to ground movement and an associated damage assessment have been revised and are accepted as being reasonably conservative. On the basis of good control of workmanship and assuming the neighbouring buildings are in good condition, the prediction of Burland Category 1 Damage is considered achievable.

1.13. Queries and matters which required further information or clarification which have now been resolved are summarised in Appendix 2.

2.0 INTRODUCTION

2.1. CampbellReith was instructed by London Borough of Camden (LBC) on 21/01/16 to carry out a Category B Audit on the Basement Impact Assessment (BIA) submitted as part of the Planning Submission documentation for 8-10 Stukeley Street, London, WC2B 5LB (planning reference 2015/7028/P).

2.2. The Audit was carried out in accordance with the Terms of Reference set by LBC. It reviewed the Basement Impact Assessment for potential impact on land stability and local ground and surface water conditions arising from basement development.

2.3. A BIA is required for all planning applications with basements in Camden in general accordance with policies and technical procedures contained within

- Guidance for Subterranean Development (GSD). Issue 01. November 2010. Ove Arup & Partners.
- Camden Planning Guidance (CPG) 4: Basements and Lightwells.
- Camden Development Policy (DP) 27: Basements and Lightwells.
- Camden Development Policy (DP) 23: Water

2.4. The BIA should demonstrate that schemes:

a) maintain the structural stability of the building and neighbouring properties;

b) avoid adversely affecting drainage and run off or causing other damage to the water environment; and,

c) avoid cumulative impacts upon structural stability or the water environment in the local area.

and evaluate the impacts of the proposed basement considering the issues of hydrology, hydrogeology and land stability via the process described by the GSD and to make recommendations for the detailed design.

2.5. LBC's Audit Instruction described the planning proposal as *"Demolition of mansard roof (no.8), refurbishment and extension of facades, excavation to create new basement, erection of single storey mansard (no.10 & no 8), rear extension at 1st floor level. New Office and residential floor space at basement & ground floor level".*

2.6. CampbellReith accessed LBC's Planning Portal on 26/02/16 and gained access to the following relevant documents for audit purposes:

- Basement Impact Assessment Report (BIA) dated 24/11/15 by Croft Structural Engineering
- Ground Investigation Report dated November 2015 by ground&water
- Design Access Statement dated November 2015 by Krause Architects
- Planning Application Drawings consisting of

  Location Plan

  Existing Plans, Elevations & Sections

  Demolition Plans

  Proposed Plans, Elevations & Sections

  (Drawings by Rev 00 dated November 2015 by Krause Architects)
- Planning Comments and Response

2.7. Following issue on 03/03/16 of a draft BIA Audit report by CampbellReith, further documentation was provided including;

- Hydrogeology and Land Stability Report dated 10/11/15 by Maund Geo-Consulting.
- An updated Basement Impact Assessment Report (BIA) dated 27/05/16 by Croft Structural Engineering.

2.8. The information noted above was considered in revision D2 of the audit report which identified that a number of queries remained, mainly in relation to the ground movement assessment and further information was provided in September & October 2016 comprising;

- A revised Ground Movement Assessment & associated series of emails from Maund Geo-Consulting 20/09/16 – 14/10/16
- Retaining wall calculations and series of emails from Croft Structural Engineers

This final report considers the latest information.

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3.0 BASEMENT IMPACT ASSESSMENT AUDIT CHECK LIST

Item	Yes/No/NA	Comment
Are BIA Author(s) credentials satisfactory?	Yes	The report has been compiled by a number of authors. All have satisfactory credentials. See discussion Section 4.1
Is data required by Cl.233 of the GSD presented?	Yes	
Does the description of the proposed development include all aspects of temporary and permanent works which might impact upon geology, hydrogeology and hydrology?	Yes	Comments raised on a number of items. See section 4.0 of the audit report
Are suitable plan/maps included?	Yes	Location identified. Plans included showing Hydro-geological map and surface flooding maps.
Do the plans/maps show the whole of the relevant area of study and do they show it in sufficient detail?	Yes	Extracts of Maps included.
Land Stability Screening: Have appropriate data sources been consulted? Is justification provided for 'No' answers?	Yes	Justification provided for 'No' answers where relevant.
Hydrogeology Screening: Have appropriate data sources been consulted? Is justification provided for 'No' answers?	Yes	Justification provided for 'No' answers where relevant.
Hydrology Screening: Have appropriate data sources been consulted? Is justification provided for 'No' answers?	Yes	
Is a conceptual model presented?	Yes	
Land Stability Scoping Provided? Is scoping consistent with screening outcome?	Yes	Table 7.2 of Geologist's report

Item	Yes/No/NA	Comment
Hydrogeology Scoping Provided? Is scoping consistent with screening outcome?	Yes	Table 7.2 of Geologist's report
Hydrology Scoping Provided? Is scoping consistent with screening outcome?	Yes	
Is factual ground investigation data provided?	Yes	
Is monitoring data presented?	Yes	Limited monitoring data is provided although allowance is made for this in design. Refer to discussion in Section 4.0
Is the ground investigation informed by a desk study?	Yes	Desk study by Structural Engineer (Page 16 of BIA).
Has a site walkover been undertaken?	Yes	18/09/2015 – Ref Page 15 of BIA.
Is the presence/absence of adjacent or nearby basements confirmed?	Yes	To immediately adjacent buildings.
Is a geotechnical interpretation presented?	Yes	Within the Ground Investigation Report by ground & water.
Does the geotechnical interpretation include information on retaining wall design?	Yes	Within the Ground Investigation Report by ground & water.
Are reports on other investigations required by screening and scoping presented?	Yes	
Are the baseline conditions described, based on the GSD?	Yes	
Do the base line conditions consider adjacent or nearby basements?	Yes	
Is an Impact Assessment provided?	Yes	
Are estimates of ground movement and structural impact presented?	Yes	See further commentary on this in discussion Section 4.0.

Item	Yes/No/NA	Comment
Is the Impact Assessment appropriate to the matters identified by screen and scoping?	Yes	
Has the need for mitigation been considered and are appropriate mitigation methods incorporated in the scheme?	Yes	Some considered e.g. surface water attenuation to limit run off. Others may need to be developed. See discussion Section 4.0
Has the need for monitoring during construction been considered?	Yes	
Have the residual (after mitigation) impacts been clearly identified?	Yes	
Has the scheme demonstrated that the structural stability of the building and neighbouring properties and infrastructure will be maintained?	Yes	See further commentary on this in discussion Section 4.0
Has the scheme avoided adversely affecting drainage and run-off or causing other damage to the water environment?	Yes	
Has the scheme avoided cumulative impacts upon structural stability or the water environment in the local area?	Yes	
Does report state that damage to surrounding buildings will be no worse than Burland Category 2?	Yes	Refer to discussion Section 4.13 for further commentary.
Are non-technical summaries provided?	No	Though not headed as such within the report, there is considered to be sufficient non technical commentary provided.

4.0 DISCUSSION

4.1. The BIA has been carried out by an established firm of engineering consultants, Croft Structural Engineers. The report is noted as having been compiled by a number of people which is accepted. The cover notes that the Structural / Civil aspects of the design have been reviewed by a Chartered Engineer. It was not clear whether the full report had been reviewed by a Chartered Engineer as required by CPG 4, however this has now been confirmed by the applicant.

4.2. The Design & Access Statement identified that 8-10 Stukeley Street is within the Seven Dials Conservation Area, which identifies the properties as *'buildings of merit'.*

4.3. The existing properties which make up 8-12 Stukeley Street are L-shaped on plan and 'wrap around' the adjacent buildings such that they are essentially mid-terrace. The buildings are between one and two storeys high and believed to be comprised of traditional load bearing masonry and timber floor construction. The roofs are understood to be timber construction containing a number of skylight openings.

4.4. The proposed basement consists of a single storey construction formed by utilising sequential underpinning of existing boundary / party walls. Underpins are estimated to be around 3m deep and take the form of cantilever reinforced concrete retaining walls which are tied together with dowel bars. A new reinforced concrete slab will form the base of the basement and be connected to the retaining wall bases. The overall basement excavation is to be 3.7m below existing ground level.

4.5. The BIA has identified that the existing building is underlain by Made Ground to a depth of 3.70 metres below which lies Lynch Hill Gravel, thickness 3.30 metres, below which lies the London Clay Formation.

4.6. The information provided makes reference to separate report by the Chartered Geologist in relation to the detailed screening, scoping and impact assessment for matters relating to slope stability and hydrogeology. Whilst missing from the initial information submitted, this has now been provided.

4.7. Site investigation works carried out in October 2015 did not look at the form and depth of foundations to the boundary / party walls however trial pit information dating from 1984 is provided on page 8 of the latest BIA. Whilst not current, it is accepted that this information is likely to reflect the existing foundation form and depth and be suitable for use in the preliminary design.

4.8. The BIA notes (Page 10) that groundwater was recorded at a level of between 5.03m and 5.90m BGL. Readings were taken approximately 3 weeks apart and at the end of the summer. Both the Hydrogeology and Land Stability Report and the BIA note that further monitoring will be carried out prior to construction works being carried out which is accepted.

4.9. In addition to further monitoring, for the purposes of the BIA, an elevated groundwater level has been used in checks on the proposed basement structure to ensure that should groundwater levels increase, it will not invalidate the assumptions made in the BIA which is accepted.

4.10. An allowable bearing pressure of $200kN/m^2$ with an associated settlement of < 25mm is noted in Section 5.2 of the Hydrogeology & Land Stability report as the criteria for use in the design of foundations. Retaining wall calculations have considered a lower allowable bearing pressure of $100kN/m^2$ to allow for a potential rise in groundwater level which is accepted.

4.11. The BIA proposes that the new basement will be formed using a series of cantilever retaining walls. Calculations are provided which consider permanent and variable structural loads applied to the top of the underpin / retaining wall, as well as lateral forces due to earth and hydrostatic pressure. The loads applied appear to be correct however the initial calculations provided included combinations of load which were not necessarily those that could generate the worst case bearing stresses. Further calculations have been provided confirming the worst case loading arrangement and associated bearing pressures which are considered acceptable.

4.12. A number of steel beams are shown on the Croft Structural Engineers drawing 140906 'Proposed Plan at Ground Floor Level'. A number of these beams were understood to support internal walls above ground floor level and will transmit the load from the structure above onto the top of the retaining wall underpins, either via stub columns or pad stones. It had been advised that these reactions and their influence on the retaining wall underpin design will be considered at the detailed design stage, however given the potential magnitude of some of the point loads, it was requested that sufficient preliminary calculations or justification is provided as part of the BIA to ensure that safe bearing pressures will not be exceeded and the stability of the buildings will be maintained. Further clarification on this point was provided by Croft Structural Engineers which confirmed that the loads would be due to the ground floor only and as such would not constitute loads onto the top of the retaining wall underpins that were sufficiently large to influence the design.

4.13. Where the beams described in 4.12 will support existing load bearing internal walls, commentary on the installation approach is included in Section 5 of the Construction Method Statement. The process described is accepted in principle though further clarification was requested on the sequencing of this operation in relation to timing of underpinning, formation of temporary foundations, installation of props etc. As with point 4.12, it was confirmed that the beams would only be carrying ground floor loads and as the internal load bearing walls were not retained on these beams, the concerns regarding sequencing and temporary works were negated.

4.14. The calculations in relation to ground movement and the risk of potential damage to the adjacent buildings are contained within a chain of emails between Maund Geo-Consulting and CampbellReith in September & October 2016 (Refer to Appendix 3). The calculations base the assessment of the likely ground movement and damage on the guidance and methodology noted within CIRIA C580 which is accepted. Strictly speaking C580 relates to embedded retaining walls however a number of BIAs proposing a similar construction methodology have adopted it to estimate ground movements associated with underpinning.

4.15. The calculations contained on Pages 36-38 of the BIA have been reviewed and a number of comments are noted below:

- 8-10 Stukeley Street is 'L' Shaped on plan and is surrounded by a number of buildings of differing widths and heights in a complicated arrangement. Originally only one damage assessment was included and it had not been identified which building this related to. Checks have now been presented for 182 Drury lane and No's 6 & 12 Stukeley Street which predict damage category 1.
- Where basements have re-entrant corners, there is potential for ground movements to be amplified in these areas from those generated by the standard CIRIA C580 approach. These may in turn have an adverse effect on the neighbouring buildings. It is accepted that the revised calculations and damage assessment are appropriately conservative. Mitigation requirements comprise temporary propping.
- It has been confirmed that foundation settlements are considered in the ground movement assessment.

4.16. In reference to Point 1.3 of the Construction Method Statement (Page 84 of the BIA), it is highlighted that should an appointed contractor propose any changes to the fundamental concepts of the construction methodology put forward in the BIA, the BIA may require resubmission.

4.17. The BIA notes some concerns with regards to structural stability of the existing buildings at roof levels and notes extensive cracking is present. Consideration should be given to the sequencing of works such that any ground movements or vibrations caused by the basement construction do not exacerbate the situation and lead to instability. The impact of this existing cracking on the damage predictions should be considered as the Burland Methodology assumes the structures are in sound condition.

4.18. It is accepted that there will be a slight increase in the area of hard standing as a result of the works but that attenuation storage will be provided to limit the run off rate as described on Page 30 of the BIA.

5.0 CONCLUSIONS

5.1. The BIA has been carried out by an established firm of engineering consultants using individuals who possess suitable qualifications.

5.2. The BIA has confirmed that the proposed basement will be founded in the area where the Made Ground is anticipated to meet the Lynch Hill Gravel below and that the excavation should be deepened if necessary to ensure a suitable bearing is utilised.

5.3. The BIA states that basement walls will be formed by RC underpinning. The structural information indicates construction sequence and temporary works requirements. Some further clarification was requested with regards to the underpin sequencing in areas where new beams will be installed supporting load bearing walls, which has now been provided.

5.4. The BIA contains calculations to justify the retaining wall underpin design. A number of queries were raised in relation to the loading applied to the pins and the influence of their settlement on the ground movement assessment. Further commentary provided and an updated ground movement have now addressed these queries.

5.5. The ground investigation and groundwater monitoring indicates that groundwater is at a level of between 5.03m and 5.90m BGL. The BIA notes that further monitoring will be carried out prior to construction and conservative allowances for a rise in groundwater levels have been made within the BIA.

5.6. Calculations in relation to ground movement and an associated damage assessment have been revised and are accepted as being reasonably conservative. On the basis of good control of workmanship and assuming the neighbouring buildings are in good condition, the prediction of Burland Category 1 Damage is considered achievable.

5.7. It is accepted that given the proposals, including provision of attenuation, the development will not impact on the wider hydrology of the area and is not in an area subject to flooding.

5.8. Queries or matters which required further information or clarification are summarised in Appendix 2, all of which are now resolved.

Appendix 1: Residents' Consultation Comments

Residents' Consultation Comments

Surname	Address	Date	Issue raised	Response
Lock	14 Church Close, Kelsale Suffolk IP17 2PA	14/01/16	Structural stability	Refer to discussion section 4.11-4.15

Appendix 2: Audit Query Tracker

Audit Query Tracker

Query No	Subject	Query	Status	Date closed out
1	Investigations	More extensive below ground investigations required, see section 4.8	Closed – Further trial pit information provided in updated BIA.	31/05/16
2	Reports	Geologists reports required.	Closed – Report provided.	09/05/16
3	Qualifications	Confirmation requested in relation to author / checkers input. See section 4.1	Closed – Confirmation provided via email 10/08/16.	10/08/16
4	Ground Movement	Further consideration required, see discussion section 4.15 & 4.17	Closed – Refer to series of emails from Maund Geo-Consulting 20/09/16 – 14/10/16	14/10/16
5	Retaining Underpin Design	Further consideration required, see section 4.11 & 4.12	Closed – Updated calculations provided via email of 10/08/16	10/08/16
6	Construction Sequencing	Further consideration required, see section 4.13	Closed – Confirmation provided via email 10/08/16.	10/08/16

Appendix 3: Supplementary Supporting Documents

- Email Correspondence with Croft Structural Engineers
- Email Correspondence with Maund Geo-Consulting
- Updated retaining wall calculations

FW: 8-10 Stukeley Street
Clark, James
to:
WilliamShaw@campbellreith.com
10/08/2016 14:20
Cc:
"LizBrown@campbellreith.com"
Hide Details
From: "Clark, James" <James.Clark@camden.gov.uk>
To: "WilliamShaw@campbellreith.com" <WilliamShaw@campbellreith.com>
Cc: "LizBrown@campbellreith.com" <LizBrown@campbellreith.com>
Security:
To ensure privacy, images from remote sites were prevented from downloading. Show Images

3 Attachments

image011.jpg image012.jpg image013.jpg image014.jpg image015.jpg image016.jpg image017.jpg image018.jpg image019.jpg

image020.jpg 8-10 Stukeley Street Camden Basement Impact Assessment - rev3 Ground movement section.pdf

8-10 Stukeley Street Ground Movement Assessment - MGC-16-25-GMA.pdf

8-10 Stukeley Street Calculations for planning requested by Campbell Reith Rev3.pdf

Hi Will/Liz,

I hope your both well can you advise a date when Campbell Reith would be able to provide a full audit on the revised information submitted.

Kind Regards
--
James Clark
Planning Officer

Telephone: 02079742050

h h h h

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From: Eleni Pappa [mailto:epappa@croftse.co.uk]
Sent: 10 August 2016 11:34
To: WilliamShaw@campbellreith.com
Cc: 'Yumeng Chan'; 'Andreas Krause'; 'Gudjon Erlendsson'; 'Hannah Willcock'; Clark, James
Subject: RE: 8-10 Stukeley Street

Dear Mr Shaw,

Please see below our answers in Green. We are hoping that you are now satisfied with the extended information we have provided regarding the design of the Retaining Walls and the Ground Movement Assessment which has been carried out by a Chartered Geologist.

Attached you will find the following for your approval:

- Ground movement Assessment report with reference No.MGC-16-25GMA
- Revised pages 36-38 on BIA referring to the ground movement assessment and the predicted damage category and
- the additional calculations you have requested (these include the original calculations already submitted which indicate the worst case, as well as the additional calculations you have requested for the planning stage)

Furthermore, there has been a couple of occasions in the last month when we have tried to contact you and left you messages to return our calls. However, we have not heard back from you in order to discuss the additional information which we would like to send to you and as per our last discussions.

We are hoping that you are now satisfied that we have considered all the risks and that you are happy with our mitigation procedures provided. However, if you have any queries on the attached we would be more than happy to go through the additional information with you.

Kind Regards

Eleni Pappa
Senior Structural Engineer
MSc, BEng (Hons)

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From: WilliamShaw@campbellreith.com [mailto:WilliamShaw@campbellreith.com]
Sent: 01 July 2016 15:44
To: Eleni Pappa <epappa@croftse.co.uk>
Cc: 'Andreas Krause' <andreas@krausearchitects.com>; 'Gudjon Erlendsson' <gudjon.erlendsson@krausearchitects.com>; 'Hannah Willcock' <hannah.willcock@dp9.co.uk>; Clark, James <James.Clark@camden.gov.uk>
Subject: Re: FW: 8-10 Stukeley Street

Dear Ms Pappa

Thank you for your email. Please see our responses to your points noted below in Red.

At present we do not believe the comments close out all of the points raised by the BIA Audit.

We would be grateful if you could provide the information / clarification as requested below.

I have copied in James Clark the planning officer so he is aware of the current status of the BIA.

Regards

William Shaw
Associate

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From: "Eleni Pappa" <epappa@croftse.co.uk>

To: <WilliamShaw@campbellreith.com>
Cc: "'Andreas Krause'" <andreas@krausearchitects.com>, "'Gudjon Erlendsson'" <gudjon.erlendsson@krausearchitects.com>, "'Hannah Willcock'" <hannah.willcock@dp9.co.uk>
Date: 23/06/2016 18:42
Subject: FW: 8-10 Stukeley Street

Dear Mr Shaw,

Thank you very much for your revised audit report . We have reviewed your comments and we have attached any additional information you require for this BIA.

4.0 Discussion

Point 4.1. - Why is this asked at this stage and when clearly shown on the front page of the BIA? See front page showing the credentials.
The point of the query raised and in line with the CPG 4, '*at each stage, the person undertaking the BIA process should hold qualifications relevant to the matters being considered'*. As noted in the audit report, it is not clear from the front page that a suitably qualified person has reviewed the BIA in it's entirety. Please confirm.
Yes, we confirm as per our front page of the BIA that the report has been reviewed by a suitably qualified person.

Points 4.2 – 4.10 - Noted and agree with all comments. Points closed

Point 4.11 - We have provided you with more than sufficient calculations and information on stability and propping within our method statement to demonstrate that no adverse effects will arise from the construction of the basement. We have considered the worst cases and these you had from the beginning of this process. You agree that detailed calculations are not required. In fact, we can see no request anywhere for any calculations to be issue as part of the CGP4 DOCUMENT OF CAMDEN during the planning stage. However, you are asking for more and more calculations. You are asking for consideration on different load cases on hydrostatic and surcharge loads which are details provided during the detailed stage design. These have been considered anyway and the worst case has been issued to you already. This seems to be wasting everyone's time for information not even required as part of this process. However, to end this argument we have attached the additional information for your consideration (showing not the worst case).

We would like to request if you could point out to us where in the CGP4 document this is requested as a requirement for planning. I would like to know on what page it states that as part of planning we will have to submit calculations.

We would request you do not charge the client for the audit of this information as we see this to be overly excessive and unnecessary and we find Campbell Reith to be preventing the process for moving forward with planning.

We do not believe that the worst case had been considered previously but we thank you for the additional calculations in relation to the point raised.

The updated calculations provided have omitted the beneficial effects of the ground water but still include the beneficial effects due to surcharge loading. In terms of assessing the worst case bearing pressures under the wall toe, surcharge will have the effect of reducing the maximum stress by acting as a 'restoring' moment on the wall. A 10kN/m^2 surcharge is a design allowance not a permanent load that will be present.

Please review.

In reference to the query on the requirement for calculations, the CPG 4 guidance requires that *'all basement development applications provide evidence that the structural stability of adjoining or neighbouring buildings is not put at risk'*. In the majority of BIA submissions, providing evidence takes the form of sufficient calculations and commentary to show that stability is maintained and neighbouring buildings are not put at risk.

As bearing stress and in turn settlement of the retaining wall underpin will be linked to the ground movement and damage assessment, considering the worst case is important. Please be assured we are not trying to 'waste everyone's time'.

As previously mentioned the worst case for the walls had always been assessed and submitted to you with the first revision of the BIA submitted in 2015. However, since it was not assumed by Campbell Reith that this is the worst case we have provided additional evidence to prove our case.

Points 4.12 - Similar to point 4.11 above. This is excessive calculations that you are requesting for the planning process and yes we can confirm that the bearing pressures will not be exceeded as a result of the steel beams bearing on the new rc walls. The steel beams will be supporting a new floor only and some stud walls will be constructed. However, in order to move things forward see additional calcs to show a potential higher point load on the rc walls showing the GB

pressure to be within the allowable.
Please see comments on 4.11
Evidence on extensive calculations to prove the basement will not affect the neighbouring properties has been provided as per Campbell Reith requests.

Again we would like to request to point out to us where in the CGP4 document, calculations for this are requested as a requirement for planning.
Please see comments on 4.11
Evidence on extensive calculations to prove the basement will not affect the neighbouring properties has been provided as per Campbell Reith requests

Points 4.13 - On section 5 of the basement method statement there is a very clear explanation as to how the walls are supported above. Needles are installed first before the permanent supporting beams are installed to take the vertical loads. The underpins will be completed along the party walls first, if stub columns are to be supporting steel beams (this exercise will be submitted as part of the detailed design stage) are installed in position, steel beams installed and supported on new RC walls. Once the permanent beams/columns are installed the needles may be removed.

A sketch detail would help to clarify this although we note from your response to 4.12 that the new beams will not be carrying significant forces as 'beams will support new floors and stud walls only'.
If this is the case, we are satisfied that the temporary works sequencing is less critical as existing internal load bearing walls are not retained whilst underpinning is carried out.
Please advise if we have not understood this correctly, otherwise we have no further concerns on this point. This is correct. The forces will be due to the new floor and stud walls above as the existing ground floor is currently used as offices and it is mostly open plan already.

Point 4.14 - Noted and agree with all comments. Points closed

Point 4.15 -

"8-10 Stukeley Street is 'L' Shaped on plan and is surrounded by a number of buildings of differing widths and heights in a complicated arrangement however only one damage assessment is included and it is not identified which building this relates to. It is requested that sufficient design checks are included with movements and a damage category clearly identified for each potentially affected adjacent building. " - We have already considered all the properties adjacent to 8-12 Stukeley street and we have submitted the worst case. However, to move things forward find attached the additional information for 182 Drury Lane and 6 and revised titled 12 Stukeley Street.

The ground movement assessments provided have been reviewed by our Geotechnical department. There are a number of issues that repeat across the checks provided:
- The length and height considered should relate to the neighbouring building being assessed.
- The same 'L' should be employed when determining distortions and deflection ratios.
- Re-entrant corners will have an affect of amplifying figures as advised in our Audit report

Please see attached mark up to help clarify where updates are required.

Given the above it is not possible for us to determine if the anticipated damage category for each building is correct and within the CPG4 limits.
Please refer to full GMA report attached.

For the design check which is included, the building geometry that has been used does not seem to reflect that shown on Page 37 of the BIA report. This should be amended / clarified as part of any updated calculations.
We are assuming you are referring to page 38 of the BIA? Page 37 does not have a shape of a building. The geometry shown on this page is representing a section and not a plan of the building to show the L shape. This is clearly showing the basement and the adjoining property in a section.

Comments were in relation to the section shown on Page 37. Comments included as part of commentary on GMA above and attached.
Please refer to full GMA report attached.

Where basements have re-entrant corners, there is potential for ground movements to be amplified in these areas from those generated by the standard CIRIA C580 approach. These may in turn have an adverse effect on the neighbouring buildings. Consideration should be given to this in the calculations and damage assessment and when considering any associated mitigation requirements. Your statement is not correct. According to CIRIA C580 the corners of the excavation tend to restrict movement. In the corners the potential ground movements are not amplified but if anything they would be reduced. Consideration has been given regarding the movement and damage assessment and information already submitted. This has not accounted for the benefit of the of corner effects and is therefore conservative in this respect.

Corners of excavations tend to restrict movement due to the stiffening effect in the two orthogonal directions. Re-entrant corners, as is the case here, will have the opposite effect. Please see attached sketch to help clarify. Commentary / further calculation should be provide as to what affect this will have on the ground movement assessment calculations and / or how the effects will be mitigated to ensure movement and damage to the adjoining buildings will be restricted to acceptable levels.
Please refer to full GMA report attached.

On the basis of the quoted allowable bearing pressure, settlement of the proposed new underpin retaining walls could be 10-15mm, this should be considered in conjunction with the movement and damage assessment. Foundation settlements will be additive to those derived from the CIRIA C580 approach. You are predicting a settlement of the permanent structure of up to 15mm. This would happen over a long period of time and following construction of the full basement. The settlement you are referring to cannot be taken into account with the same movement calculations and damage assessment during the construction stage. This is not a valid point and cannot be taken into consideration for the long term effects when the movement assessment is assessing movement during construction stage (temporary condition).

Having discussed further with other Geotechnical colleagues our view is unchanged. The anticipated settlement of the foundations should be considered as part of the ground movement assessment. Whether the settlement happens during the basement construction or over time does not make a difference to the total movement that will occur in the ground and the corresponding movement that the surrounding buildings will be subjected to. Please review further.
Please refer to full GMA report attached.

Point 4.16 - Ok, noted. Point closed

Point 4.17 - Ok, noted and agree with your comment. They have been considered as stated within our BIA and monitoring on movement is introduced to monitor any new/existing cracks. Point closed

Pointe 4.18 - Noted and agree with comment. Point closed

I would appreciate it if you could respond back to my email to confirm receipt of the additional documents and that you are able to access all the attached documents.

Kind Regards

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MSc, BEng (Hons)

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From: Eleni Pappa [mailto:epappa@croftse.co.uk]
Sent: 27 May 2016 17:37
To: 'WilliamShaw@campbellreith.com' <WilliamShaw@campbellreith.com>
Cc: 'Andreas Krause' <andreas@krausearchitects.com>; 'Yumeng Chan' <ymchan@benetonproperties.com>; 'Hannah Willcock' <hannah.willcock@dp9.co.uk>; 'Gudjon Erlendsson' <gudjon.erlendsson@krausearchitects.com>

Subject: 8-10 Stukeley Street [Filed 27 May 2016 17:37]

Dear Mr Shaw,

Following our telephone conversation from last week please find below our answers to your statements/queries from your Audit report (also attached). As discussed and agreed on the phone we have covered and answered to your statements below within this email and where additional information is required the BIA has been updated to reflect our answers. The BIA is attached and I would appreciate it if you confirm receipt of this document.

4.0 Discussion

Point 4.6. - Additional information regarding the Chartered Geologist report has already been issued by DP9 Ltd. As discussed with you on the phone last week this has now been confirmed, that Campbell Reith have received the additional information regarding the hydrogeologist report. We had no further comments from Campbell Reith following the submission of the missing information.

4.8 Investigations

Point 4.8.1. - Yes, this is correct.

Point 4.8.2. - The water levels during the SI report have been recorded to be below the founding level of the proposed basement. We have mitigation measures in place should water levels rise during the construction. These are pointed out page 46 of the BIA and this will include localized dewatering to the pins. No change required to BIA

Point 4.8.5. - Yes, we agree. Water levels could rise and this has been taken into consideration within our design for planning purposes by reducing the allowable GBP by half and taken as 100kN/m2 within our calculations to accommodate such issues, should they arise. Additional design calculations will be provided during the detailed design stage to accompany the more detailed structural drawings and details. No change required to BIA

Point 4.8.6. - Yes we agree. No change required to BIA

Point 4.8.7. - Trial pits have been undertaken in the property in 1984 and the results had already been taken into consideration as illustrated on our structural drawing HD-02. Corbel footings over the mass concrete. These included the foundations for both party walls either side. The TP results have now been added to our BIA and basement method statement. Planning drawing HD-02 has also been updated to include the note on the TP results. (drawing attached) The existing footings will be exposed prior to any works undertaken by the appointed contractor and if there are any discrepancies they will report this back to the Engineers to amend our design and details as necessary. The trial pit information has been added within our basement construction method statement under Section 2. Enabling Works point 2.4 “On commencement of construction the contractor will determine the foundation type, width and depth. Any discrepancies will be reported to the structural engineer in order that the detailed design may be modified as necessary.”

Point 4.8.8. - Please refer to answer above on point 4.8.7. this has now been updated to include the TP results for the party walls undertaken in 1984. The results had already been taken into account within our proposals. The method statement and the BIA have been revised accordingly.

Point 4.8.9. - During planning stage sufficient information has been provided to demonstrate the buildability of the proposal without impacting the neighboring properties. As mentioned on your report a “developed detail” will be issued ones we move onto the detailed design where prior to any ground works undertaken, all the existing footings will be confirmed by the contractor. See also answer on point 4.8.7. above. More site investigations will be implemented before and during the construction stage. No change on the BIA on this point.

4.9 Design

Point 4.9.2. - Yes, we can confirm that the loadings from the adjacent properties have been taken into consideration. No change to BIA on this point.

Point 4.9.3. - Yes, we agree. Additional combination loads will be applied and submitted during the detailed design stage. The calculations submitted for the planning stage within the BIA, are not to demonstrate the detailed design but to confirm that the basement can be constructed safely without having an impact on the neighboring properties. During the detailed stage design additional calculations will be completed. We have taken the allowable GBP 100kN/m2 to accommodate the higher stresses you are referring to as a mitigation factor. This can be found within the BIA retaining wall calculations. No change on the BIA on this point.

Point 4.9.4. - Yes, this has been taken into consideration. The 10kN/m2 is a surcharge taken for highways and this is to the highways code. No change on the BIA on this point.

Point 4.9.5. - Temporary propping to the base will be achieved by installing cross props at 2.5mc/c 1/3 height of the wall. This is already illustrated within our basement method statement (pictures also included). The alternative temporary propping achieved by propping to the central soil dumpling has been removed as requested. Additional information has been added to the method statement and the BIA report. Additional drawing HD-03 to show propping sequence provided.

Point 4.9.6. - This statement is not correct. This is clearly illustrated in the design for the retaining walls within the BIA. Since you are referring to a loadbearing wall we would both agree that on a LB wall, reinforcement should be provided to both the external and internal face. This is a retaining wall and has lateral forces subjected to it, hence it has a moment to the back face which is taken care of from the installed reinforcement. Reinforcement is not required to the internal face of the wall. However, you will notice from the calculations that reinforcement is provided to both external and internal face of the retaining walls transferring the loads down to the base. This would make your statement not valid.
Since you appear to consider the retaining wall stem and the reinforcement provided not to act sufficiently as a load bearing wall, I would like to know the alternative design you might be recommending to allow for the retaining/loadbearing wall design to take the loads from above into account and transfer them to the base. No change on the BIA on this point.

Point 4.9.7. - Further calculations and design load cases will be considered in the detailed stage design. The calculations submitted are only to demonstrate that the proposed basement can be built without having any impact on the neighboring properties. However, for benefit of doubt additional calculations are added to demonstrate the water level at 1m BGL. The design or reinforcement remain the same.

Point 4.9.8. - Croft always check and provide calculations regarding the slab and the effects of hydrostatic pressures during the detailed design stage. For planning purposes, the calculations submitted are to demonstrate that the proposals will not impact the neighboring properties and the basement can safely be constructed.
Furthermore:

§ the water table has been shown to be below the founding level of the proposed basement.
§ The basement will be founded on the Lynch hill gravel soils which is a combination of sand and gravel
§ the proposed basement will be fully under the footprint of the existing building.

Taking the above into consideration an uplift is not the critical case for the design. However, for benefit of doubt additional calculations are added to cover your statement regarding the uplift on the slab.

4.10 Ground Movement

Point 4.10.2. - This has now been updated. Please refer to updated calculations within BIA.

Point 4.10.3. - Ok. We agree. No change on the BIA on this point.

Point 4.10.4. - This is correct. The retaining wall design has been performed to allow for the retaining walls to be cantilevered and stable without the need for additional propping during the construction stage. However, in the temporary condition we allow for temporary propping near the head of the retaining wall regarding of our design calculations. This is our mitigation method to further control movement to the adjacent properties during the construction stage. This is mentioned within our basement construction method statement and if the statement is read properly, one understands the sequence of works which also include pictures showing how it will be built. Point 1.6 of the basement method statement has now been re-vised for your consideration and understanding.

Point 4.10.5. - This statement is not true. This has been taken into consideration and already discussed above. We complete our structural design as cantilevered retaining walls to get the worst case for the reinforcement design and ground bearing pressures. However, as mentioned within our basement construction method statement propping will be provided during the construction stage. This is done as a mitigation measure to control any movements to the adjacent properties.

Point 4.10.6. - ok. Noted and documents updated.

Point 4.10.7. - ok. Yes. This will be considered in the detailed design stage. The steel beams are to demonstrate that the proposals are adequate and will cause no harm to the neighboring properties. The steel beams will either be supported on padstones or stub columns founded at the top of the retaining walls. The point loads will be considered in the detailed design stage. This also correlates to the

The details you are asking at this stage are not for planning purposes but for the detailed design stage where the demonstration of full design calculations for steel beam, slabs and different load cases on retaining walls are required. This is not required at planning stage and as mentioned before and within our BIA document, all of these are considered during the detailed design stage.

4.11 Ground Movement

Point 4.11.1. - This has now been revised to allow for cross props across the full width of the property. Method statement updated. This has already been queried previously why ask again?

Point 4.11.2. - Yes, we agree. Further site investigations will be undertaken prior to any works starting. This has already been queried previously why ask again?

Point 4.11.3. - The construction method statement is very clear and specific to this project. If read and followed correctly, then it is perfectly understandable. The numbering sequence has been revised.

1.3 - This query should not require a resubmission of the BIA: the contractor has not been appointed yet. The purpose of the construction method statement at BIA stage is to demonstrate that the basement can be feasibly constructed, using safe and controlled procedures.

There is a sentence that relates to the contractor producing the final method statement. This is a caveat; it is intended for the party wall application at detailed design stage. It is unreasonable to expect contractor involvement at planning stage, before permission is granted. This sentence and the related query should therefore not require a re-submission of the BIA.

1.5 - It is clear from the drawings provided within the BIA that steelwork is necessary to support the walls above which are not party walls. Furthermore, it will support the new flooring. The ends of the steel beams will rest on the party walls either on padstones within the brickwork or supported on stub columns which will be founded on top of the retaining walls. This is a standard way of building basements and supporting the internal walls from above on steelwork. No change on the BIA on this point.

1.6 - Propping is provided as clearly shown on our method statement. See comments above. This has already been queried previously. Additional drawings HD-03 and

2.4 - Yes, we agree and as mentioned within our method statement further site investigations will be carried prior to any works starting. Existing footing findings have been added to the BIA and method statement. This has already been queried previously. No change on the BIA on this point.

3.1 - The wall above. No change on the BIA on this point.

3.11.2 - Yes, we agree. This is a complex operation. Further details will be provided during the detailed stage design. No change on the BIA on this point.

3.12.1.1.2 - Where do you read this? If you read our method statement and point 1.1.2. of our method statement (now updated to point 3.12.3) correctly we do not recommend for drainage bedded in pea shingle. Instead our statement reads: "Place below slab drainage. We recommend that all drainage is encased in concrete below the slab and cast monolithically with the slab. Placing drainage on pea shingle below the slab allows greater penetration for water ingress."

2.5.1 - ok. We agree. No change on the BIA on this point.

2.21.1 - ok. We agree. No change on the BIA on this point.

4.11.4. - Why does the audit report only lists a few of the key comments? The Basement method statement is not generic and specific to this project. The information included within our basement method statement are specific to this project with the site investigations and details as provided. The results to the SI report are within the statement and the references are specific to the address. For your information the propping to the base as well as an additional sequence as to how this basement will be constructed has been added.

<u>4.12 General Comments</u>

Point 4.12.1. - yes, temporary propping to the upper floors will be provided during the basement construction works. This will be taken into consideration during the detailed design stage.

Point 4.12.2. - Monitoring has been added to front façade as requested. See revised drawing No. M-PL-40

Point 4.12.3. - ok. This is now revised on page 39 attached.

Point 4.12.4. - Highways loading is required and hence the 10kN/m2 as discussed above. BIA page 44 revised and attached.

Point 4.12.5. - This is completed during the detailed design stage and the pump chambers location are not yet known. In order to install the pump chambers the contractor will have to dig deeper to install the boxes. As mentioned on our method statement localized dewatering may be required should water be found on site.

Kind Regards

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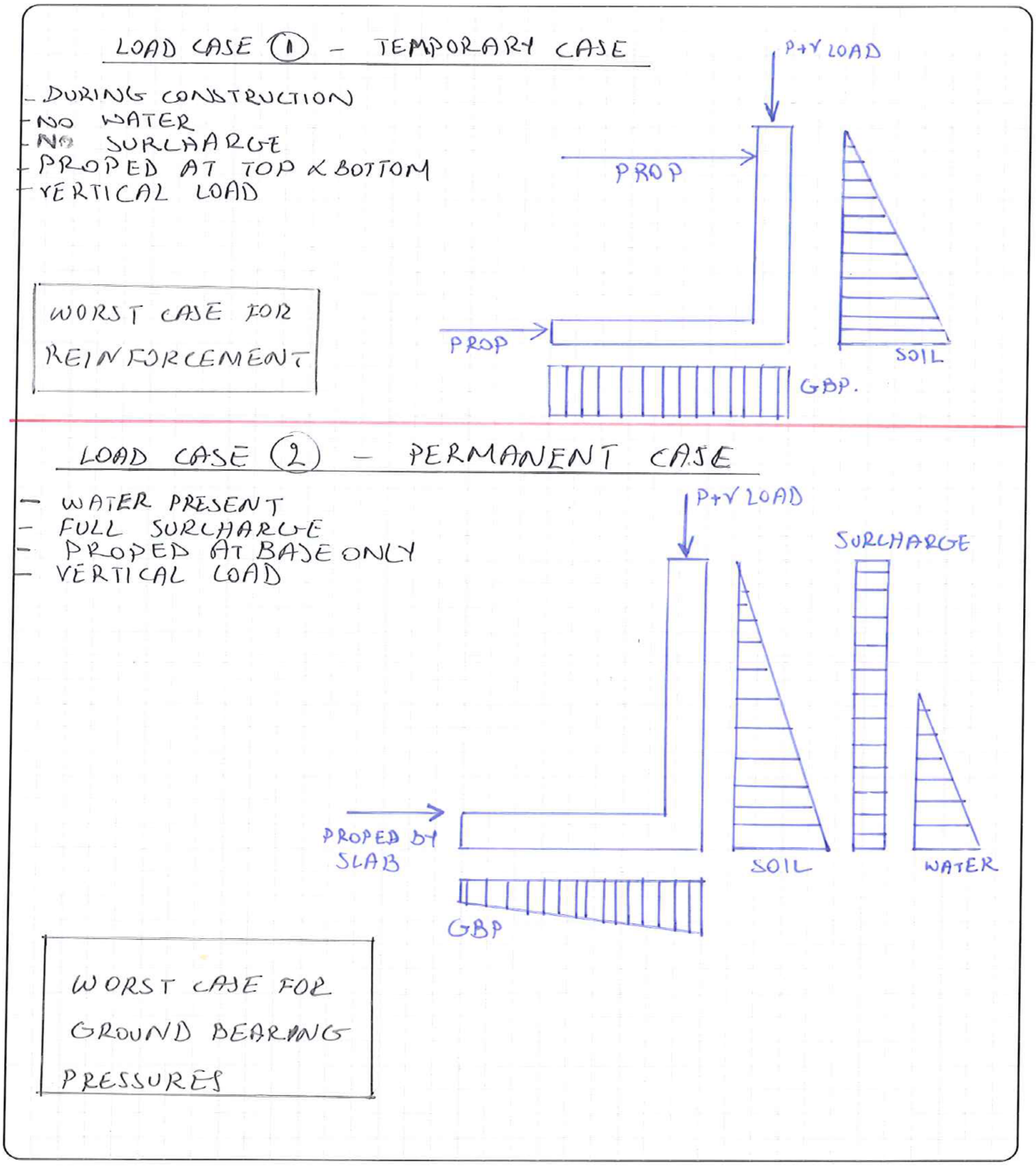
Retaining Wall Calculations

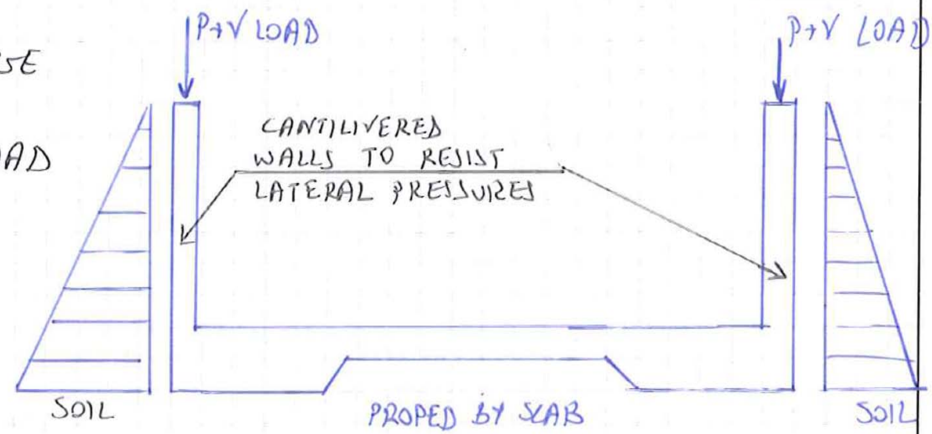
Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street				Job Ref. 140906	
	Section Retaining walls design				Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date

THE FOLLOWING INFORMATION IS PROVIDED TO IDENTIFY THE DIFFERENT LOADCASES FOR THE RETAINING WALLS. THE WORST CASES ARE DESIGNED FOR IN DETAIL BELOW.



LOAD CASE (3) – PERMANENT CASE FULL BASEMENT

- NO SURCHARGE
- NO WATER
- VERTICAL LOAD



FOR THIS CASE TO BE APPLIED AND NO SURCHARGE APPLIED THE FULL BASEMENT WILL NEED TO BE IN PLACE. THIS DOES NOT POSE THE WORST CASE FOR THE CONSTRUCTION OF THE BASEMENT. HOWEVER, THIS LOAD CASE IS CONSIDERED AND A FULL DESIGN WILL BE PERFORMED AT THE DETAILED DESIGN STAGE

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street			Job Ref. 140906	
	Section Retaining walls design			Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date

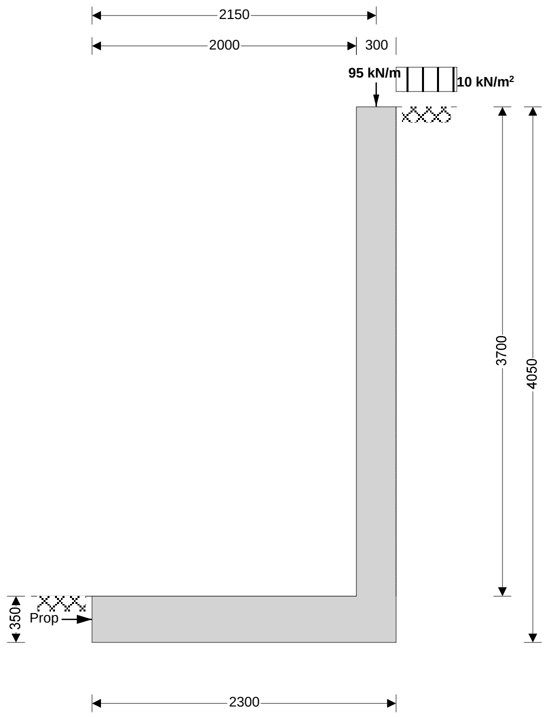
LOAD CASE 1 - RETAINING WALL A DESIGN NO WATER

Loading

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m^2			kN/m^2	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			
				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type **Cantilever propped at base**

Height of retaining wall stem h_{stem} = **3700** mm

Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **2000** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2300** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1900** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

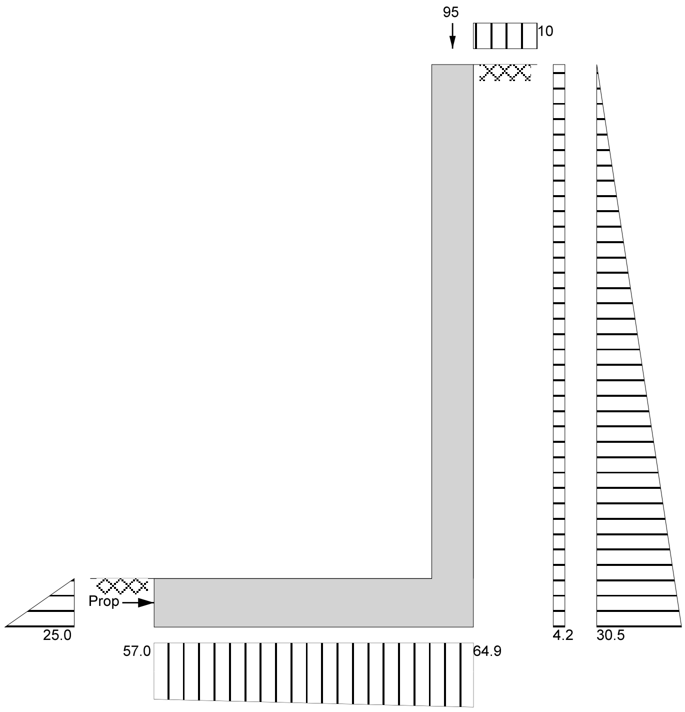
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 – \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **10.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **70.0** kN/m
Applied vertical live load on wall	W_{live} = **25.0** kN/m
Position of applied vertical load on wall	l_{load} = **2150** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **19** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **95** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **140.2** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **61.8** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a}$ = **78.7** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0\text{ kN/m})$

F_{prop} = **35.6** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **83.4** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a}$ = **117.7** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **56.3** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **21.8** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load}$ = **150.5** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **228.7** kNm/m

Check bearing pressure

Design vertical live load $M_{live} = W_{live} \times l_{load}$ = **53.8** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{live}$ = **164.7** kNm/m

Total vertical reaction $R = W_{total} = \mathbf{140.2}$ kN/m

Distance to reaction $x_{bar} = M_{total} / R = \mathbf{1175}$ mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) = \mathbf{25}$ mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{57}$ kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = \mathbf{64.9}$ kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **26.6** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **138** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **201.3** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **122** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **160.2** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **99.8** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **164.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **242.1** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **78.8** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **30.6** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **296.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **406.1** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **164.1** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **201.3** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **815** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **335** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **163.9** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **11.1** kN/m^2

Rate of change of base reaction $\text{rate} = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **66.47** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **31** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **21** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **11.1** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **195** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **23.1** kN/m

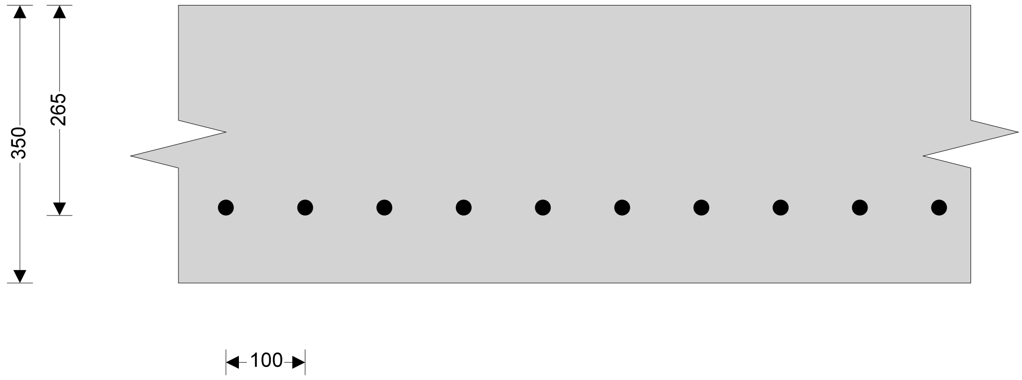
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **171.8** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **268.8** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **26.7** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **242.1** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} – c_{toe} – (\phi_{toe} / 2)$ = **265.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.086**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))},0.95) \times d_{toe}$

z_{toe} = **237** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **2353** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **455** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **2353** mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **3142** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.648** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1$ N/mm^2 = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement — f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in stem — c_{stem} = **75** mm

Cover to reinforcement in wall — c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge — $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **101.8** kN/m

Calculate shear for stem design

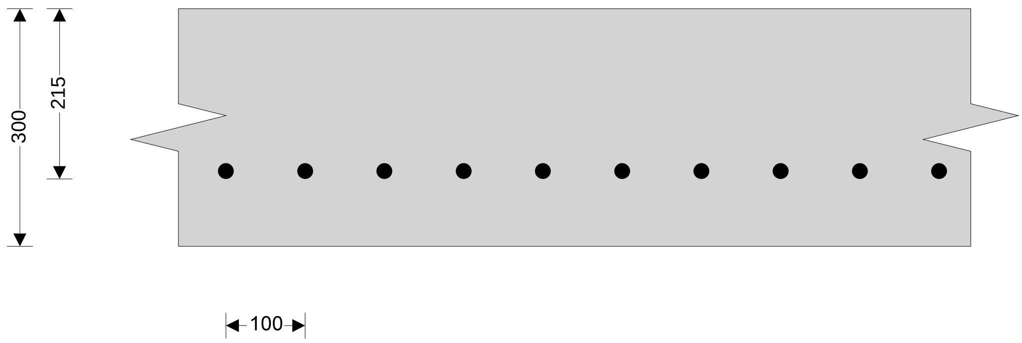
Shear at base of stem — $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} - F_{prop\_f}$ = **36.9** kN/m

Calculate moment for stem design

Surcharge — $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **143.3** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **214.1** kNm/m



Check wall stem in bending

Width of wall stem — b = **1000** mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.116**

Compression reinforcement is not required

Lever arm — $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **182** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2698** mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **2698** mm^2/m

Reinforcement provided — **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **3142** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.172** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** N/mm^2

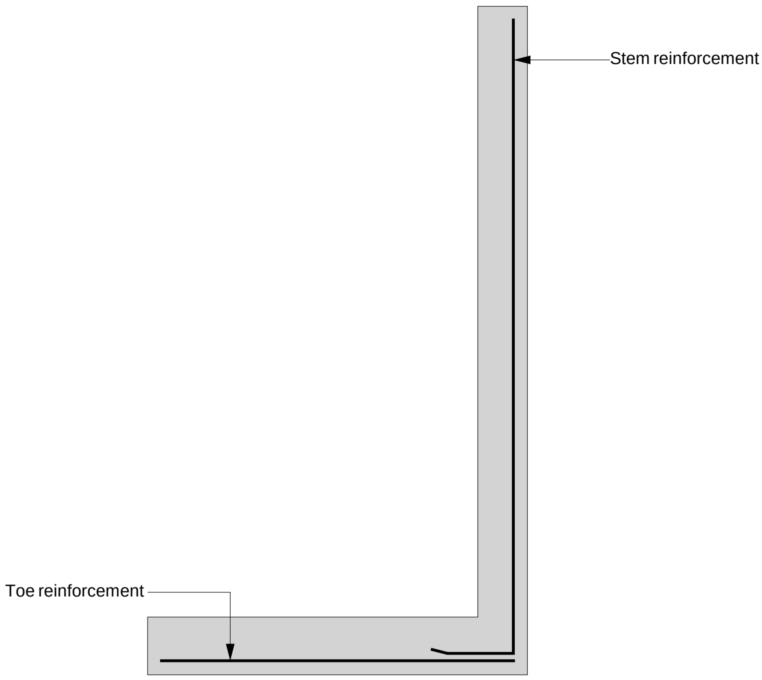
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.980** N/mm^2

v_{stem} < v_{c_stem} - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

LOAD CASE 1 - RETAINING WALL A NO WATER/NO SURCHARGE

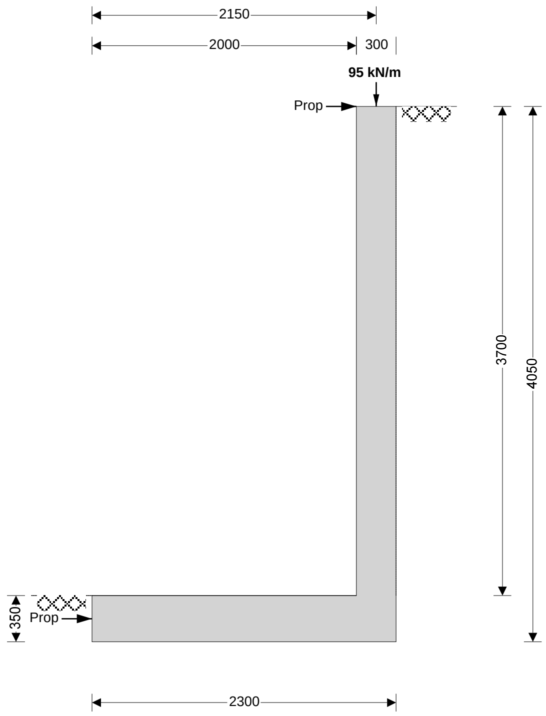
Loading

Location	Area	Type	L	Action	Actions, kN or kN/m

	L	W	m²			kN/m²	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			
				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type **Cantilever propped at both**

Height of retaining wall stem h_{stem} = **3700** mm

Thickness of wall stem t_{wall} = **300** mm

Length of toe l_{toe} = **2000** mm

Length of heel l_{heel} = **0** mm

Overall length of base $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2300** mm

Thickness of base t_{base} = **350** mm

Depth of downstand d_{ds} = **0** mm

Position of downstand l_{ds} = **900** mm

Thickness of downstand t_{ds} = **350** mm

Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **18.6** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.369}$$

Passive pressure coefficient for base material

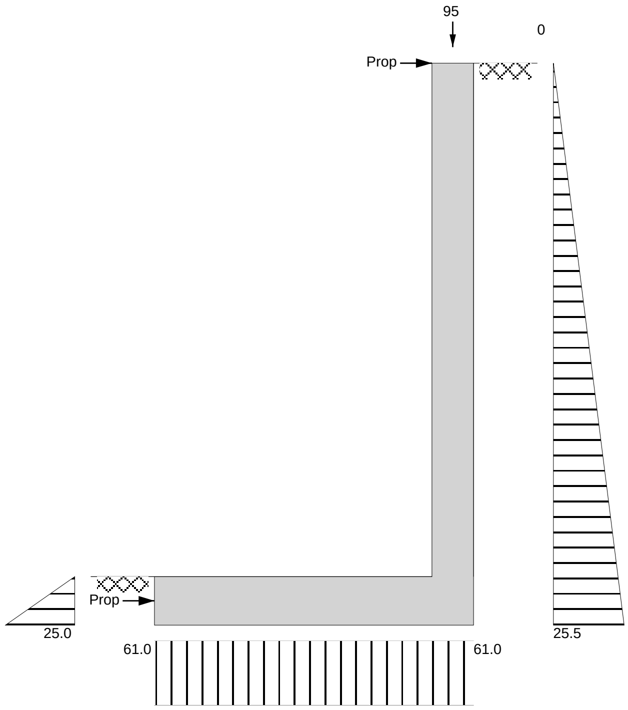
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 – \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **0.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **69.1** kN/m
Applied vertical live load on wall	W_{live} = **25.9** kN/m
Position of applied vertical load on wall	l_{load} = **2150** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m²

Vertical forces on wall

Wall stem — $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base — $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **19** kN/m

Applied vertical load — $W_v = W_{dead} + W_{live}$ = **95** kN/m

Total vertical load — $W_{total} = w_{wall} + w_{base} + W_v$ = **140.2** kN/m

Horizontal forces on wall

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \cos(90 - \alpha + \delta) \times \gamma_m \times (h_{eff} - h_{water})^2$ = **51.6** kN/m

Total horizontal load — $F_{total} = F_{m\_a}$ = **51.6** kN/m

Calculate total propping force

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force — $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0\text{ kN/m})$

F_{prop} = **8.8** kN/m

Overturning moments

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **69.7** kNm/m

Total overturning moment — $M_{ot} = M_{m\_a}$ = **69.7** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **56.3** kNm/m

Wall base — $M_{base} = w_{base} \times l_{base} / 2$ = **21.8** kNm/m

Design vertical dead load — $M_{dead} = W_{dead} \times l_{load}$ = **148.6** kNm/m

Total restoring moment — $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **226.7** kNm/m

Check bearing pressure

Total vertical reaction — $R = W_{total}$ = **140.2** kN/m

Distance to reaction — $x_{bar} = l_{base} / 2$ = **1150** mm

Eccentricity of reaction — $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{61}$ kN/m²

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = \mathbf{61}$ kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{0.689}$ kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top} = \mathbf{8.118}$ kN/m

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street			Job Ref. 140906	
	Section Retaining walls design			Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **26.6** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **138.2** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **201.5** kN/m

Factored horizontal at-rest forces on wall

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **122** kN/m

Total horizontal load $F_{total\_f} = F_{m\_a\_f}$ = **122** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **62.0** kN/m

Factored overturning moments

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **164.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{m\_a\_f}$ = **164.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **78.8** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **30.6** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **297.1** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **406.5** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **201.5** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **1150** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **87.6** kN/m²

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **87.6** kN/m²

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **87.6** kN/m²

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **87.6** kN/m²

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **87.6** kN/m²

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **-5.436** kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **67.414** kN/m

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **175.2** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **23.1** kN/m

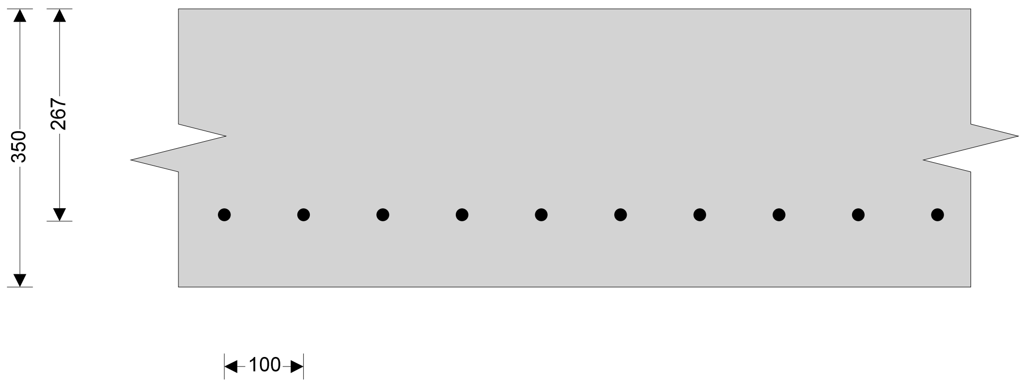
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **152** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **202.4** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **26.7** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **175.7** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **267.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.062**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **247** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **1634** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **455** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **1634** mm^2/m

Reinforcement provided **16 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **2011** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.569** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \mathrm{N/mm^2})}, 5) \times 1\ \mathrm{N/mm^2}$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.744** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **75** mm

Factored horizontal at-rest forces on stem

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **101.8** kN/m

Calculate shear for stem design

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **79.5** kN/m

Total shear for stem design $V_{stem} = V_{s\_m\_a\_f}$ = **79.5** kN/m

Calculate moment for stem design

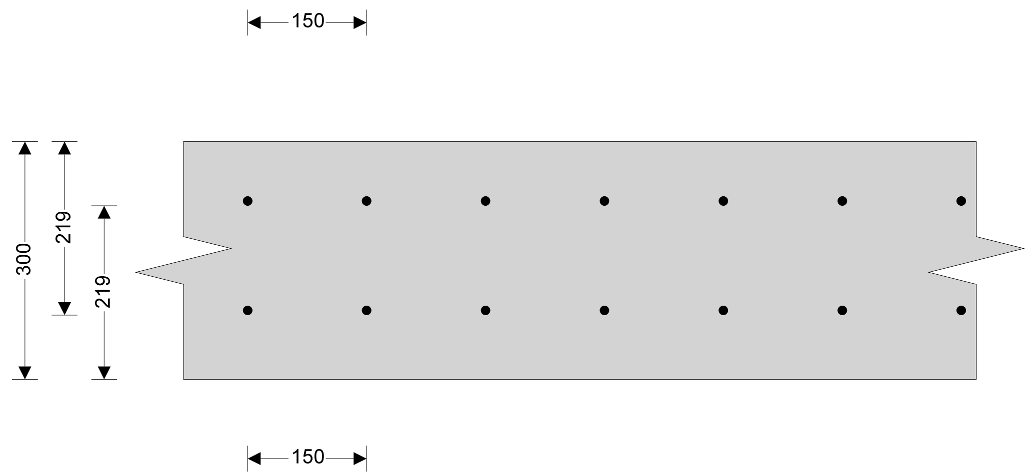
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **56.9** kNm/m

Total moment for stem design $M_{stem} = M_{s\_m\_a}$ = **56.9** kNm/m

Calculate moment for wall design

Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3+5 \times a_l \times L^2)/(5 \times L^3)-0.577^2/3]$ = **23.5** kNm/m

Total moment for wall design $M_{wall} = M_{w\_m\_a}$ = **23.5** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **219.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.030**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **208** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **628** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **628** mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **754** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.363** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.602** N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2)$ = **219.0** mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu})$ = **0.012**

Compression reinforcement is not required

Lever arm $z_{wall} = \text{Min}(0.5 + \sqrt{(0.25 - (\min(K_{wall}, 0.225) / 0.9))}, 0.95) \times d_{wall}$

z_{wall} = **208** mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall})$ = **260** mm^2/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_wall\_req} = \text{Max}(A_{s\_wall\_des}, A_{s\_wall\_min})$ = **390** mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov}$ = **754** mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas}$ = **20**

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov})$ = **277.8** N/mm^2

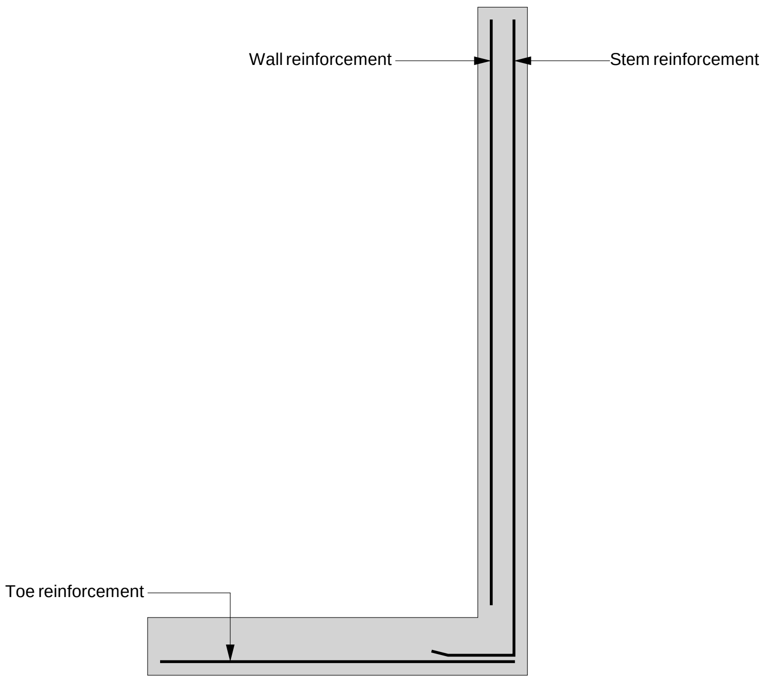
Modification factor $factor_{tens} = \min(0.55 + (477 \text{ N/mm}^2 - f_s)/(120 \times (0.9 \text{ N/mm}^2 + (M_{stem}/(b \times d_{stem}^2)))),2)$ = **1.35**

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens}$ = **26.92**

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem}$ = **16.89**

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 100 mm centres - (2011 mm^2/m)
Wall bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Stem bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)

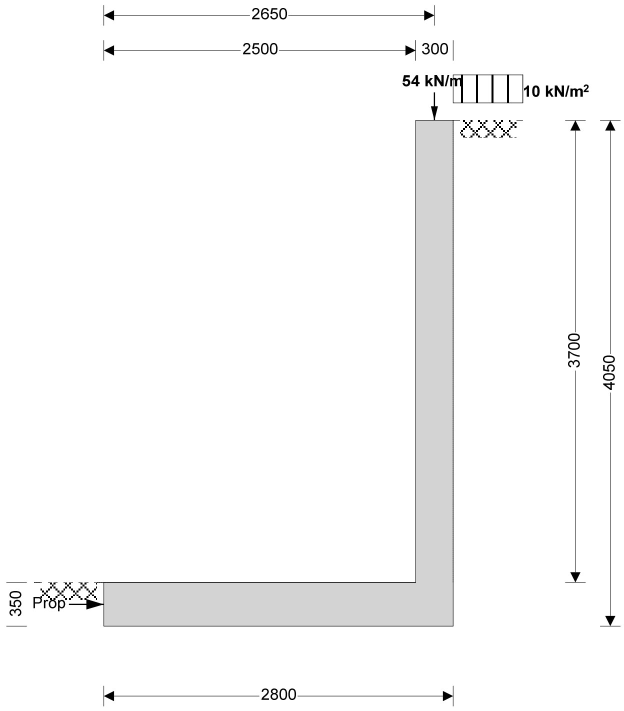
LOAD CASE 1 - RETAINING WALL B DESIGN, NO WATER

Loading

section B-B										
Ground floor	3.9	1	3.9	g_k		0.63	2.5			
				q_k		1.50			5.9	
Solid wall	9	1	9	g_k		5.00	45.0			
							47.5	kN/m	5.9	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **3700** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **2500** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2800** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1900** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 – \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **10.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **48.0** kN/m

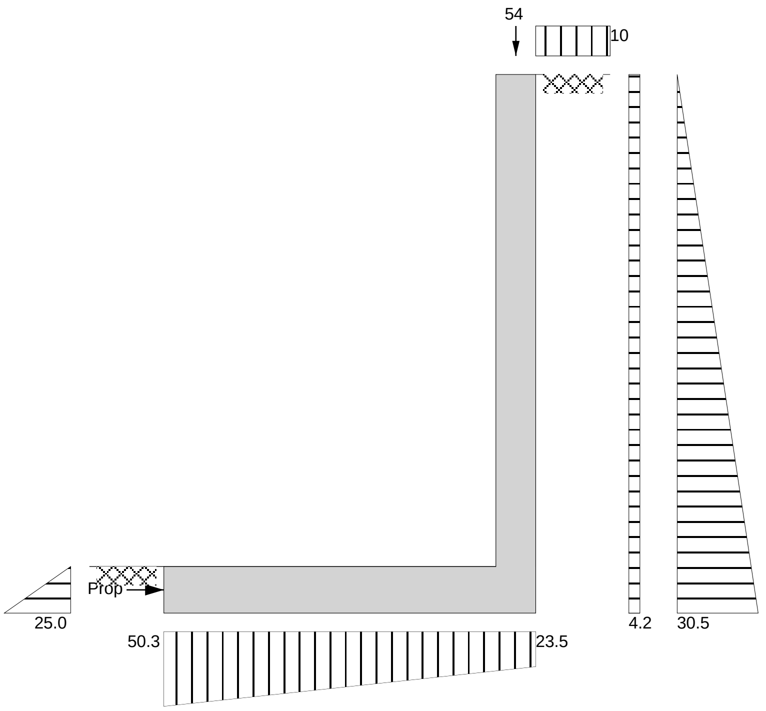
Applied vertical live load on wall W_{live} = **6.0** kN/m

Position of applied vertical load on wall l_{load} = **2650** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.1** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **54** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **103.3** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **61.8** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a}$ = **78.7** kN/m

Calculate propping force

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force — $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **41.6** kN/m

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **83.4** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a}$ = **117.7** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **69.4** kNm/m

Wall base — $M_{base} = w_{base} \times l_{base} / 2$ = **32.4** kNm/m

Design vertical dead load — $M_{dead} = W_{dead} \times l_{load}$ = **127.2** kNm/m

Total restoring moment — $M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **229** kNm/m

Check bearing pressure

Design vertical live load — $M_{live} = W_{live} \times l_{load}$ = **15.9** kNm/m

Total moment for bearing — $M_{total} = M_{rest} - M_{ot} + M_{live}$ = **127.2** kNm/m

Total vertical reaction — $R = W_{total}$ = **103.3** kN/m

Distance to reaction — $x_{bar} = M_{total} / R$ = **1231** mm

Eccentricity of reaction — $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **169** mm

Reaction acts within middle third of base

Bearing pressure at toe — $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **50.3** kN/m²

Bearing pressure at heel — $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **23.5** kN/m²

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **32.4** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **76.8** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **145.9** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times$ Surcharge $\times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **122** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f}$ = **160.2** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **108.2** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **164.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f}$ = **242.1** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **97.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **45.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **203.5** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **346** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **104** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **145.9** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **713** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **687** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **136.4** kN/m^2

Bearing pressure at heel p_{heel_f} = 0 kN/m^2 = **0** kN/m^2

Rate of change of base reaction rate = $p_{toe\_f} / (3 \times x_{bar\_f})$ = **63.78** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **0** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **0** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **0** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2$ = **145.9** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **28.9** kN/m

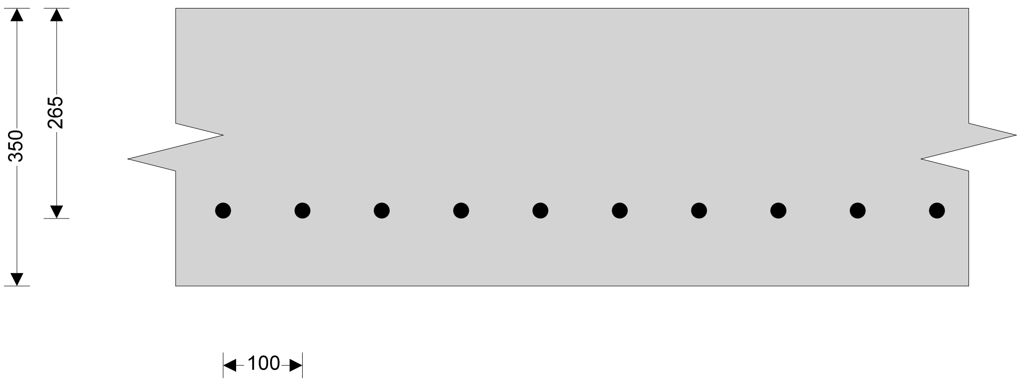
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **116.9** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2$ = **282.5** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **40.6** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **241.9** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **265.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.086**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))},0.95) \times d_{toe}$

z_{toe} = **237** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **2351** mm^2/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base}$ = **455** mm^2/m

Area of tension reinforcement required $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **2351** mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov}$ = **3142** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.441** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **101.8** kN/m

Calculate shear for stem design

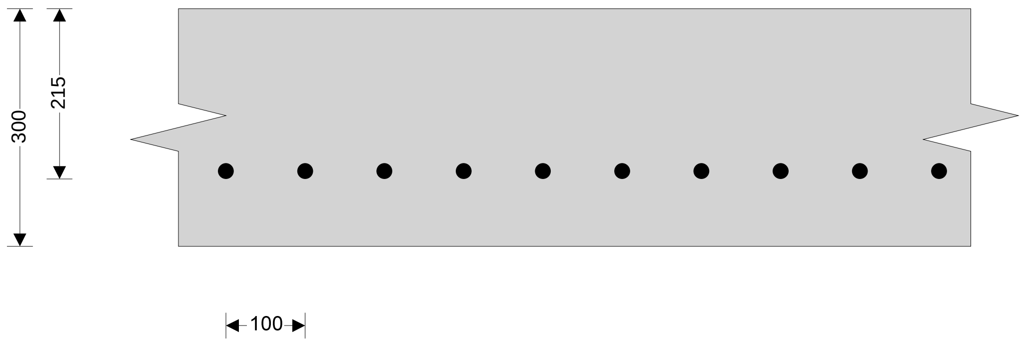
Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} - F_{prop\_f}$ = **28.5** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **143.3** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a}$ = **214.1** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.116**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **182** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2698** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **2698** mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **3142** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.133** N/mm^2

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2$ = **5.000** N/mm^2

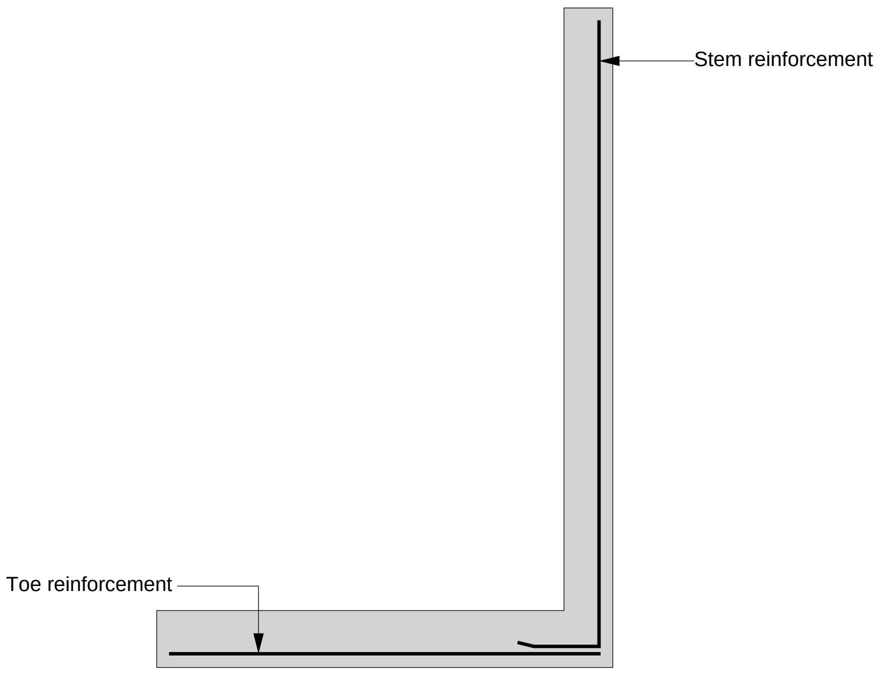
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.980** N/mm^2

v_{stem} < v_{c_stem} - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

LOAD CASE 1 - RETAINING WALL B NO WATER NO SURCHARGE

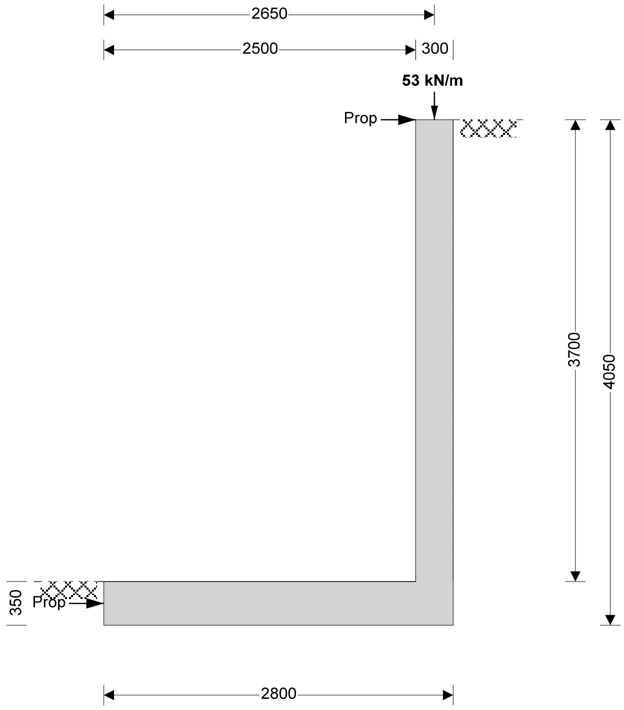
Loading

section B-B										
Ground floor	3.9	1	3.9	g_k		0.63	2.5			
				q_k		1.50			5.9	
Solid wall	9	1	9	g_k		5.00	45.0			
							47.5	kN/m	5.9	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street			Job Ref. 140906	
	Section Retaining walls design			Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date



Wall details

Retaining wall type — **Cantilever propped at both**

Height of retaining wall stem — h_{stem} = **3700** mm

Thickness of wall stem — t_{wall} = **300** mm

Length of toe — l_{toe} = **2500** mm

Length of heel — l_{heel} = **0** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2800** mm

Thickness of base — t_{base} = **350** mm

Depth of downstand — d_{ds} = **0** mm

Position of downstand — l_{ds} = **1900** mm

Thickness of downstand — t_{ds} = **350** mm

Height of retaining wall — $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm

Depth of cover in front of wall — d_{cover} = **0** mm

Depth of unplanned excavation — d_{exc} = **0** mm

Height of ground water behind wall — h_{water} = **0** mm

Height of saturated fill above base — $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **0** mm

Density of wall construction — γ_{wall} = **23.6** kN/m^3

Density of base construction — γ_{base} = **23.6** kN/m^3

Angle of rear face of wall — α = **90.0** deg

Angle of soil surface behind wall — β = **0.0** deg

Effective height at virtual back of wall — $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor — M = **1.5**

Moist density of retained material — γ_m = **18.0** kN/m^3

Saturated density of retained material — γ_s = **21.0** kN/m^3

Design shear strength — ϕ' = **24.2** deg

Angle of wall friction — δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 – \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **0.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **47.5** kN/m

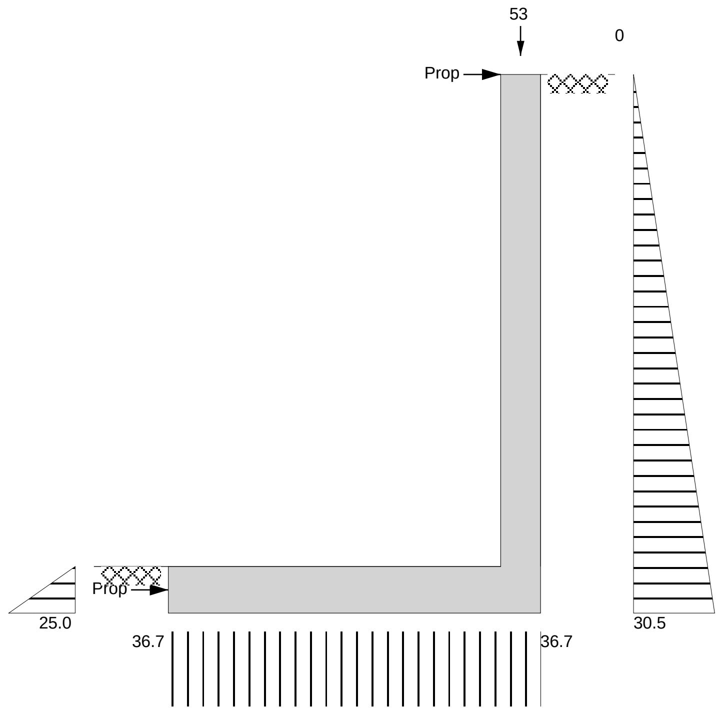
Applied vertical live load on wall W_{live} = **5.9** kN/m

Position of applied vertical load on wall l_{load} = **2650** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.1** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **53.4** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **102.7** kN/m

Horizontal forces on wall

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2 = \mathbf{61.8}$ kN/m

Total horizontal load $F_{total} = F_{m\_a} = \mathbf{61.8}$ kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb} = \mathbf{4.4}$ kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

$F_{prop} = \mathbf{24.8}$ kN/m

Overturning moments

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3 = \mathbf{83.4}$ kNm/m

Total overturning moment $M_{ot} = M_{m\_a} = \mathbf{83.4}$ kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2) = \mathbf{69.4}$ kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 = \mathbf{32.4}$ kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load} = \mathbf{125.9}$ kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead} = \mathbf{227.7}$ kNm/m

Check bearing pressure

Total vertical reaction $R = W_{total} = \mathbf{102.7}$ kN/m

Distance to reaction $x_{bar} = l_{base} / 2 = \mathbf{1400}$ mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar}) = \mathbf{0}$ mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{36.7}$ kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) = \mathbf{36.7}$ kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top} = (M_{ot} - M_{rest} + R \times l_{base} / 2 - F_{prop} \times t_{base} / 2) / (h_{stem} + t_{base} / 2) = \mathbf{-1.238}$ kN/m

Propping force to base of wall $F_{prop\_base} = F_{prop} - F_{prop\_top} = \mathbf{26.061}$ kN/m

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **32.4** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **75.9** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **145** kN/m

Factored horizontal at-rest forces on wall

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **122** kN/m

Total horizontal load $F_{total\_f} = F_{m\_a\_f}$ = **122** kN/m

Calculate total propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **70.2** kN/m

Factored overturning moments

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **164.6** kNm/m

Total overturning moment $M_{ot\_f} = M_{m\_a\_f}$ = **164.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **97.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **45.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **201.2** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **343.8** kNm/m

Factored bearing pressure

Total vertical reaction $R_f = W_{total\_f}$ = **145.0** kN/m

Distance to reaction $x_{bar\_f} = l_{base} / 2$ = **1400** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **0** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **51.8** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **51.8** kN/m^2

Rate of change of base reaction rate $= (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **0.00** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **51.8** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0 \text{ kN/m}^2)$ = **51.8** kN/m^2

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0 \text{ kN/m}^2)$ = **51.8** kN/m^2

Calculate propping forces to top and base of wall

Propping force to top of wall

$F_{prop\_top\_f} = (M_{ot\_f} - M_{rest\_f} + R_f \times l_{base} / 2 - F_{prop\_f} \times t_{base} / 2) / (h_{stem} + t_{base} / 2)$ = **2.989** kN/m

Propping force to base of wall $F_{prop\_base\_f} = F_{prop\_f} - F_{prop\_top\_f}$ = **67.220** kN/m

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement — f_y = **500** N/mm^2

Base details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in toe — c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2$ = **129.5** kN/m

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base}$ = **28.9** kN/m

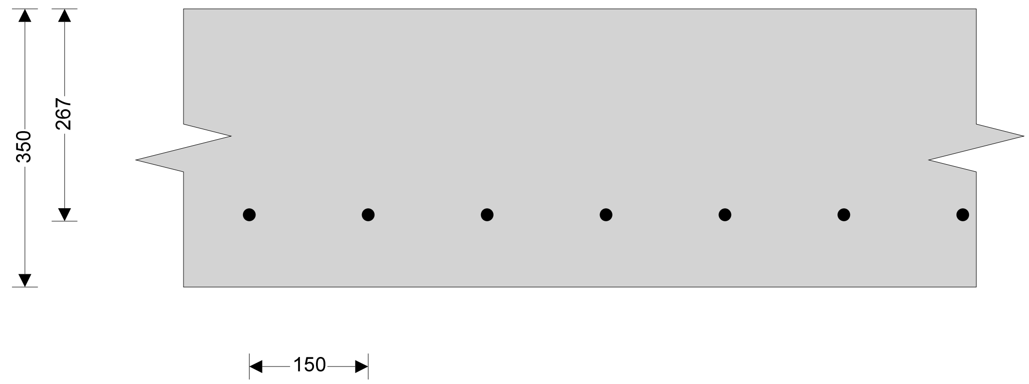
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base}$ = **100.5** kN/m

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6$ = **181.8** kNm/m

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2)$ = **40.6** kNm/m

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base}$ = **141.2** kNm/m



Check toe in bending

Width of toe — b = **1000** mm/m

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2)$ = **267.0** mm

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu})$ = **0.050**

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **251** mm

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe})$ = **1291** mm^2/m

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base}$ = **455** mm^2/m

Area of tension reinforcement required — $A_{s\_toe\_req} = \mathrm{Max}(A_{s\_toe\_des}, A_{s\_toe\_min})$ = **1291** mm^2/m

Reinforcement provided — **16 mm dia.bars @ 150 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov}$ = **1340** mm^2/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe})$ = **0.377** N/mm^2

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \mathrm{N/mm^2})}, 5) \times 1\ \mathrm{N/mm^2}$ = **5.000** N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — v_{c_toe} = **0.650** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street				Job Ref. 140906	
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	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **75** mm

Factored horizontal at-rest forces on stem

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **101.8** kN/m

Calculate shear for stem design

Moist backfill above water table $V_{s\_m\_a\_f} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - b_l^2) / (5 \times L^3)$ = **79.5** kN/m

Total shear for stem design $V_{stem} = V_{s\_m\_a\_f}$ = **79.5** kN/m

Calculate moment for stem design

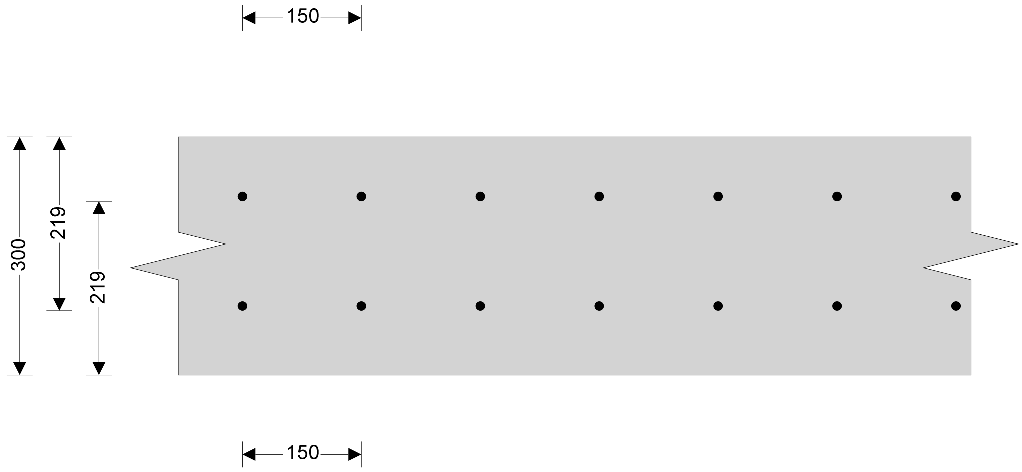
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times b_l \times ((5 \times L^2) - (3 \times b_l^2)) / (15 \times L^2)$ = **56.9** kNm/m

Total moment for stem design $M_{stem} = M_{s\_m\_a}$ = **56.9** kNm/m

Calculate moment for wall design

Moist backfill above water table $M_{w\_m\_a} = F_{s\_m\_a\_f} \times 0.577 \times b_l \times [(b_l^3 + 5 \times a_l \times L^2)/(5 \times L^3) - 0.577^2/3]$ = **23.5** kNm/m

Total moment for wall design $M_{wall} = M_{w\_m\_a}$ = **23.5** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **219.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.030**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **208** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **628** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = \mathrm{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **628** mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **754** mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.363}$ N/mm^2

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}$ N/mm^2

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_stem} = \mathbf{0.602}$ N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Check mid height of wall in bending

Depth of reinforcement $d_{wall} = t_{wall} - c_{wall} - (\phi_{wall} / 2) = \mathbf{219.0}$ mm

Constant $K_{wall} = M_{wall} / (b \times d_{wall}^2 \times f_{cu}) = \mathbf{0.012}$

Compression reinforcement is not required

Lever arm $z_{wall} = Min(0.5 + \sqrt{(0.25 - (min(K_{wall}, 0.225) / 0.9))},0.95) \times d_{wall}$

$z_{wall} = \mathbf{208}$ mm

Area of tension reinforcement required $A_{s\_wall\_des} = M_{wall} / (0.87 \times f_y \times z_{wall}) = \mathbf{260}$ mm^2/m

Minimum area of tension reinforcement $A_{s\_wall\_min} = k \times b \times t_{wall} = \mathbf{390}$ mm^2/m

Area of tension reinforcement required $A_{s\_wall\_req} = Max(A_{s\_wall\_des}, A_{s\_wall\_min}) = \mathbf{390}$ mm^2/m

Reinforcement provided **12 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_wall\_prov} = \mathbf{754}$ mm^2/m

PASS - Reinforcement provided to the retaining wall at mid height is adequate

Check retaining wall deflection

Basic span/effective depth ratio $ratio_{bas} = \mathbf{20}$

Design service stress $f_s = 2 \times f_y \times A_{s\_stem\_req} / (3 \times A_{s\_stem\_prov}) = \mathbf{277.8}$ N/mm^2

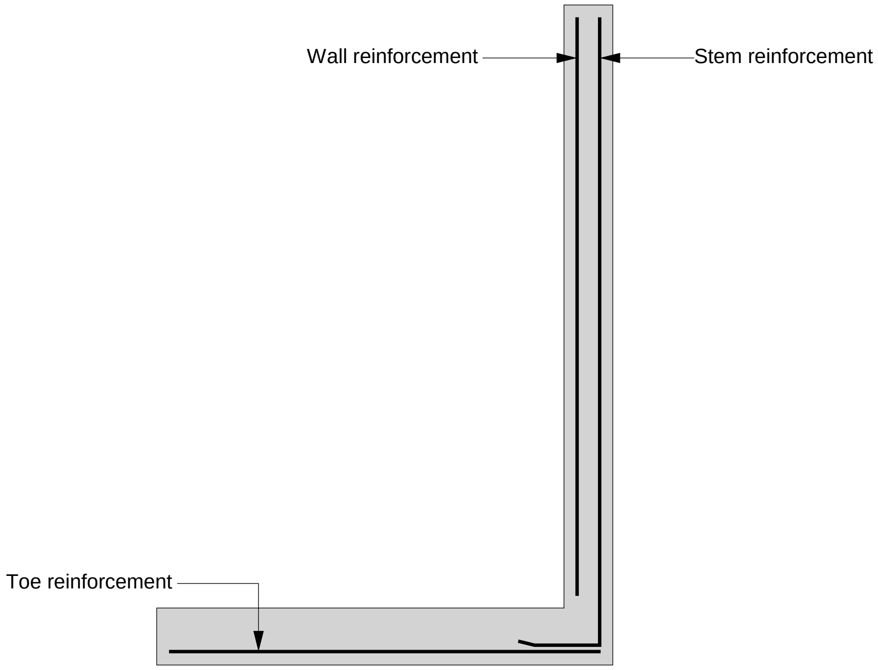
Modification factor $factor_{tens} = min(0.55 + (477\ N/mm^2 - f_s)/(120 \times (0.9\ N/mm^2 + (M_{stem}/(b \times d_{stem}^2)))),2) = \mathbf{1.35}$

Maximum span/effective depth ratio $ratio_{max} = ratio_{bas} \times factor_{tens} = \mathbf{26.92}$

Actual span/effective depth ratio $ratio_{act} = h_{stem} / d_{stem} = \mathbf{16.89}$

PASS - Span to depth ratio is acceptable

Indicative retaining wall reinforcement diagram



Toe bars - 16 mm dia.@ 150 mm centres - (1340 mm^2/m)
Wall bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)
Stem bars - 12 mm dia.@ 150 mm centres - (754 mm^2/m)

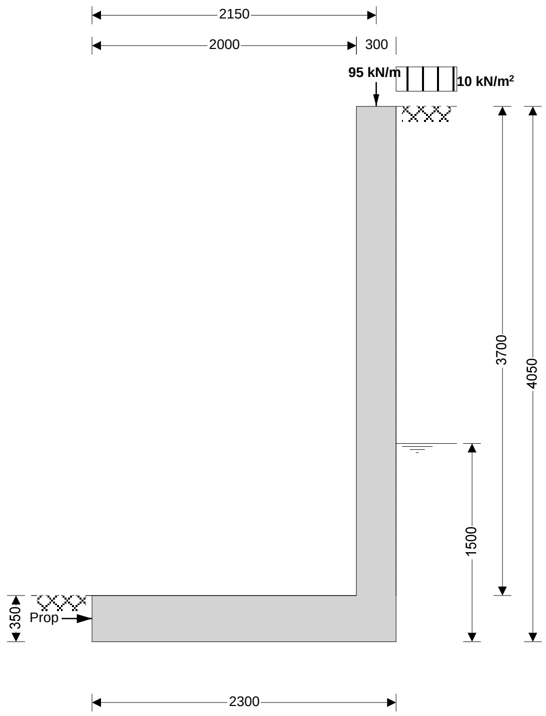
LOAD CASE 2 - RETAINING WALL A

Loading

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m^2			kN/m^2	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			
				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type — **Cantilever propped at base**

Height of retaining wall stem — h_{stem} = **3700** mm

Thickness of wall stem — t_{wall} = **300** mm

Length of toe — l_{toe} = **2000** mm

Length of heel — l_{heel} = **0** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2300** mm

Thickness of base t_{base} = **350** mm

Depth of downstand d_{ds} = **0** mm

Position of downstand l_{ds} = **1900** mm

Thickness of downstand t_{ds} = **350** mm

Height of retaining wall $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm

Depth of cover in front of wall d_{cover} = **0** mm

Depth of unplanned excavation d_{exc} = **0** mm

Height of ground water behind wall h_{water} = **1500** mm

Height of saturated fill above base $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **1150** mm

Density of wall construction γ_{wall} = **23.6** kN/m^3

Density of base construction γ_{base} = **23.6** kN/m^3

Angle of rear face of wall α = **90.0** deg

Angle of soil surface behind wall β = **0.0** deg

Effective height at virtual back of wall $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor M = **1.5**

Moist density of retained material γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m^3

Design shear strength ϕ' = **24.2** deg

Angle of wall friction δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **10.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **70.0** kN/m

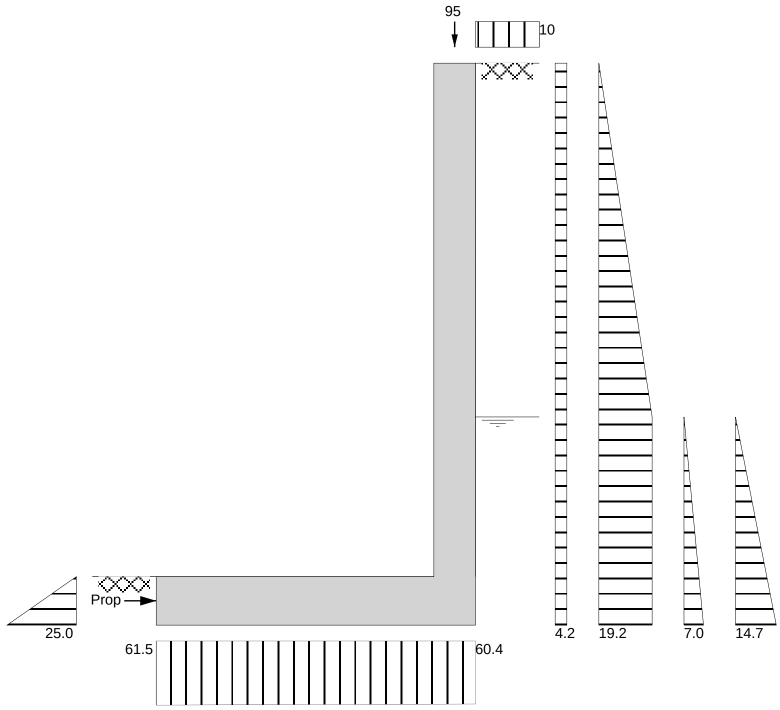
Applied vertical live load on wall W_{live} = **25.0** kN/m

Position of applied vertical load on wall l_{load} = **2150** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **19** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **95** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **140.2** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **24.5** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **28.8** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **5.3** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **11** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **86.6** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **43.4** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **57.6** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **21.6** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **2.6** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.5** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **121.6** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **56.3** kNm/m

Wall base	$M_{base} = w_{base} \times l_{base} / 2 =$ **21.8** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load} =$ **150.5** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{dead} =$ **228.7** kNm/m

Check bearing pressure

Design vertical live load	$M_{live} = W_{live} \times l_{load} =$ **53.8** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{live} =$ **160.8** kNm/m
Total vertical reaction	$R = W_{total} =$ **140.2** kN/m
Distance to reaction	$x_{bar} = M_{total} / R =$ **1147** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar}) =$ **3** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **61.5** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **60.4** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **26.6** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **138** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **201.3** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **48.3** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **56.9** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **10.4** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **15.5** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **169.3** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop_f} = **108.9** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **113.6** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **42.7** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.2** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **7.7** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **246.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **78.8** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **30.6** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **296.7** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **406.1** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **159.5** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **201.3** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **793** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **357** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **169.1** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **5.9** kN/m^2

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **70.96** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **27.2** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{16.5}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{5.9}\ kN/m^2$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe $c_{toe} = \mathbf{75}$ mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{196.3}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{23.1}$ kN/m

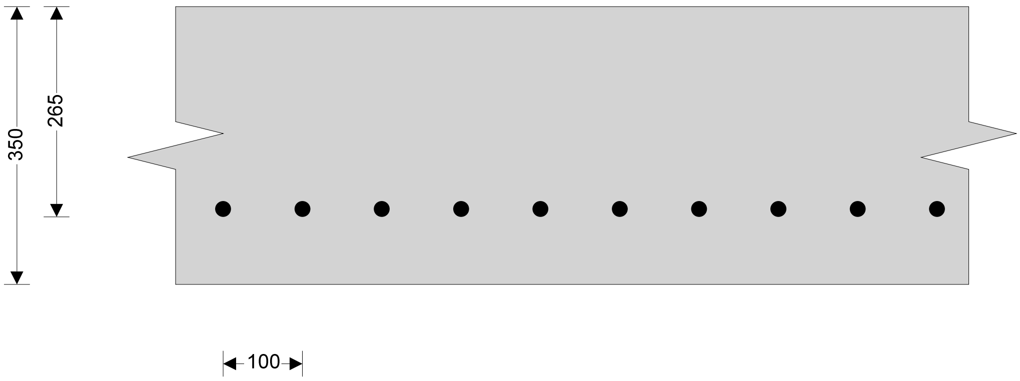
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{173.2}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{273.3}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{26.7}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{246.6}$ kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{265.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.088}$

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} = \mathbf{236}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{2402}\ mm^2/m$

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455}\ mm^2/m$

Area of tension reinforcement required $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{2402}\ mm^2/m$

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{3142}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.654}\ N/mm^2$

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}\ N/mm^2$

PASS - Design shear stress is less than maximum shear stress

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From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times$ Surcharge $\times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **48.3** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **43.6** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **6.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **9.1** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **33.2** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

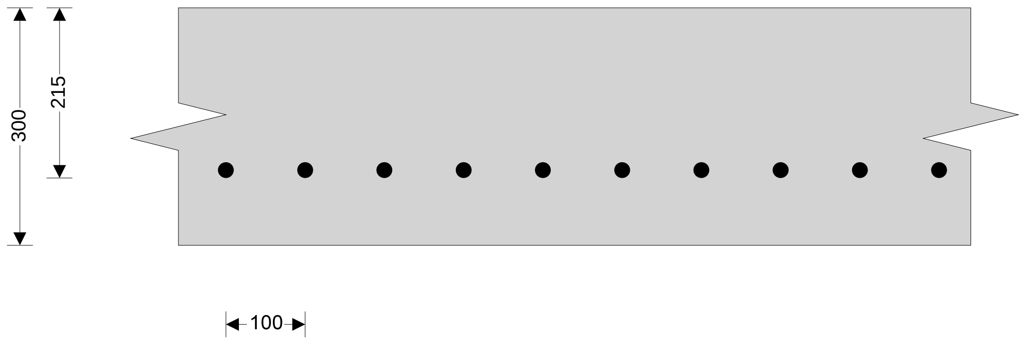
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **105.2** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **25.1** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **2.3** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **3.5** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **206.8** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.112**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **184** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2587** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{390}$ mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{2587}$ mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov} = \mathbf{3142}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.154}$ N/mm^2

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2 = \mathbf{5.000}$ N/mm^2

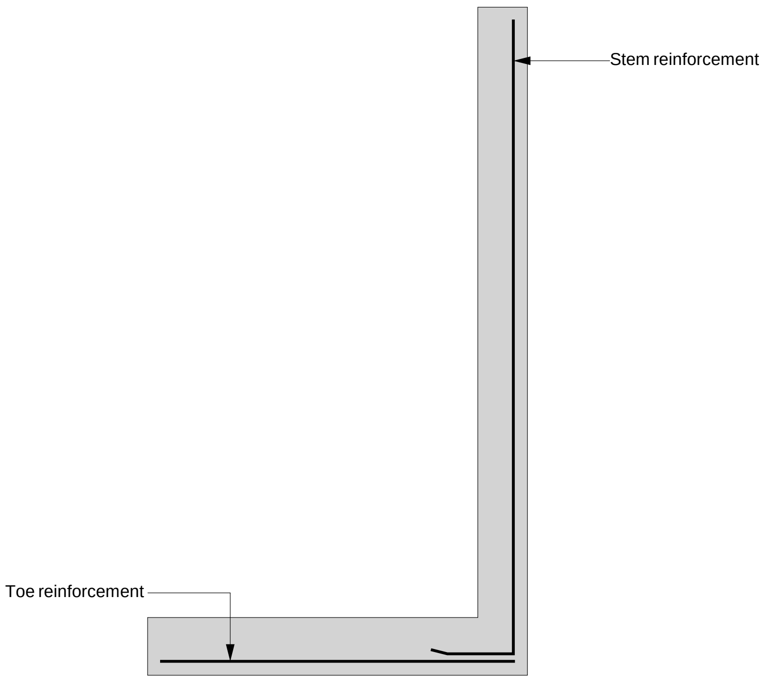
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_stem} = \mathbf{0.980}$ N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

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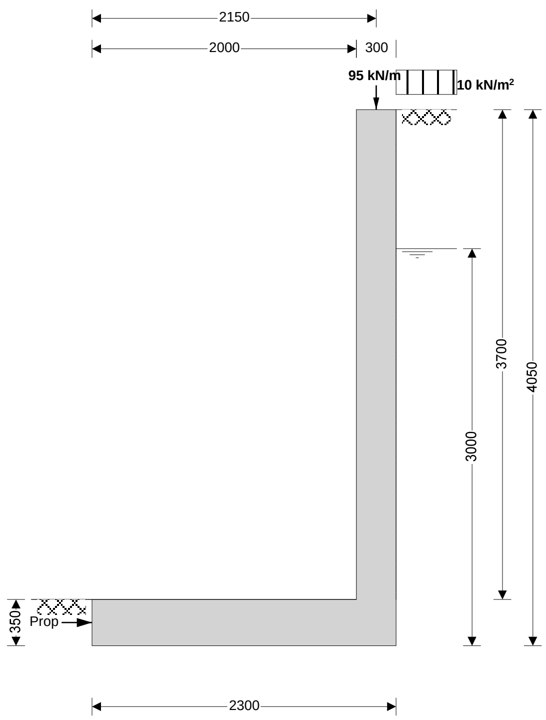
LOADCASE 2 - RETAINING WALL A (WATER TABLE HIGHER)

Loading

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m^2			kN/m^2	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			
				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type **Cantilever propped at base**

Height of retaining wall stem h_{stem} = **3700** mm

Thickness of wall stem t_{wall} = **300** mm

Length of toe l_{toe} = **2000** mm

Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2300** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1900** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **3000** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **2650** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **10.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **70.0** kN/m
Applied vertical live load on wall	W_{live} = **25.0** kN/m
Position of applied vertical load on wall	l_{load} = **2150** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm

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	Section Retaining walls design				Sheet no./rev. 3	
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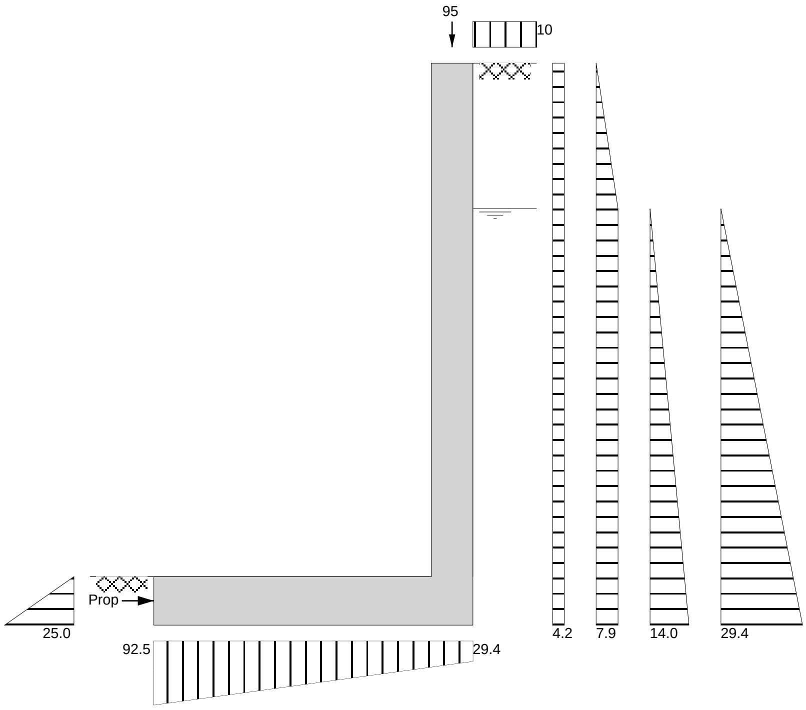


Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem — $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base — $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **19** kN/m

Applied vertical load — $W_v = W_{dead} + W_{live}$ = **95** kN/m

Total vertical load — $W_{total} = w_{wall} + w_{base} + W_v$ = **140.2** kN/m

Horizontal forces on wall

Surcharge — $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table — $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **4.2** kN/m

Moist backfill below water table — $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **23.7** kN/m

Saturated backfill — $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **21.1** kN/m

Water — $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **44.1** kN/m

Total horizontal load — $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **110.1** kN/m

Calculate propping force

Passive resistance of soil in front of wall — $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force — $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **66.9** kN/m

Overturning moments

Surcharge — $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table — $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **13.9** kNm/m

Moist backfill below water table — $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **35.6** kNm/m

Saturated backfill — $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **21.1** kNm/m

Water — $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **44.1** kNm/m

Total overturning moment — $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **149** kNm/m

Restoring moments

Wall stem — $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **56.3** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **21.8** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load} =$ **150.5** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead} =$ **228.7** kNm/m

Check bearing pressure

Design vertical live load $M_{live} = W_{live} \times l_{load} =$ **53.8** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{live} =$ **133.4** kNm/m

Total vertical reaction $R = W_{total} =$ **140.2** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **951** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) =$ **199** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **92.5** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **29.4** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor	γ_{f_d} = **1.4**
Live load factor	γ_{f_l} = **1.6**
Earth and water pressure factor	γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem	$w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m
Wall base	$w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **26.6** kN/m
Applied vertical load	$W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **138** kN/m
Total vertical load	$W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **201.3** kN/m

Factored horizontal at-rest forces on wall

Surcharge	$F_{sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times h_{eff}$ = **38.2** kN/m
Moist backfill above water table	$F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **8.2** kN/m
Moist backfill below water table	$F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **46.8** kN/m
Saturated backfill	$F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **41.6** kN/m
Water	$F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **61.8** kN/m
Total horizontal load	$F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **196.7** kN/m

Calculate propping force

Passive resistance of soil in front of wall	$F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m
Propping force	$F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$ F_{prop_f} = **136.3** kN/m

Factored overturning moments

Surcharge	$M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m
Moist backfill above water table	$M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **27.5** kNm/m
Moist backfill below water table	$M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **70.3** kNm/m
Saturated backfill	$M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **41.6** kNm/m
Water	$M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **61.8** kNm/m
Total overturning moment	$M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **278.6** kNm/m

Restoring moments

Wall stem	$M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **78.8** kNm/m
Wall base	$M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **30.6** kNm/m
Design vertical load	$M_{v\_f} = W_{v\_f} \times l_{load}$ = **296.7** kNm/m
Total restoring moment	$M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **406.1** kNm/m

Factored bearing pressure

Total moment for bearing	$M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **127.6** kNm/m
Total vertical reaction	$R_f = W_{total\_f}$ = **201.3** kN/m
Distance to reaction	$x_{bar\_f} = M_{total\_f} / R_f$ = **634** mm
Eccentricity of reaction	$e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **516** mm

Reaction acts outside middle third of base

Bearing pressure at toe	$p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **211.7** kN/m^2
Bearing pressure at heel	p_{heel_f} = 0 kN/m^2 = **0** kN/m^2
Rate of change of base reaction	rate = $p_{toe\_f} / (3 \times x_{bar\_f})$ = **111.31** kN/m^2/m
Bearing pressure at stem / toe	$p_{stem\_toe\_f} = \max(p_{toe\_f} - (\text{rate} \times l_{toe}), 0 \text{ kN/m}^2)$ = **0** kN/m^2

Bearing pressure at mid stem — $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{0}\ kN/m^2$

Bearing pressure at stem / heel — $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{0}\ kN/m^2$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — $f_{cu} = \mathbf{40}\ N/mm^2$

Characteristic strength of reinforcement — $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in toe — $c_{toe} = \mathbf{75}$ mm

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2 = \mathbf{201.3}$ kN/m

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{23.1}$ kN/m

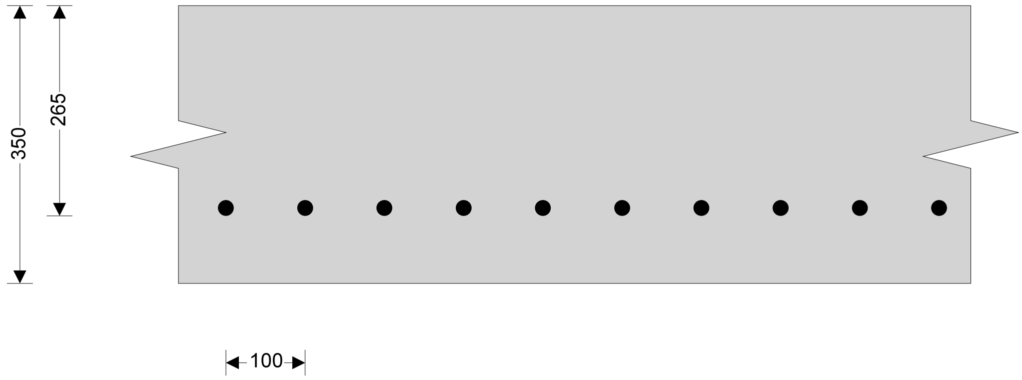
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{178.1}$ kN/m

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2 = \mathbf{305.1}$ kNm/m

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{26.7}$ kNm/m

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{278.4}$ kNm/m



Check toe in bending

Width of toe — b = **1000** mm/m

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{265.0}$ mm

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.099}$

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} = \mathbf{232}$ mm

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{2764}\ mm^2/m$

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455}\ mm^2/m$

Area of tension reinforcement required — $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{2764}\ mm^2/m$

Reinforcement provided — **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov} = \mathbf{3142}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.672}\ N/mm^2$

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}\ N/mm^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **8.2** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **41.4** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **32.5** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **48.2** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **28.9** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

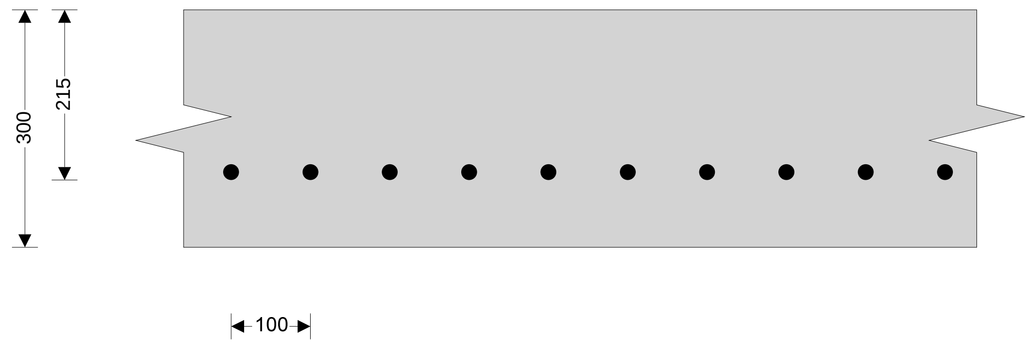
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **26** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **54.8** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **28.7** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **42.6** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **222.9** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.121**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **181** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2834** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{390}$ mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{2834}$ mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov} = \mathbf{3142}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.134}$ N/mm^2

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}$ N/mm^2

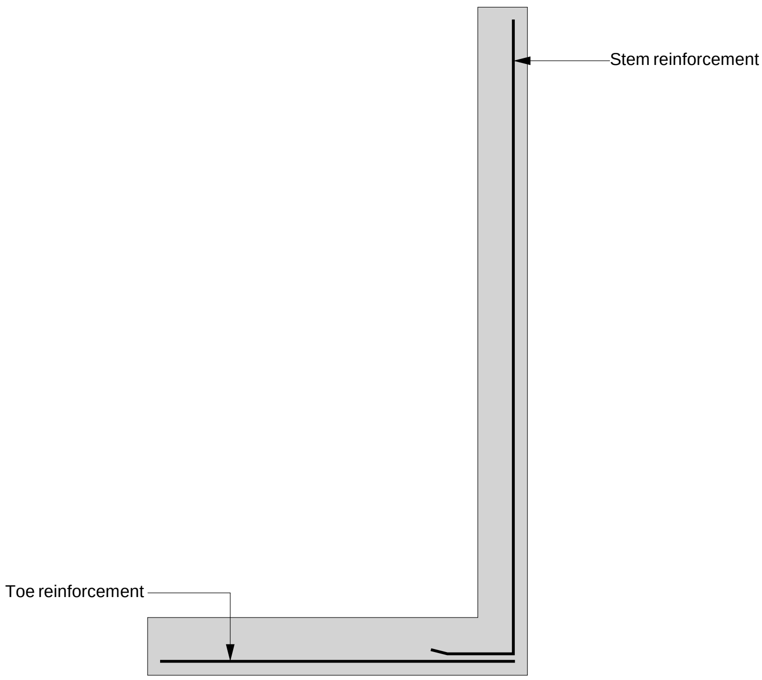
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_stem} = \mathbf{0.980}$ N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

LOAD CASE 2 - RETAINING WALL B (PERMANENT CASE)

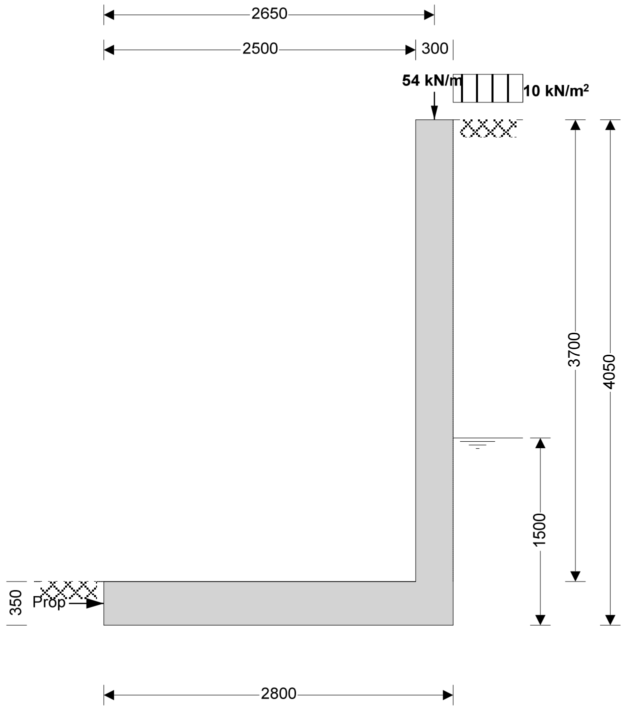
Loading

section B-B										
Ground floor	3.9	1	3.9	g_k		0.63	2.5			
				q_k		1.50			5.9	
Solid wall	9	1	9	g_k		5.00	45.0			
							47.5	kN/m	5.9	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street			Job Ref. 140906	
	Section Retaining walls design			Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **3700** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **2500** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2800** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1900** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm
Height of ground water behind wall	h_{water} = **1500** mm
Height of saturated fill above base	$h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\text{ mm})$ = **1150** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{}(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

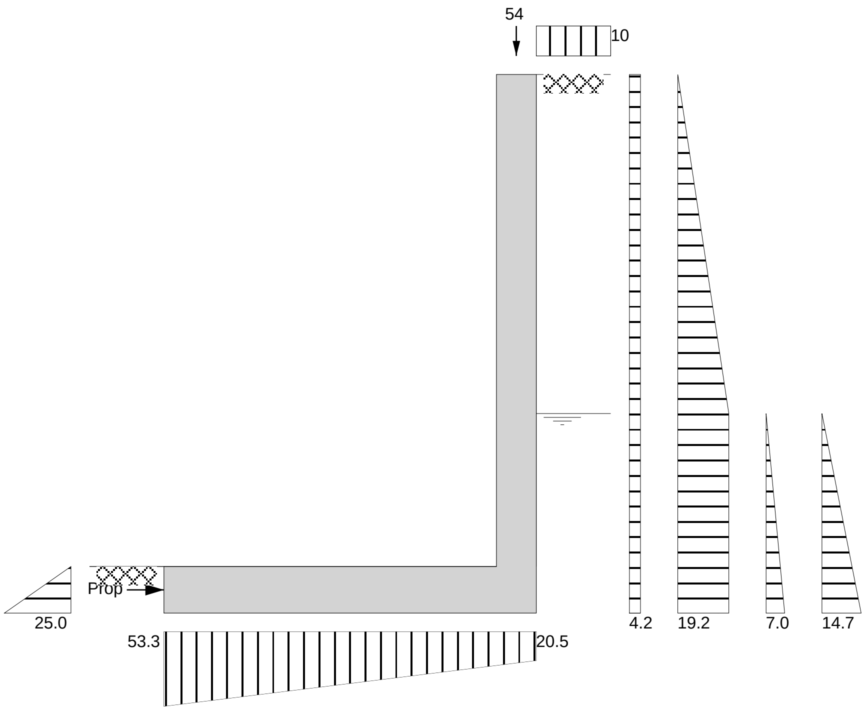
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{}(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **10.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **48.0** kN/m
Applied vertical live load on wall	W_{live} = **6.0** kN/m
Position of applied vertical load on wall	l_{load} = **2650** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem	$w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m
Wall base	$w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.1** kN/m
Applied vertical load	$W_v = W_{dead} + W_{live}$ = **54** kN/m
Total vertical load	$W_{total} = w_{wall} + w_{base} + W_v$ = **103.3** kN/m

Horizontal forces on wall

Surcharge	$F_{sur} = K_a \times Surcharge \times h_{eff}$ = **16.9** kN/m
Moist backfill above water table	$F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **24.5** kN/m
Moist backfill below water table	$F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **28.8** kN/m
Saturated backfill	$F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **5.3** kN/m
Water	$F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **11** kN/m
Total horizontal load	$F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **86.6** kN/m

Calculate propping force

Passive resistance of soil in front of wall	$F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m
Propping force	$F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0$ kN/m)
	F_{prop} = **49.4** kN/m

Overturning moments

Surcharge	$M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m
Moist backfill above water table	$M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **57.6** kNm/m
Moist backfill below water table	$M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **21.6** kNm/m
Saturated backfill	$M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **2.6** kNm/m
Water	$M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.5** kNm/m
Total overturning moment	$M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **121.6** kNm/m

Restoring moments

Wall stem	$M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **69.4** kNm/m
Wall base	$M_{base} = w_{base} \times l_{base} / 2$ = **32.4** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load}$ = **127.2** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{dead}$ = **229** kNm/m

Check bearing pressure

Design vertical live load	$M_{live} = W_{live} \times l_{load}$ = **15.9** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{live}$ = **123.3** kNm/m
Total vertical reaction	$R = W_{total}$ = **103.3** kN/m
Distance to reaction	$x_{bar} = M_{total} / R$ = **1193** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar})$ = **207** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **53.3** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2)$ = **20.5** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **32.4** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **76.8** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **145.9** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **48.3** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **56.9** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **10.4** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **15.5** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **169.3** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **117.3** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **113.6** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **42.7** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.2** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **7.7** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **246.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **97.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **45.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **203.5** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **346** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **99.4** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **145.9** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **682** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **718** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **142.7** kN/m²

Bearing pressure at heel $p_{heel\_f} = 0 \text{ kN/m}^2$ = **0** kN/m²

Rate of change of base reaction $rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **69.77** kN/m²/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0 \text{ kN/m}^2)$ = **0** kN/m²

Bearing pressure at mid stem — $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0\ \text{kN/m}^2) = \mathbf{0}\ \text{kN/m}^2$

Bearing pressure at stem / heel — $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\ \text{kN/m}^2) = \mathbf{0}\ \text{kN/m}^2$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — $f_{cu} = \mathbf{40}\ \text{N/mm}^2$

Characteristic strength of reinforcement — $f_y = \mathbf{500}\ \text{N/mm}^2$

Base details

Minimum area of reinforcement — $k = \mathbf{0.13}\ \%$

Cover to reinforcement in toe — $c_{toe} = \mathbf{75}\ \text{mm}$

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2 = \mathbf{145.9}\ \text{kN/m}$

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{28.9}\ \text{kN/m}$

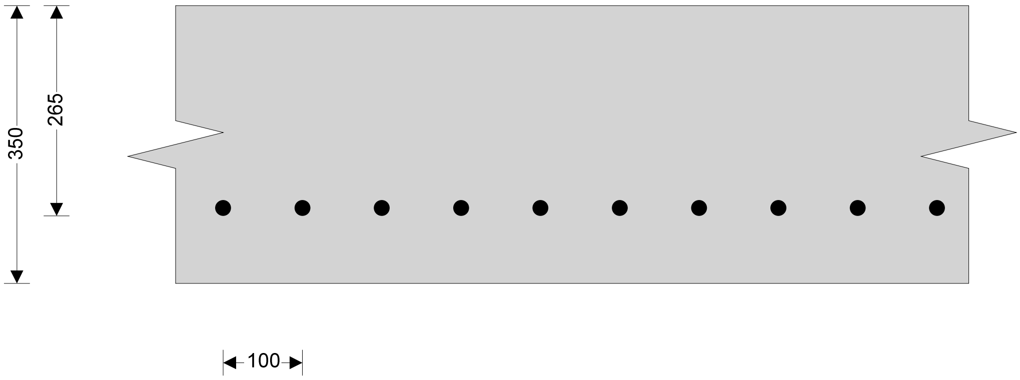
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{116.9}\ \text{kN/m}$

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2 = \mathbf{287.1}\ \text{kNm/m}$

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{40.6}\ \text{kNm/m}$

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{246.5}\ \text{kNm/m}$



Check toe in bending

Width of toe — $b = \mathbf{1000}\ \text{mm/m}$

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{265.0}\ \text{mm}$

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.088}$

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} = \mathbf{236}\ \text{mm}$

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{2401}\ \text{mm}^2\text{/m}$

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455}\ \text{mm}^2\text{/m}$

Area of tension reinforcement required — $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{2401}\ \text{mm}^2\text{/m}$

Reinforcement provided — **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov} = \mathbf{3142}\ \text{mm}^2\text{/m}$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.441}\ \text{N/mm}^2$

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \text{N/mm}^2)}, 5) \times 1\ \text{N/mm}^2 = \mathbf{5.000}\ \text{N/mm}^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

v_{toe} < v_{c_toe} - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **48.3** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **43.6** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **6.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **9.1** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **24.7**
kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

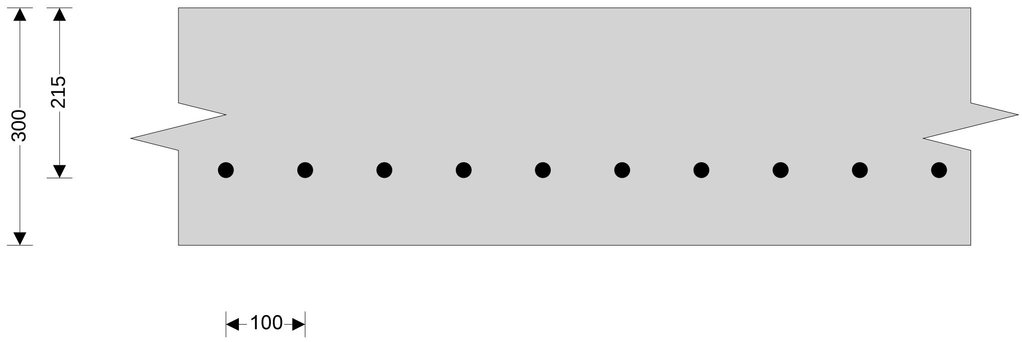
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **105.2** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **25.1** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **2.3** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **3.5** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **206.8** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.112**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **184** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2587** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **2587** mm²/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov}$ = **3142** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.115** N/mm²

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2$ = **5.000** N/mm²

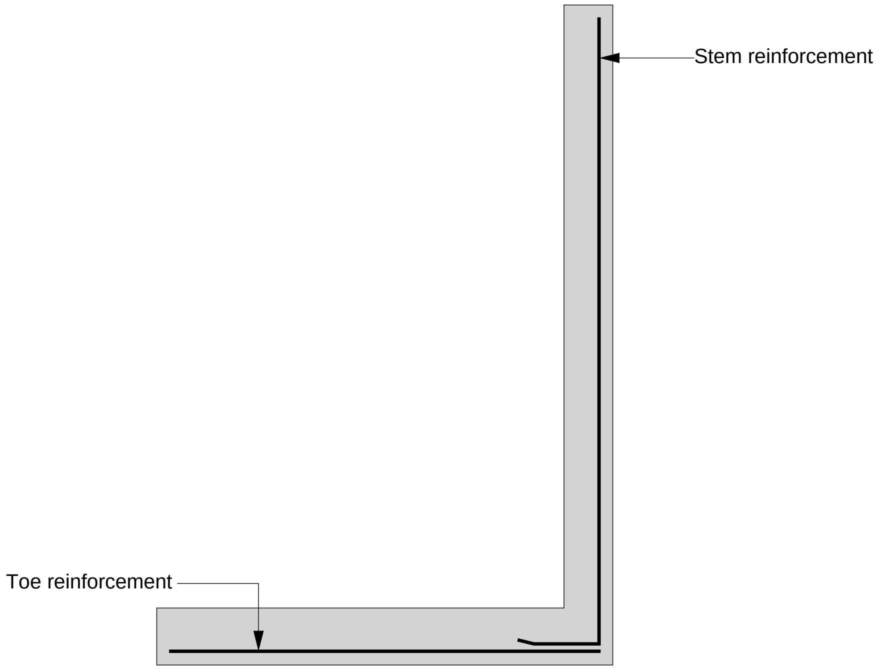
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_stem} = **0.980** N/mm²

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)
Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

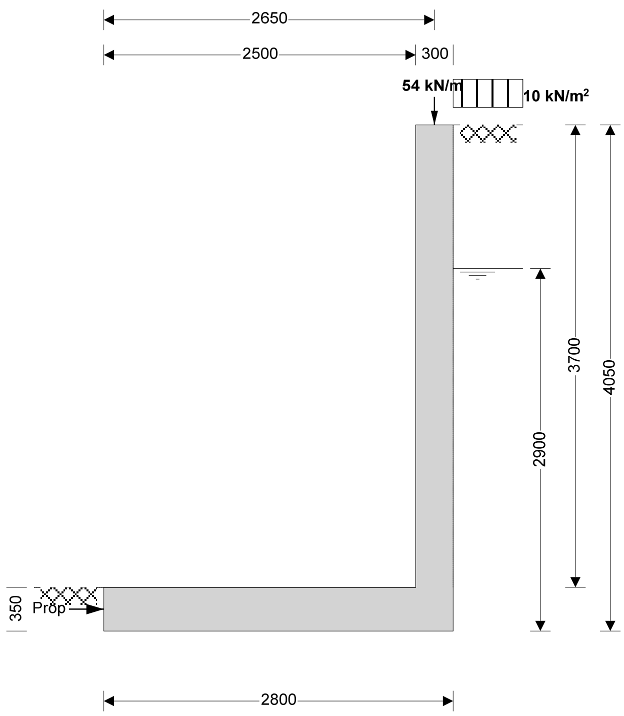
LOAD CASE 2 - RETAINING WALL B DESIGN (WATER TABLE HIGHER)

Loading

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m²			kN/m²	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			
				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type — **Cantilever propped at base**

Height of retaining wall stem — h_{stem} = **3700** mm

Thickness of wall stem — t_{wall} = **300** mm

Length of toe — l_{toe} = **2500** mm

Length of heel — l_{heel} = **0** mm

Overall length of base — $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2800** mm

Thickness of base — t_{base} = **350** mm

Depth of downstand d_{ds} = **0** mm
Position of downstand l_{ds} = **1900** mm
Thickness of downstand t_{ds} = **350** mm
Height of retaining wall $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall d_{cover} = **0** mm
Depth of unplanned excavation d_{exc} = **0** mm
Height of ground water behind wall h_{water} = **2900** mm
Height of saturated fill above base $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0\ mm)$ = **2550** mm
Density of wall construction γ_{wall} = **23.6** kN/m^3
Density of base construction γ_{base} = **23.6** kN/m^3
Angle of rear face of wall α = **90.0** deg
Angle of soil surface behind wall β = **0.0** deg
Effective height at virtual back of wall $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor M = **1.5**
Moist density of retained material γ_m = **18.0** kN/m^3
Saturated density of retained material γ_s = **21.0** kN/m^3
Design shear strength ϕ' = **24.2** deg
Angle of wall friction δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3
Design shear strength ϕ'_b = **24.2** deg
Design base friction δ_b = **18.6** deg
Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

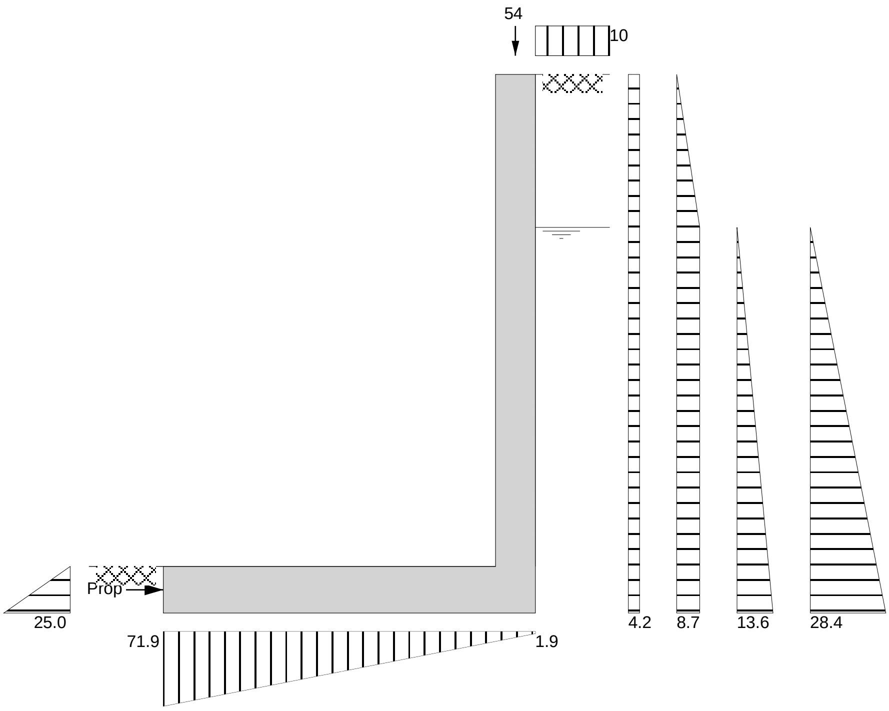
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **10.0** kN/m^2
Applied vertical dead load on wall W_{dead} = **48.0** kN/m
Applied vertical live load on wall W_{live} = **6.0** kN/m
Position of applied vertical load on wall l_{load} = **2650** mm
Applied horizontal dead load on wall F_{dead} = **0.0** kN/m
Applied horizontal live load on wall F_{live} = **0.0** kN/m
Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.1** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **54** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **103.3** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **5** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **25.1** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **19.7** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **41.3** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **108** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **70.9** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **16.4** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **36.4** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **19** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **39.9** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **146** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **69.4** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2 =$ **32.4** kNm/m

Design vertical dead load $M_{dead} = W_{dead} \times l_{load} =$ **127.2** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base} + M_{dead} =$ **229** kNm/m

Check bearing pressure

Design vertical live load $M_{live} = W_{live} \times l_{load} =$ **15.9** kNm/m

Total moment for bearing $M_{total} = M_{rest} - M_{ot} + M_{live} =$ **98.9** kNm/m

Total vertical reaction $R = W_{total} =$ **103.3** kN/m

Distance to reaction $x_{bar} = M_{total} / R =$ **957** mm

Eccentricity of reaction $e = abs((l_{base} / 2) - x_{bar}) =$ **443** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **71.9** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **1.9** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **32.4** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **76.8** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **145.9** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **9.8** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **49.6** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **38.9** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **57.8** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **194.3** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0\ kN/m)$

F_{prop_f} = **142.3** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **32.3** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **71.9** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **37.6** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **55.8** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **275** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **97.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **45.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **203.5** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **346** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **71** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **145.9** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **487** mm

Eccentricity of reaction $e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **913** mm

Reaction acts outside middle third of base

Bearing pressure at toe $p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **199.7** kN/m^2

Bearing pressure at heel $p_{heel\_f} = 0\ kN/m^2$ = **0** kN/m^2

Rate of change of base reaction $rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **136.72** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **0** kN/m^2

Bearing pressure at mid stem $p_{stem\_mid\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2) = \mathbf{0}\ kN/m^2$

Bearing pressure at stem / heel $p_{stem\_heel\_f} = \max(p_{toe\_f} - (\text{rate} \times (l_{toe} + t_{wall})), 0\ kN/m^2) = \mathbf{0}\ kN/m^2$

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete $f_{cu} = \mathbf{40}\ N/mm^2$

Characteristic strength of reinforcement $f_y = \mathbf{500}\ N/mm^2$

Base details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in toe $c_{toe} = \mathbf{75}$ mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} / 2 = \mathbf{145.9}$ kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{28.9}$ kN/m

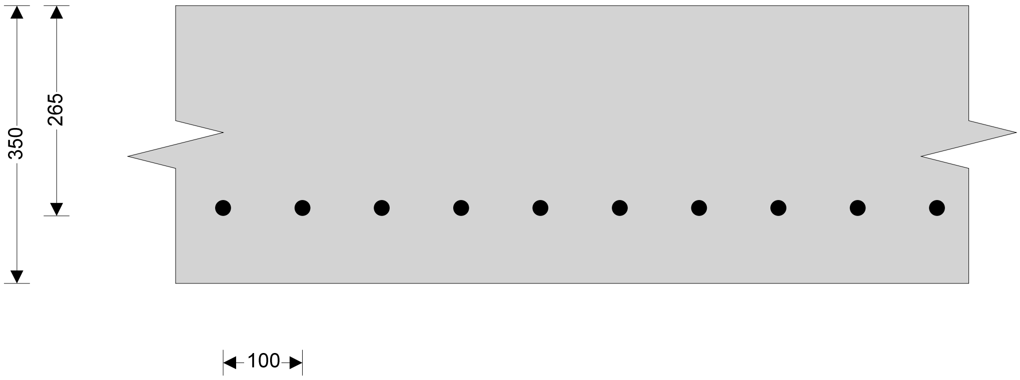
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{116.9}$ kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = 3 \times p_{toe\_f} \times x_{bar\_f} \times (l_{toe} - x_{bar\_f} + t_{wall} / 2) / 2 = \mathbf{315.5}$ kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{40.6}$ kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{274.9}$ kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{265.0}$ mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.098}$

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} = \mathbf{232}$ mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{2723}\ mm^2/m$

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455}\ mm^2/m$

Area of tension reinforcement required $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{2723}\ mm^2/m$

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} = \mathbf{3142}\ mm^2/m$

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.441}\ N/mm^2$

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 = \mathbf{5.000}\ N/mm^2$

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **9.8** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **43.6** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **30.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **44.7** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **20.8** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

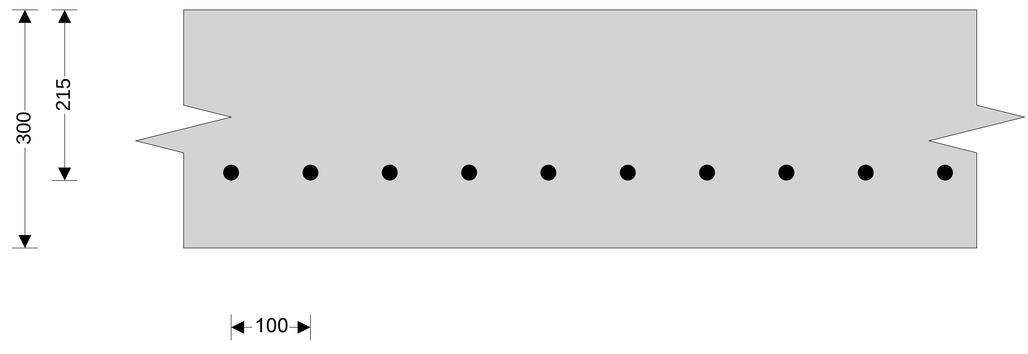
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **30.6** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **55.6** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **25.5** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **38** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **220.4** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.119**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **181** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2796** mm^2/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall} =$ **390** mm²/m

Area of tension reinforcement required — $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min}) =$ **2796** mm²/m

Reinforcement provided — **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_stem\_prov} =$ **3142** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem}) =$ **0.097** N/mm²

Allowable shear stress — $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2 =$ **5.000** N/mm²

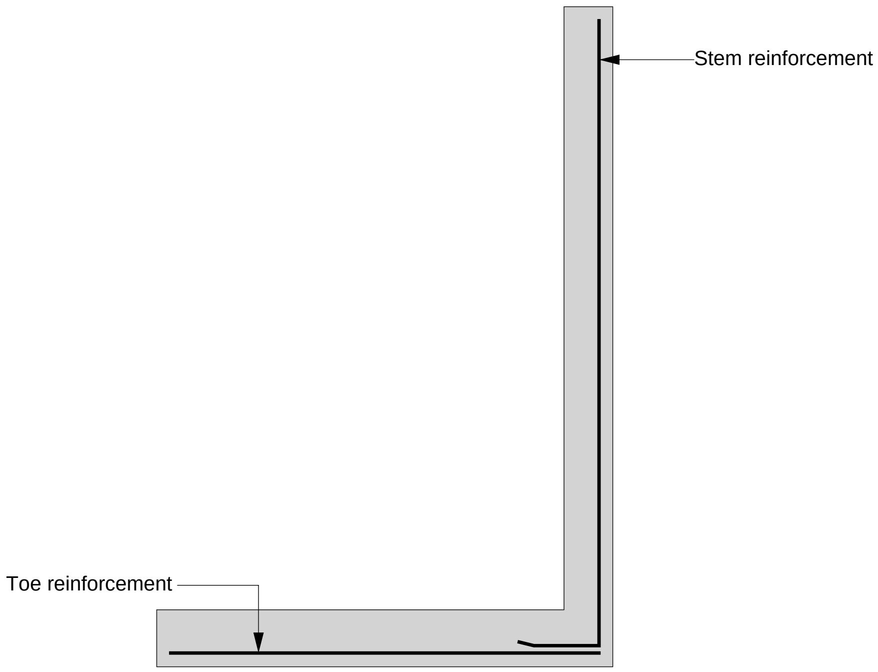
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — $v_{c\_stem} =$ **0.980** N/mm²

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm²/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm²/m)

LOAD CASE 3 - RETAINING WALL A

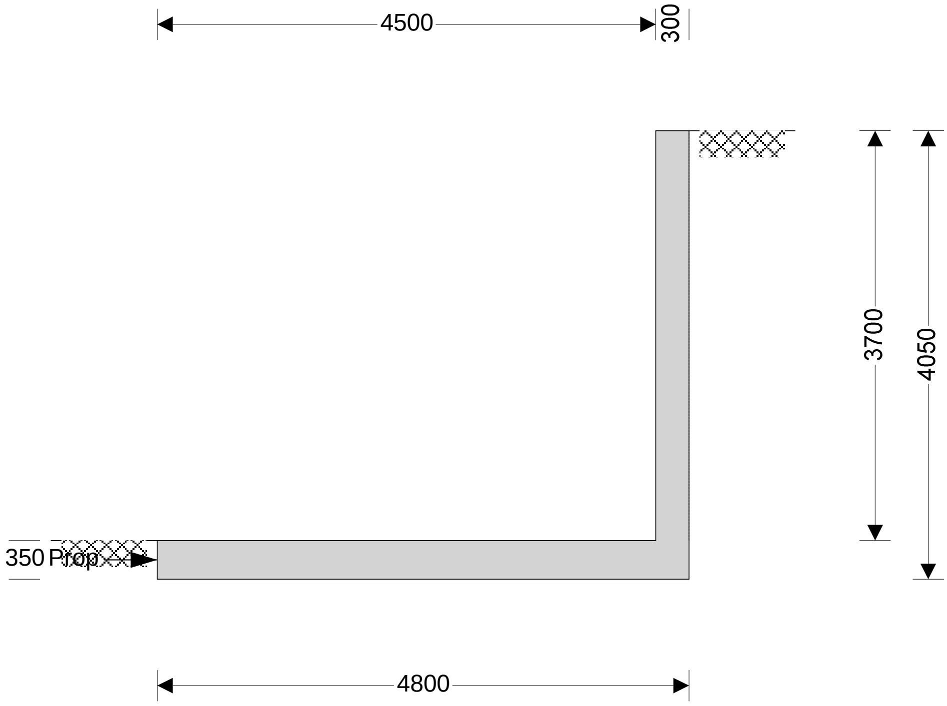
Loading

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m²			kN/m²	Perm., g_k	%	Var., q_k	Total
section A-A										
mansard roof	3.9	1	3.9	g_k		3.48	13.6			

				q_k		0.00			0.0	
3rd/2nd/1st Floor	3.9	1	3.9	g_k	3	0.63	7.4			
				q_k		1.50			17.6	
Ground floor	5	1	5	g_k		0.63	3.2			
				q_k		1.50			7.5	
Solid wall	9	1	9	g_k		5.00	45.0			
							69.1	kN/m	25.1	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type	**Cantilever propped at base**
Height of retaining wall stem	h_{stem} = **3700** mm
Thickness of wall stem	t_{wall} = **300** mm
Length of toe	l_{toe} = **4500** mm
Length of heel	l_{heel} = **0** mm
Overall length of base	$l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **4800** mm
Thickness of base	t_{base} = **350** mm
Depth of downstand	d_{ds} = **0** mm
Position of downstand	l_{ds} = **1900** mm
Thickness of downstand	t_{ds} = **350** mm
Height of retaining wall	$h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm
Depth of cover in front of wall	d_{cover} = **0** mm
Depth of unplanned excavation	d_{exc} = **0** mm

Height of ground water behind wall	h_{water} = **0** mm
Height of saturated fill above base	h_{sat} = max(h_{water} - t_{base} - d_{ds}, 0 mm) = **0** mm
Density of wall construction	γ_{wall} = **23.6** kN/m^3
Density of base construction	γ_{base} = **23.6** kN/m^3
Angle of rear face of wall	α = **90.0** deg
Angle of soil surface behind wall	β = **0.0** deg
Effective height at virtual back of wall	$h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor	M = **1.5**
Moist density of retained material	γ_m = **18.0** kN/m^3
Saturated density of retained material	γ_s = **21.0** kN/m^3
Design shear strength	ϕ' = **24.2** deg
Angle of wall friction	δ = **0.0** deg

Base material details

Moist density	γ_{mb} = **18.0** kN/m^3
Design shear strength	ϕ'_b = **24.2** deg
Design base friction	δ_b = **18.6** deg
Allowable bearing pressure	$P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

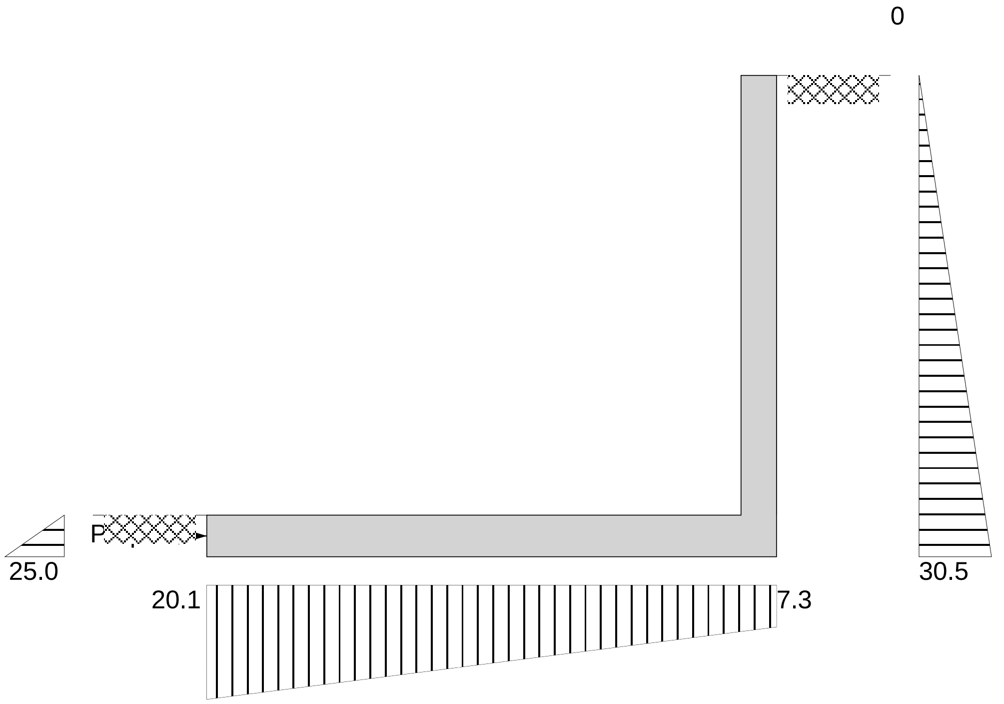
$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material	$K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan	Surcharge = **0.0** kN/m^2
Applied vertical dead load on wall	W_{dead} = **0.0** kN/m
Applied vertical live load on wall	W_{live} = **0.0** kN/m
Position of applied vertical load on wall	l_{load} = **0** mm
Applied horizontal dead load on wall	F_{dead} = **0.0** kN/m
Applied horizontal live load on wall	F_{live} = **0.0** kN/m
Height of applied horizontal load on wall	h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **39.6** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base}$ = **65.8** kN/m

Horizontal forces on wall

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **61.8** kN/m

Total horizontal load $F_{total} = F_{m\_a}$ = **61.8** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **35.2** kN/m

Overturning moments

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **83.4** kNm/m

Total overturning moment $M_{ot} = M_{m\_a}$ = **83.4** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **121.8** kNm/m

Wall base $M_{base} = w_{base} \times l_{base} / 2$ = **95.2** kNm/m

Total restoring moment $M_{rest} = M_{wall} + M_{base}$ = **217** kNm/m

Check bearing pressure

Total moment for bearing $M_{total} = M_{rest} - M_{ot}$ = **133.6** kNm/m

Total vertical reaction $R = W_{total}$ = **65.8** kN/m

Distance to reaction $x_{bar} = M_{total} / R$ = **2028** mm

Eccentricity of reaction $e = \text{abs}((l_{base} / 2) - x_{bar})$ = **372** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe} = (R / l_{base}) + (6 \times R \times e / l_{base}^2)$ = **20.1** kN/m^2

Bearing pressure at heel $p_{heel} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) = \mathbf{7.3}\ kN/m^2$

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor	γ_{f_d} = **1.4**
Live load factor	γ_{f_l} = **1.6**
Earth and water pressure factor	γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem	$w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m
Wall base	$w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **55.5** kN/m
Total vertical load	$W_{total\_f} = w_{wall\_f} + w_{base\_f}$ = **92.2** kN/m

Factored horizontal at-rest forces on wall

Moist backfill above water table	$F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **122** kN/m
Total horizontal load	$F_{total\_f} = F_{m\_a\_f}$ = **122** kN/m

Calculate propping force

Passive resistance of soil in front of wall	$F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m
Propping force	$F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f}) \times \tan(\delta_b), 0\ kN/m)$ F_{prop_f} = **84.8** kN/m

Factored overturning moments

Moist backfill above water table	$M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **164.6** kNm/m
Total overturning moment	$M_{ot\_f} = M_{m\_a\_f}$ = **164.6** kNm/m

Restoring moments

Wall stem	$M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **170.5** kNm/m
Wall base	$M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **133.2** kNm/m
Total restoring moment	$M_{rest\_f} = M_{wall\_f} + M_{base\_f}$ = **303.8** kNm/m

Factored bearing pressure

Total moment for bearing	$M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **139.1** kNm/m
Total vertical reaction	$R_f = W_{total\_f}$ = **92.2** kN/m
Distance to reaction	$x_{bar\_f} = M_{total\_f} / R_f$ = **1509** mm
Eccentricity of reaction	$e_f = abs((l_{base} / 2) - x_{bar\_f})$ = **891** mm
	Reaction acts outside middle third of base
Bearing pressure at toe	$p_{toe\_f} = R_f / (1.5 \times x_{bar\_f})$ = **40.7** kN/m^2
Bearing pressure at heel	p_{heel_f} = 0 kN/m^2 = **0** kN/m^2
Rate of change of base reaction	$rate = p_{toe\_f} / (3 \times x_{bar\_f})$ = **8.99** kN/m^2/m
Bearing pressure at stem / toe	$p_{stem\_toe\_f} = \max(p_{toe\_f} - (rate \times l_{toe}), 0\ kN/m^2)$ = **0.2** kN/m^2
Bearing pressure at mid stem	$p_{stem\_mid\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall} / 2)), 0\ kN/m^2)$ = **0** kN/m^2
Bearing pressure at stem / heel	$p_{stem\_heel\_f} = \max(p_{toe\_f} - (rate \times (l_{toe} + t_{wall})), 0\ kN/m^2)$ = **0** kN/m^2

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete	f_{cu} = **40** N/mm^2
Characteristic strength of reinforcement	f_y = **500** N/mm^2

Base details

Minimum area of reinforcement	k = **0.13** %
Cover to reinforcement in toe	c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 =$ **92.2** kN/m

Shear from weight of base $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} =$ **52** kN/m

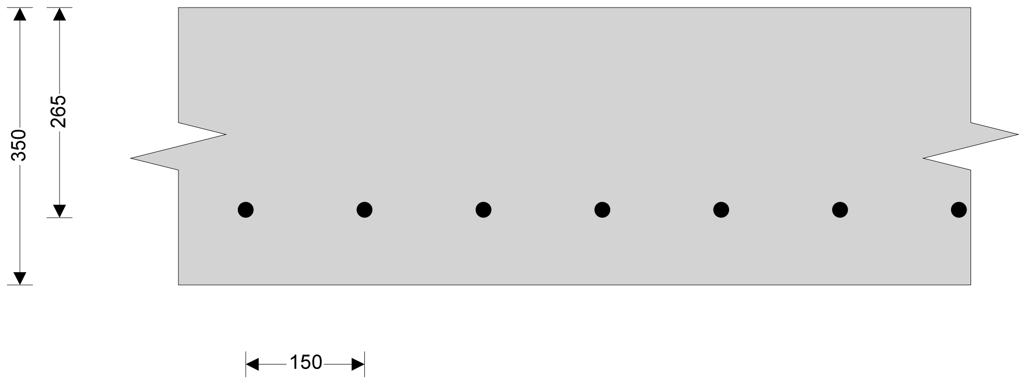
Total shear for toe design $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} =$ **40.1** kN/m

Calculate moment for toe design

Moment from bearing pressure $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 =$ **293.5** kNm/m

Moment from weight of base $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) =$ **125** kNm/m

Total moment for toe design $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} =$ **168.5** kNm/m



Check toe in bending

Width of toe b = **1000** mm/m

Depth of reinforcement $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) =$ **265.0** mm

Constant $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) =$ **0.060**

Compression reinforcement is not required

Lever arm $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

$z_{toe} =$ **246** mm

Area of tension reinforcement required $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) =$ **1575** mm²/m

Minimum area of tension reinforcement $A_{s\_toe\_min} = k \times b \times t_{base} =$ **455** mm²/m

Area of tension reinforcement required $A_{s\_toe\_req} = \text{Max}(A_{s\_toe\_des}, A_{s\_toe\_min}) =$ **1575** mm²/m

Reinforcement provided **20 mm dia.bars @ 150 mm centres**

Area of reinforcement provided $A_{s\_toe\_prov} =$ **2094** mm²/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress $v_{toe} = V_{toe} / (b \times d_{toe}) =$ **0.151** N/mm²

Allowable shear stress $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ N/mm^2)}, 5) \times 1\ N/mm^2 =$ **5.000** N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_toe} =$ **0.758** N/mm²

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

<u>Design of reinforced concrete retaining wall stem (BS 8002:1994)</u>

Material properties

Characteristic strength of concrete $f_{cu} =$ **40** N/mm²

Characteristic strength of reinforcement $f_y =$ **500** N/mm²

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem — c_{stem} = **75** mm

Cover to reinforcement in wall — c_{wall} = **75** mm

Factored horizontal at-rest forces on stem

Moist backfill above water table — $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **101.8** kN/m

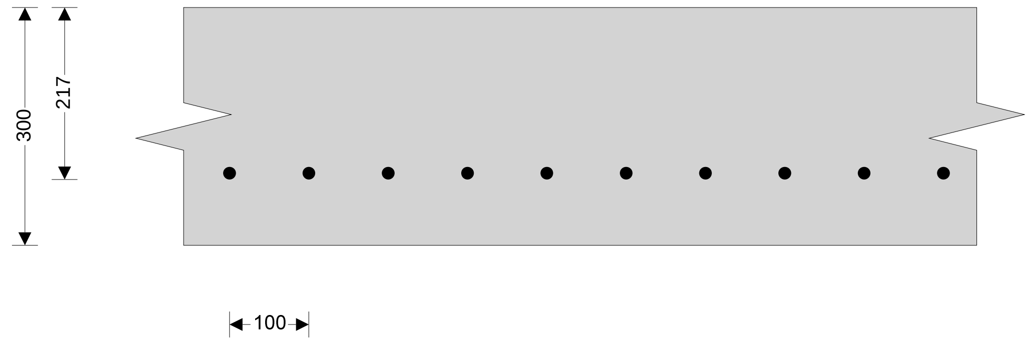
Calculate shear for stem design

Shear at base of stem — $V_{stem} = F_{s\_m\_a\_f} - F_{prop\_f}$ = **17** kN/m

Calculate moment for stem design

Moist backfill above water table — $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **143.3** kNm/m

Total moment for stem design — $M_{stem} = M_{s\_m\_a}$ = **143.3** kNm/m



Check wall stem in bending

Width of wall stem — b = **1000** mm/m

Depth of reinforcement — $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **217.0** mm

Constant — $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.076**

Compression reinforcement is not required

Lever arm — $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))},0.95) \times d_{stem}$

z_{stem} = **197** mm

Area of tension reinforcement required — $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **1675** mm²/m

Minimum area of tension reinforcement — $A_{s\_stem\_min} = k \times b \times t_{wall}$ = **390** mm²/m

Area of tension reinforcement required — $A_{s\_stem\_req} = \text{Max}(A_{s\_stem\_des}, A_{s\_stem\_min})$ = **1675** mm²/m

Reinforcement provided — **16 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_stem\_prov}$ = **2011** mm²/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress — $v_{stem} = V_{stem} / (b \times d_{stem})$ = **0.078** N/mm²

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1\ \text{N/mm}^2)}, 5) \times 1\ \text{N/mm}^2$ = **5.000** N/mm²

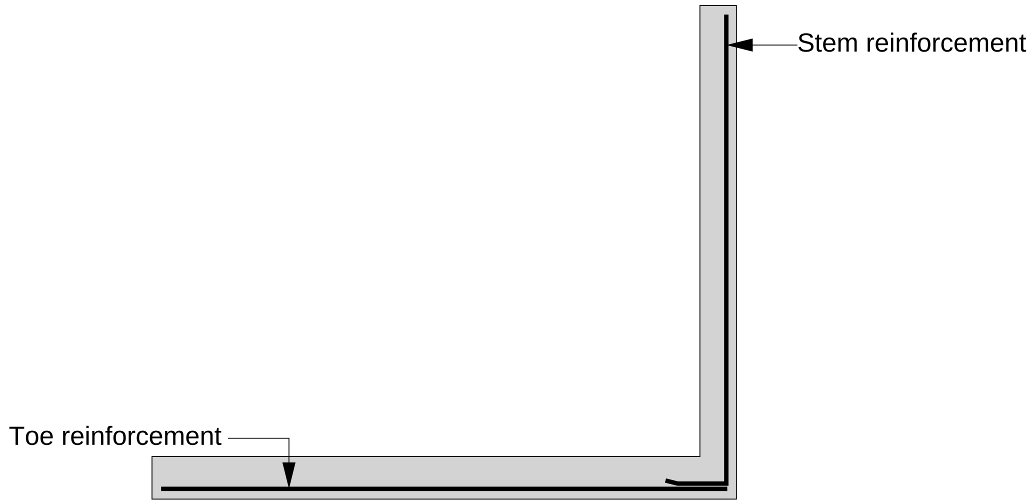
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress — v_{c_stem} = **0.840** N/mm²

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

Indicative retaining wall reinforcement diagram



Toe bars - 20 mm dia.@ 150 mm centres - (2094 mm^2/m)

Stem bars - 16 mm dia.@ 100 mm centres - (2011 mm^2/m)

IT CAN BE SEEN FROM THE CALCULATIONS ABOVE THAT THIS IS NOT THE WORST CASE FOR THE RETAINING WALLS AND FOR PLANNING PURPOSES NO FURTHER DESIGN IS REQUIRED. DURING THE DETAILED DESIGN STAGE THE CALCULATIONS WILL BE CONSIDERED FURTHER.

UPLIFT CHECK ON SLAB

Croft Structural Engineers Rear of 60 Saxon Rd Selhurst SE25 5EH	Project 8-10 Stukeley Street				Job Ref. 140906	
	Section Retaining walls design				Sheet no./rev. 3	
	Calc. by EP	Date 09/08/2016	Chk'd by	Date	App'd by	Date

CROFT STRUCTURAL ENGINEERS Clock Shop Mews Rear of 60 Saxon Road London SE25 5EH T: 020 8684 4744 W: www.croftse.co.uk	Project: 8-10 Stukeley Street		Section	Sheet
	Date: Nov-15	Rev	Date	Description
	By: EP			
	Checked: CT			
	Job No: 140906	Status		Rev

Ref

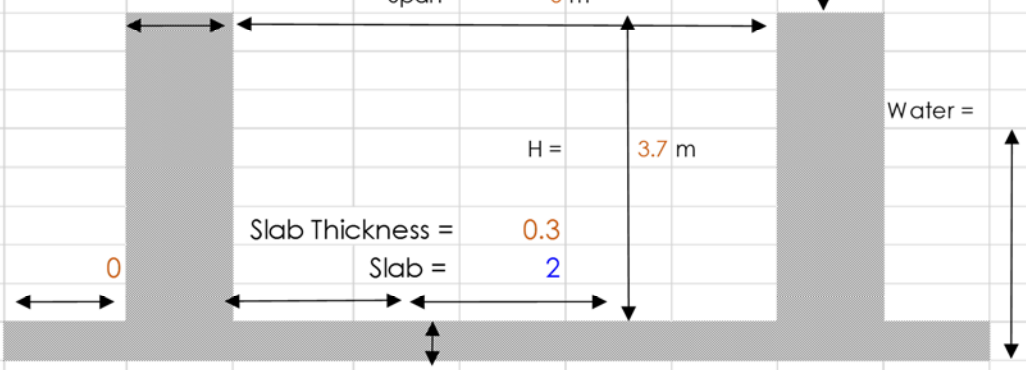
Slab Uplift

Wall DL 54 kN/m — Wall DL 95 kN/m

w= 0.3 m

soil depth above= 0 m

Span= 6 m



Toe = 0.3 m

Toewidth= 2 m — soil unit weight= 18 kN/m^3

Uplift Calc

Total Dead Load =	Slab=	15 kN/m				
	Toe and heel =	34.5 kN/m				
	Wall =	55.5				
	Soil=(	0 +	0) x 2 +	0 =	0	18.2
	Total Dead load =	254 kN/m				
Total Uplift Force=		178.2 kN/m	f.o.s.=	1.43 No Global Uplift		

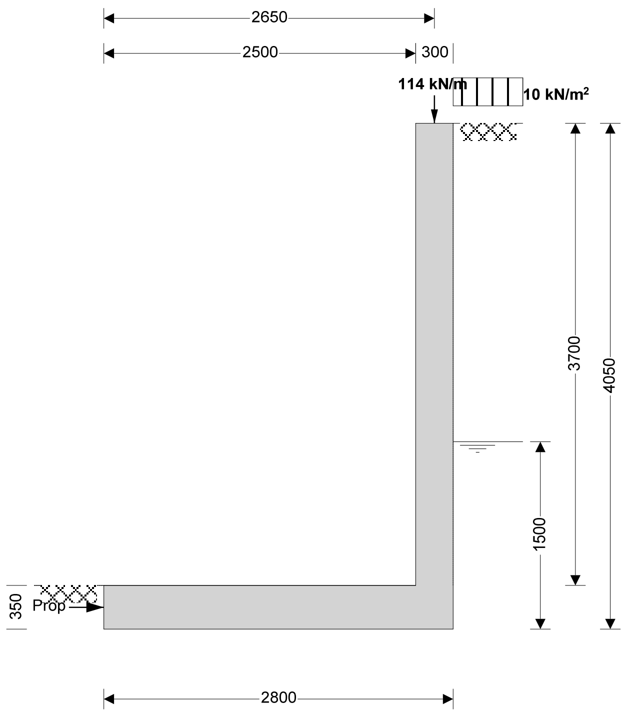
RETAINING WALL DESIGN WITH ADDITIONAL COLUMN LOAD FROM ABOVE

Location	Area			Type	L	Action	Actions, kN or kN/m			
	L	W	m^2			kN/m^2	Perm., g_k	%	Var., q_k	Total

column load										
roof	5.6	0.5	2.8	g_k		1.43	4.0			
				q_k		1.50			4.2	
3rd/2nd/1st/ground	5.6	0.5	2.8	g_k	4	0.63	7.1			
				q_k		1.50			16.8	
solid wall	4	1	4	g_k		5.00	20.0			
stud wall	10	1	10	g_k		0.52	5.2			
							36.3	kN/m	21.0	kN/m

RETAINING WALL ANALYSIS (BS 8002:1994)

TEDDS calculation version 1.2.01.06



Wall details

Retaining wall type **Cantilever propped at base**

Height of retaining wall stem h_{stem} = **3700** mm

Thickness of wall stem t_{wall} = **300** mm

Length of toe l_{toe} = **2500** mm

Length of heel l_{heel} = **0** mm

Overall length of base $l_{base} = l_{toe} + l_{heel} + t_{wall}$ = **2800** mm

Thickness of base t_{base} = **350** mm

Depth of downstand d_{ds} = **0** mm

Position of downstand l_{ds} = **1900** mm

Thickness of downstand t_{ds} = **350** mm

Height of retaining wall $h_{wall} = h_{stem} + t_{base} + d_{ds}$ = **4050** mm

Depth of cover in front of wall d_{cover} = **0** mm

Depth of unplanned excavation d_{exc} = **0** mm

Height of ground water behind wall h_{water} = **1500** mm

Height of saturated fill above base $h_{sat} = \max(h_{water} - t_{base} - d_{ds}, 0 \text{ mm})$ = **1150** mm

Density of wall construction γ_{wall} = **23.6** kN/m^3

Density of base construction γ_{base} = **23.6** kN/m^3

Angle of rear face of wall α = **90.0** deg

Angle of soil surface behind wall β = **0.0** deg

Effective height at virtual back of wall $h_{eff} = h_{wall} + l_{heel} \times \tan(\beta)$ = **4050** mm

Retained material details

Mobilisation factor M = **1.5**

Moist density of retained material γ_m = **18.0** kN/m^3

Saturated density of retained material γ_s = **21.0** kN/m^3

Design shear strength ϕ' = **24.2** deg

Angle of wall friction δ = **0.0** deg

Base material details

Moist density γ_{mb} = **18.0** kN/m^3

Design shear strength ϕ'_b = **24.2** deg

Design base friction δ_b = **18.6** deg

Allowable bearing pressure $P_{bearing}$ = **100** kN/m^2

Using Coulomb theory

Active pressure coefficient for retained material

$$K_a = \sin(\alpha + \phi')^2 / (\sin(\alpha)^2 \times \sin(\alpha - \delta) \times [1 + \sqrt{(\sin(\phi' + \delta) \times \sin(\phi' - \beta) / (\sin(\alpha - \delta) \times \sin(\alpha + \beta)))}]^2) = \mathbf{0.419}$$

Passive pressure coefficient for base material

$$K_p = \sin(90 - \phi'_b)^2 / (\sin(90 - \delta_b) \times [1 - \sqrt{(\sin(\phi'_b + \delta_b) \times \sin(\phi'_b) / (\sin(90 + \delta_b)))}]^2) = \mathbf{4.187}$$

At-rest pressure

At-rest pressure for retained material $K_0 = 1 - \sin(\phi')$ = **0.590**

Loading details

Surcharge load on plan Surcharge = **10.0** kN/m^2

Applied vertical dead load on wall W_{dead} = **84.0** kN/m

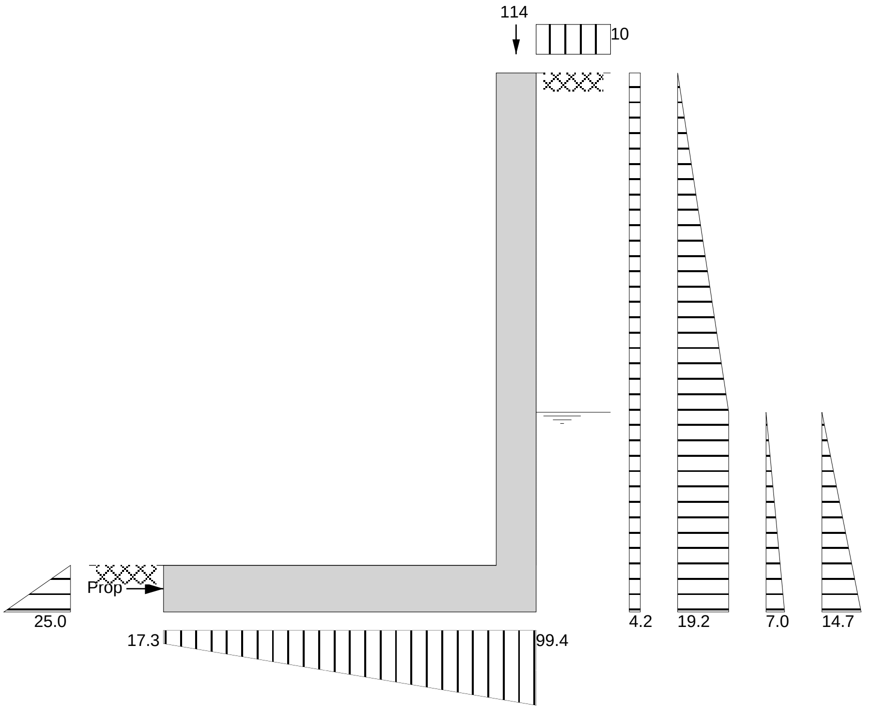
Applied vertical live load on wall W_{live} = **30.0** kN/m

Position of applied vertical load on wall l_{load} = **2650** mm

Applied horizontal dead load on wall F_{dead} = **0.0** kN/m

Applied horizontal live load on wall F_{live} = **0.0** kN/m

Height of applied horizontal load on wall h_{load} = **0** mm



Loads shown in kN/m, pressures shown in kN/m^2

Vertical forces on wall

Wall stem $w_{wall} = h_{stem} \times t_{wall} \times \gamma_{wall}$ = **26.2** kN/m

Wall base $w_{base} = l_{base} \times t_{base} \times \gamma_{base}$ = **23.1** kN/m

Applied vertical load $W_v = W_{dead} + W_{live}$ = **114** kN/m

Total vertical load $W_{total} = w_{wall} + w_{base} + W_v$ = **163.3** kN/m

Horizontal forces on wall

Surcharge $F_{sur} = K_a \times \text{Surcharge} \times h_{eff}$ = **16.9** kN/m

Moist backfill above water table $F_{m\_a} = 0.5 \times K_a \times \gamma_m \times (h_{eff} - h_{water})^2$ = **24.5** kN/m

Moist backfill below water table $F_{m\_b} = K_a \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **28.8** kN/m

Saturated backfill $F_s = 0.5 \times K_a \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **5.3** kN/m

Water $F_{water} = 0.5 \times h_{water}^2 \times \gamma_{water}$ = **11** kN/m

Total horizontal load $F_{total} = F_{sur} + F_{m\_a} + F_{m\_b} + F_s + F_{water}$ = **86.6** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_p = 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **4.4** kN/m

Propping force $F_{prop} = \max(F_{total} - F_p - (W_{total} - W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop} = **37.3** kN/m

Overturning moments

Surcharge $M_{sur} = F_{sur} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **34.3** kNm/m

Moist backfill above water table $M_{m\_a} = F_{m\_a} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **57.6** kNm/m

Moist backfill below water table $M_{m\_b} = F_{m\_b} \times (h_{water} - 2 \times d_{ds}) / 2$ = **21.6** kNm/m

Saturated backfill $M_s = F_s \times (h_{water} - 3 \times d_{ds}) / 3$ = **2.6** kNm/m

Water $M_{water} = F_{water} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.5** kNm/m

Total overturning moment $M_{ot} = M_{sur} + M_{m\_a} + M_{m\_b} + M_s + M_{water}$ = **121.6** kNm/m

Restoring moments

Wall stem $M_{wall} = w_{wall} \times (l_{toe} + t_{wall} / 2)$ = **69.4** kNm/m

Wall base	$M_{base} = w_{base} \times l_{base} / 2 =$ **32.4** kNm/m
Design vertical dead load	$M_{dead} = W_{dead} \times l_{load} =$ **222.6** kNm/m
Total restoring moment	$M_{rest} = M_{wall} + M_{base} + M_{dead} =$ **324.4** kNm/m

Check bearing pressure

Design vertical live load	$M_{live} = W_{live} \times l_{load} =$ **79.5** kNm/m
Total moment for bearing	$M_{total} = M_{rest} - M_{ot} + M_{live} =$ **282.3** kNm/m
Total vertical reaction	$R = W_{total} =$ **163.3** kN/m
Distance to reaction	$x_{bar} = M_{total} / R =$ **1728** mm
Eccentricity of reaction	$e = abs((l_{base} / 2) - x_{bar}) =$ **328** mm

Reaction acts within middle third of base

Bearing pressure at toe	$p_{toe} = (R / l_{base}) - (6 \times R \times e / l_{base}^2) =$ **17.3** kN/m^2
Bearing pressure at heel	$p_{heel} = (R / l_{base}) + (6 \times R \times e / l_{base}^2) =$ **99.4** kN/m^2

PASS - Maximum bearing pressure is less than allowable bearing pressure

RETAINING WALL DESIGN (BS 8002:1994)

TEDDS calculation version 1.2.01.06

Ultimate limit state load factors

Dead load factor γ_{f_d} = **1.4**

Live load factor γ_{f_l} = **1.6**

Earth and water pressure factor γ_{f_e} = **1.4**

Factored vertical forces on wall

Wall stem $w_{wall\_f} = \gamma_{f\_d} \times h_{stem} \times t_{wall} \times \gamma_{wall}$ = **36.7** kN/m

Wall base $w_{base\_f} = \gamma_{f\_d} \times l_{base} \times t_{base} \times \gamma_{base}$ = **32.4** kN/m

Applied vertical load $W_{v\_f} = \gamma_{f\_d} \times W_{dead} + \gamma_{f\_l} \times W_{live}$ = **165.6** kN/m

Total vertical load $W_{total\_f} = w_{wall\_f} + w_{base\_f} + W_{v\_f}$ = **234.7** kN/m

Factored horizontal at-rest forces on wall

Surcharge $F_{sur\_f} = \gamma_{f\_l} \times K_0 \times Surcharge \times h_{eff}$ = **38.2** kN/m

Moist backfill above water table $F_{m\_a\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times \gamma_m \times (h_{eff} - h_{water})^2$ = **48.3** kN/m

Moist backfill below water table $F_{m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - h_{water}) \times h_{water}$ = **56.9** kN/m

Saturated backfill $F_{s\_f} = \gamma_{f\_e} \times 0.5 \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{water}^2$ = **10.4** kN/m

Water $F_{water\_f} = \gamma_{f\_e} \times 0.5 \times h_{water}^2 \times \gamma_{water}$ = **15.5** kN/m

Total horizontal load $F_{total\_f} = F_{sur\_f} + F_{m\_a\_f} + F_{m\_b\_f} + F_{s\_f} + F_{water\_f}$ = **169.3** kN/m

Calculate propping force

Passive resistance of soil in front of wall $F_{p\_f} = \gamma_{f\_e} \times 0.5 \times K_p \times \cos(\delta_b) \times (d_{cover} + t_{base} + d_{ds} - d_{exc})^2 \times \gamma_{mb}$ = **6.1** kN/m

Propping force $F_{prop\_f} = \max(F_{total\_f} - F_{p\_f} - (W_{total\_f} - \gamma_{f\_l} \times W_{live}) \times \tan(\delta_b), 0 \text{ kN/m})$

F_{prop_f} = **100.4** kN/m

Factored overturning moments

Surcharge $M_{sur\_f} = F_{sur\_f} \times (h_{eff} - 2 \times d_{ds}) / 2$ = **77.4** kNm/m

Moist backfill above water table $M_{m\_a\_f} = F_{m\_a\_f} \times (h_{eff} + 2 \times h_{water} - 3 \times d_{ds}) / 3$ = **113.6** kNm/m

Moist backfill below water table $M_{m\_b\_f} = F_{m\_b\_f} \times (h_{water} - 2 \times d_{ds}) / 2$ = **42.7** kNm/m

Saturated backfill $M_{s\_f} = F_{s\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **5.2** kNm/m

Water $M_{water\_f} = F_{water\_f} \times (h_{water} - 3 \times d_{ds}) / 3$ = **7.7** kNm/m

Total overturning moment $M_{ot\_f} = M_{sur\_f} + M_{m\_a\_f} + M_{m\_b\_f} + M_{s\_f} + M_{water\_f}$ = **246.6** kNm/m

Restoring moments

Wall stem $M_{wall\_f} = w_{wall\_f} \times (l_{toe} + t_{wall} / 2)$ = **97.2** kNm/m

Wall base $M_{base\_f} = w_{base\_f} \times l_{base} / 2$ = **45.3** kNm/m

Design vertical load $M_{v\_f} = W_{v\_f} \times l_{load}$ = **438.8** kNm/m

Total restoring moment $M_{rest\_f} = M_{wall\_f} + M_{base\_f} + M_{v\_f}$ = **581.4** kNm/m

Factored bearing pressure

Total moment for bearing $M_{total\_f} = M_{rest\_f} - M_{ot\_f}$ = **334.7** kNm/m

Total vertical reaction $R_f = W_{total\_f}$ = **234.7** kN/m

Distance to reaction $x_{bar\_f} = M_{total\_f} / R_f$ = **1426** mm

Eccentricity of reaction $e_f = \text{abs}((l_{base} / 2) - x_{bar\_f})$ = **26** mm

Reaction acts within middle third of base

Bearing pressure at toe $p_{toe\_f} = (R_f / l_{base}) - (6 \times R_f \times e_f / l_{base}^2)$ = **79** kN/m^2

Bearing pressure at heel $p_{heel\_f} = (R_f / l_{base}) + (6 \times R_f \times e_f / l_{base}^2)$ = **88.6** kN/m^2

Rate of change of base reaction $rate = (p_{toe\_f} - p_{heel\_f}) / l_{base}$ = **-3.40** kN/m^2/m

Bearing pressure at stem / toe $p_{stem\_toe\_f} = \max(p_{heel\_f} + (rate \times (l_{heel} + t_{wall})), 0 \text{ kN/m}^2)$ = **87.5** kN/m^2

Bearing pressure at mid stem — $p_{stem\_mid\_f} = \max(p_{heel\_f} + (rate \times (l_{heel} + t_{wall} / 2)), 0 \text{ kN/m}^2) = \mathbf{88.1}$ kN/m²

Bearing pressure at stem / heel — $p_{stem\_heel\_f} = \max(p_{heel\_f} + (rate \times l_{heel}), 0 \text{ kN/m}^2) = \mathbf{88.6}$ kN/m²

Design of reinforced concrete retaining wall toe (BS 8002:1994)

Material properties

Characteristic strength of concrete — f_{cu} = **40** N/mm²

Characteristic strength of reinforcement — f_y = **500** N/mm²

Base details

Minimum area of reinforcement — k = **0.13** %

Cover to reinforcement in toe — c_{toe} = **75** mm

Calculate shear for toe design

Shear from bearing pressure — $V_{toe\_bear} = (p_{toe\_f} + p_{stem\_toe\_f}) \times l_{toe} / 2 = \mathbf{208.2}$ kN/m

Shear from weight of base — $V_{toe\_wt\_base} = \gamma_{f\_d} \times \gamma_{base} \times l_{toe} \times t_{base} = \mathbf{28.9}$ kN/m

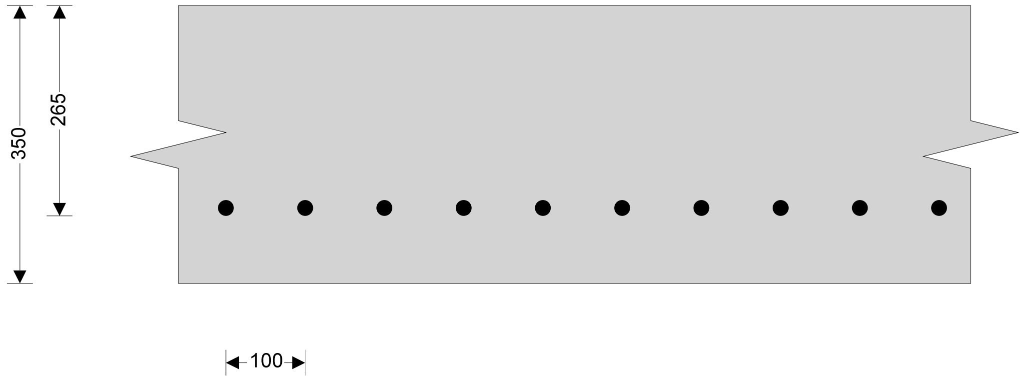
Total shear for toe design — $V_{toe} = V_{toe\_bear} - V_{toe\_wt\_base} = \mathbf{179.3}$ kN/m

Calculate moment for toe design

Moment from bearing pressure — $M_{toe\_bear} = (2 \times p_{toe\_f} + p_{stem\_mid\_f}) \times (l_{toe} + t_{wall} / 2)^2 / 6 = \mathbf{288.1}$ kNm/m

Moment from weight of base — $M_{toe\_wt\_base} = (\gamma_{f\_d} \times \gamma_{base} \times t_{base} \times (l_{toe} + t_{wall} / 2)^2 / 2) = \mathbf{40.6}$ kNm/m

Total moment for toe design — $M_{toe} = M_{toe\_bear} - M_{toe\_wt\_base} = \mathbf{247.5}$ kNm/m



Check toe in bending

Width of toe — b = **1000** mm/m

Depth of reinforcement — $d_{toe} = t_{base} - c_{toe} - (\phi_{toe} / 2) = \mathbf{265.0}$ mm

Constant — $K_{toe} = M_{toe} / (b \times d_{toe}^2 \times f_{cu}) = \mathbf{0.088}$

Compression reinforcement is not required

Lever arm — $z_{toe} = \min(0.5 + \sqrt{(0.25 - (\min(K_{toe}, 0.225) / 0.9))}, 0.95) \times d_{toe}$

z_{toe} = **236** mm

Area of tension reinforcement required — $A_{s\_toe\_des} = M_{toe} / (0.87 \times f_y \times z_{toe}) = \mathbf{2412}$ mm²/m

Minimum area of tension reinforcement — $A_{s\_toe\_min} = k \times b \times t_{base} = \mathbf{455}$ mm²/m

Area of tension reinforcement required — $A_{s\_toe\_req} = \max(A_{s\_toe\_des}, A_{s\_toe\_min}) = \mathbf{2412}$ mm²/m

Reinforcement provided — **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided — $A_{s\_toe\_prov}$ = **3142** mm²/m

PASS - Reinforcement provided at the retaining wall toe is adequate

Check shear resistance at toe

Design shear stress — $v_{toe} = V_{toe} / (b \times d_{toe}) = \mathbf{0.677}$ N/mm²

Allowable shear stress — $v_{adm} = \min(0.8 \times \sqrt{(f_{cu} / 1 \text{ N/mm}^2)}, 5) \times 1 \text{ N/mm}^2 = \mathbf{5.000}$ N/mm²

PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress v_{c_toe} = **0.867** N/mm^2

$v_{toe} < v_{c\_toe}$ - No shear reinforcement required

Design of reinforced concrete retaining wall stem (BS 8002:1994)

Material properties

Characteristic strength of concrete f_{cu} = **40** N/mm^2

Characteristic strength of reinforcement f_y = **500** N/mm^2

Wall details

Minimum area of reinforcement k = **0.13** %

Cover to reinforcement in stem c_{stem} = **75** mm

Cover to reinforcement in wall c_{wall} = **35** mm

Factored horizontal at-rest forces on stem

Surcharge $F_{s\_sur\_f} = \gamma_{f\_l} \times K_0 \times \text{Surcharge} \times (h_{eff} - t_{base} - d_{ds})$ = **34.9** kN/m

Moist backfill above water table $F_{s\_m\_a\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat})^2$ = **48.3** kN/m

Moist backfill below water table $F_{s\_m\_b\_f} = \gamma_{f\_e} \times K_0 \times \gamma_m \times (h_{eff} - t_{base} - d_{ds} - h_{sat}) \times h_{sat}$ = **43.6** kN/m

Saturated backfill $F_{s\_s\_f} = 0.5 \times \gamma_{f\_e} \times K_0 \times (\gamma_s - \gamma_{water}) \times h_{sat}^2$ = **6.1** kN/m

Water $F_{s\_water\_f} = 0.5 \times \gamma_{f\_e} \times \gamma_{water} \times h_{sat}^2$ = **9.1** kN/m

Calculate shear for stem design

Shear at base of stem $V_{stem} = F_{s\_sur\_f} + F_{s\_m\_a\_f} + F_{s\_m\_b\_f} + F_{s\_s\_f} + F_{s\_water\_f} - F_{prop\_f}$ = **41.7** kN/m

Calculate moment for stem design

Surcharge $M_{s\_sur} = F_{s\_sur\_f} \times (h_{stem} + t_{base}) / 2$ = **70.7** kNm/m

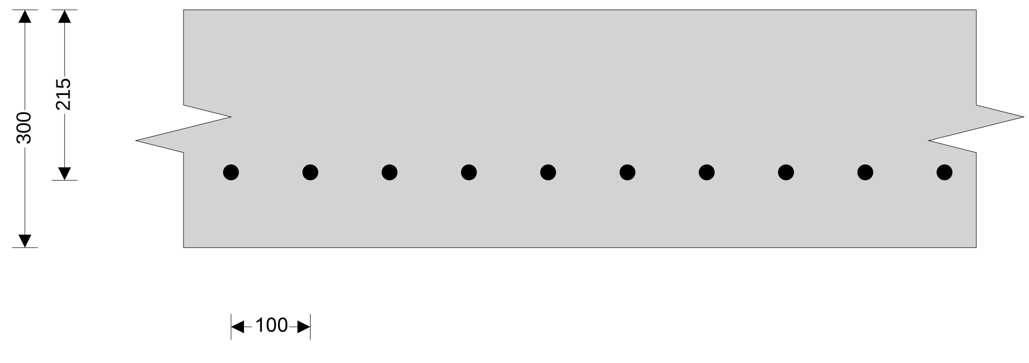
Moist backfill above water table $M_{s\_m\_a} = F_{s\_m\_a\_f} \times (2 \times h_{sat} + h_{eff} - d_{ds} + t_{base} / 2) / 3$ = **105.2** kNm/m

Moist backfill below water table $M_{s\_m\_b} = F_{s\_m\_b\_f} \times h_{sat} / 2$ = **25.1** kNm/m

Saturated backfill $M_{s\_s} = F_{s\_s\_f} \times h_{sat} / 3$ = **2.3** kNm/m

Water $M_{s\_water} = F_{s\_water\_f} \times h_{sat} / 3$ = **3.5** kNm/m

Total moment for stem design $M_{stem} = M_{s\_sur} + M_{s\_m\_a} + M_{s\_m\_b} + M_{s\_s} + M_{s\_water}$ = **206.8** kNm/m



Check wall stem in bending

Width of wall stem b = **1000** mm/m

Depth of reinforcement $d_{stem} = t_{wall} - c_{stem} - (\phi_{stem} / 2)$ = **215.0** mm

Constant $K_{stem} = M_{stem} / (b \times d_{stem}^2 \times f_{cu})$ = **0.112**

Compression reinforcement is not required

Lever arm $z_{stem} = \min(0.5 + \sqrt{(0.25 - (\min(K_{stem}, 0.225) / 0.9))}, 0.95) \times d_{stem}$

z_{stem} = **184** mm

Area of tension reinforcement required $A_{s\_stem\_des} = M_{stem} / (0.87 \times f_y \times z_{stem})$ = **2587** mm^2/m

Minimum area of tension reinforcement $A_{s\_stem\_min} = k \times b \times t_{wall} = \mathbf{390}$ mm^2/m

Area of tension reinforcement required $A_{s\_stem\_req} = Max(A_{s\_stem\_des}, A_{s\_stem\_min}) = \mathbf{2587}$ mm^2/m

Reinforcement provided **20 mm dia.bars @ 100 mm centres**

Area of reinforcement provided $A_{s\_stem\_prov} = \mathbf{3142}$ mm^2/m

PASS - Reinforcement provided at the retaining wall stem is adequate

Check shear resistance at wall stem

Design shear stress $v_{stem} = V_{stem} / (b \times d_{stem}) = \mathbf{0.194}$ N/mm^2

Allowable shear stress $v_{adm} = min(0.8 \times \sqrt{(f_{cu} / 1 N/mm^2)}, 5) \times 1 N/mm^2 = \mathbf{5.000}$ N/mm^2

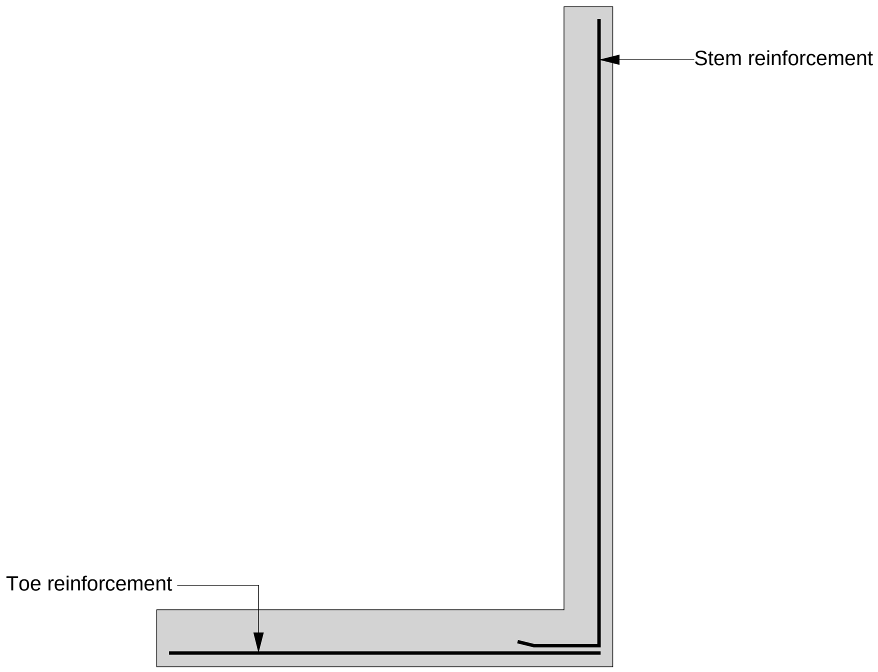
PASS - Design shear stress is less than maximum shear stress

From BS8110:Part 1:1997 – Table 3.8

Design concrete shear stress $v_{c\_stem} = \mathbf{0.980}$ N/mm^2

$v_{stem} < v_{c\_stem}$ - No shear reinforcement required

<u>Indicative retaining wall reinforcement diagram</u>



Toe bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

Stem bars - 20 mm dia.@ 100 mm centres - (3142 mm^2/m)

RE: 8-10 Stukeley Street

Julian Maund to: LizBrown 28/09/2016 15:16

Cc: "'Clark, James'", camdenaudit, WilliamShaw, FiroozehMoghaddam, "'Eleni Pappa'", "'Yumeng Chan'"

7 attachments

Figure 2 Short term undrained rev 1.pdf Figure 3 Long term drained rev.pdf Figure 4 VM No 6 rev 2.pdf

Figure 5 VM No 12 rev 2.pdf Figure 6 VM No 182 rev.pdf Figure 7 Burland Damage Category rev 2.pdf

Figure 1 Basement Outline and Surrounding Properties including GMA sect....pdf

Dear Liz

We are responding to the two final outstanding queries remaining for the BIA / GMA for 8-10 Stukeley Street.

1. Horizontal Movement of the underpin walls.

I have contacted Abbey Pynford. A copy of the correspondence is attached which shows that lateral movement can be contained to within 2-5 mm.

2. Damage Assessment

The damage assessment profile has been re-evaluated on the basis of a section at 90 degrees to the underpin wall, and allows for a lateral movement of 5 mm. I trust you agree this is a conservative case. This shows a Burland Category 1 and 2 Damage Assessment.

Revised figures are attached for all the sections taking into account 5 mm lateral movement. Figure 1 now shows the sections on the plan to provide greater clarity.

Yours sincerely

Julian Maund

From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 23 September 2016 15:55
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

Dear Liz,

Further to our phone conversation this afternoon, I have summarised the actions we discussed.

Horizontal Movement of the underpin walls.

You were concerned about our assessment of the combined movement of 2 mm. I made this assessment on the basis of very low vertical movements shown in the analysis for the predominantly dense granular soil. Due to the difficulty in modelling this movement for underpins it was agreed that the actual movement would be down to the workmanship during construction. I will contact specialist contractors to get an estimate of expected movement and re-model on this basis.

Damage Assessment
Section 1-1 in the report is taken diagonally across the re-entrant corner, for the boundary with No. 6 Stukeley Street. PDISP does show the greatest vertical ground movement on the diagonal section so this was initially taken as a worst case. However, it is accepted that this will provide a longer section across No. 6 Stukeley Street. The section will be revised to show the damage assessment at 90 degrees to the underpin wall.

Undrained / drained analysis and the impact of the 26 kPa wall load.
This query was addressed in the email below, where it was agreed the difference is negligible.

I trust this captures the issues we discussed, and the way forward to resolve these issues. I hope to be able to respond early next week to the two outstanding items.

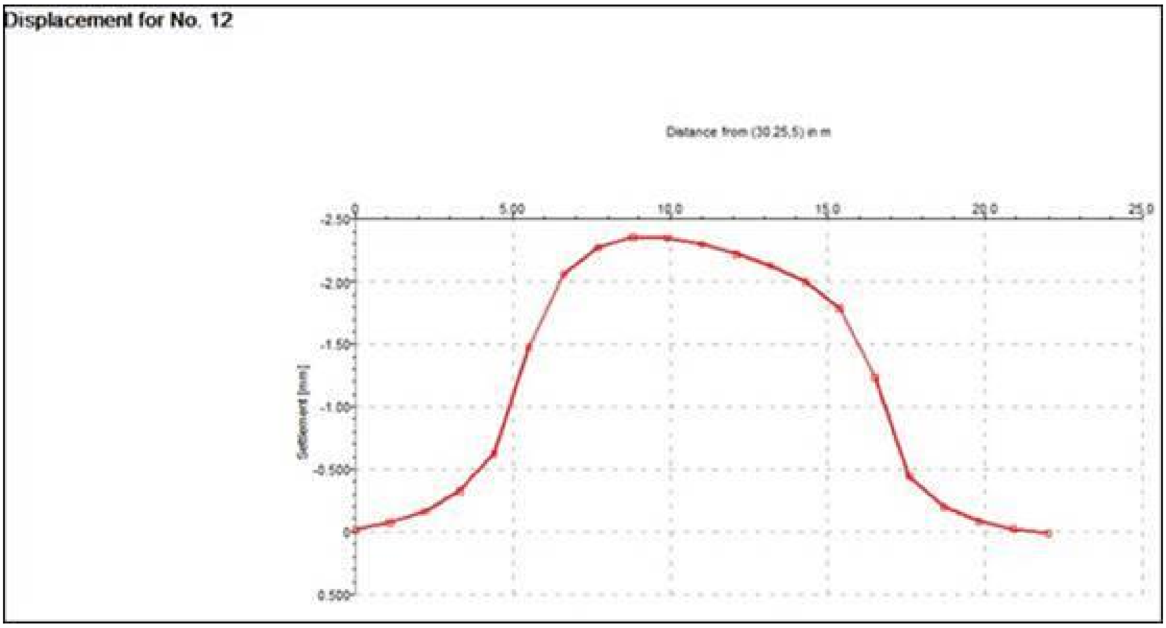
Kind regards
Julian Maund BSc PhD FGS CGeol MIMMM CEng
MAUND GEO-CONSULTING LTD
+44 (0)7817018716
Registered in England and Wales No. 7488348 at 20 Mortlake Avenue, Worcester, Worcestershire, UK, WR5 1QD

From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 21 September 2016 11:14
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

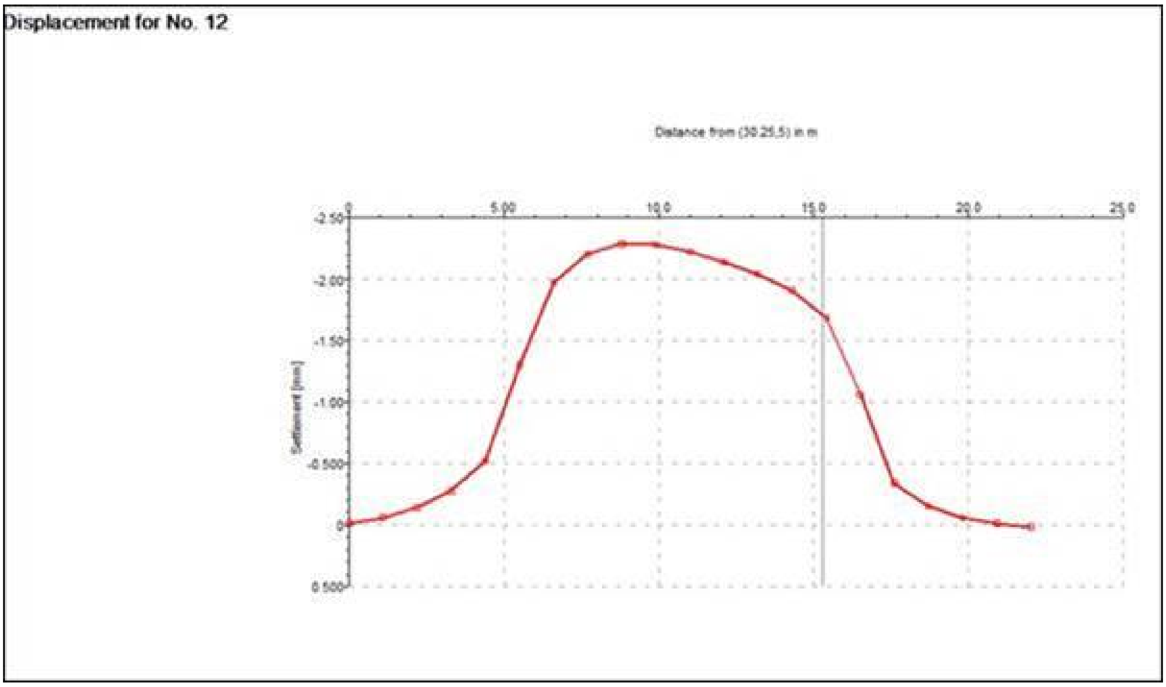
Dear Liz

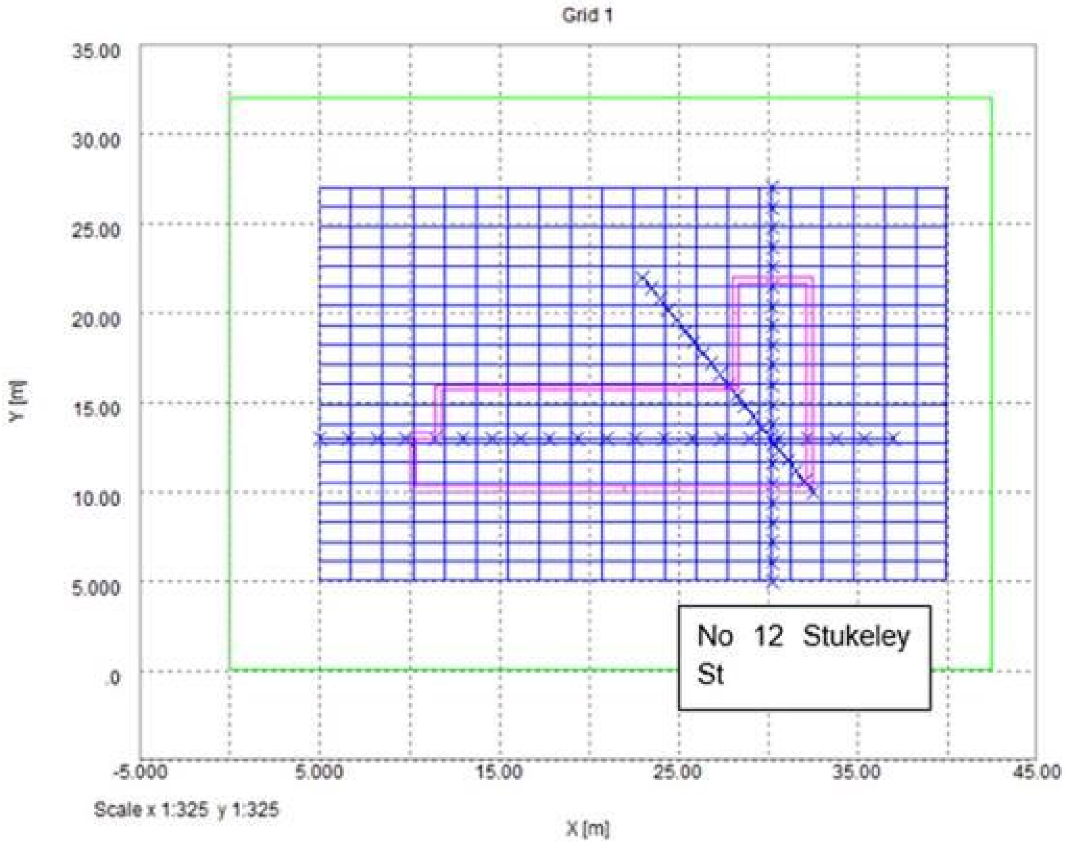
Further to my last email I have attached a sketch with screen shots to show that the wall load of 26 kPa makes almost no discernible difference (there is a very, very slight steepening of the displacement profile) . All movements are well within construction tolerance. The sections are across the basement and adjacent properties.

Undrained - no wall load



Undrained 26 kPa wall load





Kind regards

Julian Maund

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From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 20 September 2016 18:32
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

Dear Liz,
I am sorry to have missed your call. I did try to call you back this afternoon. I will be available all day

Wednesday 21st. I have responded with comments below but I think a phone call to discuss may be a preferable way forward?

Kind regards

Julian Maund

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Registered in England and Wales No. 7488348 at 20 Mortlake Avenue, Worcester, Worcestershire, UK, WR5 1QD

From: LizBrown@campbellreith.com [mailto:LizBrown@campbellreith.com]
Sent: 20 September 2016 11:34
To: Julian Maund <julian.maund@gmail.com>
Cc: Clark, James <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com
Subject: 8-10 Stukeley Street

Dear Julian

I have just tried to call and was unable to leave a message, so I thought I would summarise the current situation in an email.

We can confirm that we now consider the soil parameters adopted in the PDisp analysis to be appropriate and have received clarification of the assumptions regarding building dimensions and geometry.

There are three queries remaining however, which can broadly be described as follows:

Estimation of horizontal movements
With respect to CIRIA C580, the reason there is no curve for horizontal ground movement resulting from excavation is due to a lack of data and not because it is assumed that no movement occurs. Whilst we concur that CIRIA C580 may not be strictly applicable, there does need to be recognition of the potential for horizontal ground movement associated with excavation, especially around the re-entrant corner. In our previous correspondence we confirmed our opinion that the estimated horizontal movement associated with wall installation is appropriate but requested consideration of horizontal movement due to excavation.
The method statement shows that excavation and installation is a single process. I have allowed 2 mm of movement during this combined process.
This is an approach which has been taken by other GMAs for Camden in the past for underpins. I have no issue with referring to C580 per se and we have adopted the general approach of C580. I believe we have taken a sensible approach for the specific ground conditions and construction methodology. I would be very happy to discuss this approach.

PDisp
We note that a downward vertical load of 26kN/m2 has been applied in both the undrained and permanent drained cases. It is our understanding that the undrained case is intended to look at the situation during construction and therefore before any meaningful construction loads are applied.

This will affect the magnitude of immediate and long term vertical movements.
Undrained looks at short term movement and drained looks at long term movements due to pore-water pressure changes in the cohesive materials. At the same time the excavation of the granular materials (Lynch Hill Gravel) will not be effected by undrained or undrained movements to any significant amount. The analysis is already conservative, as excavation assumes that all the soil mass is removed at a single point in time. However the central soil mass will be used to prop against (to minimise the lateral movements from the excavation and construction of the underpin walls). It is only when the underpinned walls have been completed that the central soil mass is removed.
I would reiterate that due to the soil types present the magnitude of the immediate and long term movements are extremely small with total combined movements in the order of 6 mm. This maximum movement is within the centre of the basement which is furthest from adjacent buildings. Movements at the boundary walls is much less due to the heave and settlement virtually cancelling each other out.

Building damage assessment
The damage assessment should be carried out for the walls at risk rather than some theoretical structure case.
There may be some misunderstanding here. I have taken the actual dimensions of the sections for each adjoining property. These are not theoretical.

I hope that clarifies the situation, but if you have any further queries, please let me know.

Regards,

Elizabeth Brown
Partner

CampbellReith
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41-45 Blackfriars Road,
London
SE1 8NZ

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Click here to report this email as spam.

----- Message from "Tim Casalis de Pury" <timcasalis@abbeypynford.co.uk> on Wed, 28 Sep 2016 11:04:50 +0100 -----

To: <julian.maund@gmail.com>
cc: "Paul Bailey" <paulbailey@abbeypynford.co.uk>, <epappa@croftse.co.uk>
Subject: RE: Anticipated Ground Movement from lateral deflection for underpinned basement walls

Good morning Julian,

Further to our earlier conversation, we write to confirm that in our experience the potential lateral movement of a reinforced concrete underpin wall could be between 2 and 5mm.

Clearly the amount of movement experienced depends upon the quality of the work undertaken on site, however the steps which have been highlighted below will go a long way to ensuring that the potential movement is minimised.

I hope that this is of assistance and if we can provide any further information please do not hesitate to contact me.

Kind Regards

Tim Casalis de Pury MEng (Hons) | Estimating Manager | Abbey Pynford Basement Engineering Specialists

Abbey Pynford Geo Structures 1st Floor, West Wing, 575-599 Maxted Road, Hemel Hempstead, HP2 7DX
p: 01442 898314 | dd: 01442 898349 | m: 07971 572924 | e: timcasalis@abbeypynford.co.uk | w: www.abbeypynford.co.uk

From: Paul Bailey
Sent: 27 September 2016 18:06
To: Tim Casalis de Pury <timcasalis@abbeypynford.co.uk>
Subject: FW: Anticipated Ground Movement from lateral deflection for underpinned basement walls

From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 27 September 2016 13:53
To: Paul Bailey <paulbailey@abbeypynford.co.uk>
Cc: 'Eleni Pappa' <epappa@croftse.co.uk>
Subject: FW: Anticipated Ground Movement from lateral deflection for underpinned basement walls

Dear Paul

Further to my phone call today regarding the anticipated movement for an underpinned wall, I have provided an outline of the project below. At this stage can you please provide a general response which assumes that all reasonable steps are taken to reduce movement during construction and the construction will be fully monitored.

I have taken a section of the report for a site in LB Camden for you to comment on rather than providing the full report:

The basement will be constructed using traditional underpinning techniques with pins excavated in a hit and miss sequences in bays of 1.0 m width. Temporary propping and trench sheeting will be installed to the excavations at the top, bottom and middle of the underpin bays. The underpins will be supported in the long term by the basement and first floor slabs. The full details of the construction are included in the Basement Method Statement by Croft (ref. 140906 November 2015).

Ground movements resulting from underpinning are not well documented, and there is no specific method for assessing their magnitude. It should be noted that CIRIA C580, which is often used as a reference for ground movement assessments, is for embedded retaining walls and not concrete underpins. Therefore, although this assessment makes reference to C580, the assessment can only refer to empirical data.

When underpinning is carried out in a well-controlled manner, movements are typically sm all. The ground conditions at Stukeley Street is predominantly a granular fill over a very dense granular Lynch Hill Gravel, which appears to be above the groundwater level. The response to changes in load are anticipated to be short term in these ground conditions. The quality of workmanship and on site monitoring are key factors in minimising ground movements.

In common with other submissions relating to GMA and to provide some basis of estimating likely movements and damage resulting from excavating the basement in front of the underpinning, and in the absence of underpinning-specific guidance, the underpinned sections of the new basement are considered as stiff members. It has been assumed that the movements resulting from excavation in front of the underpins also incorporate the m ovements resulting from the construction of the underpins as (unlike for the piles for example), the construction process requires an excavation prior to the pins being formed.

The basement depth of 3.7 m and the high stiffness of the reinforced concrete underpins will result in long term deflection from the underpins themselves being negligible (< 2 mm) on the basis of records of similar basement construction using this type of method.

As shown in the Basement Method Statement lateral displacements will be resisted by propping of the underpinned foundations until such a time when the lateral loading will be transferred to the reinforced basement and ground floor slabs. For purposes of deriving a Damage Category Assessment a lateral deflection from the underpin installation is taken as 2 mm.

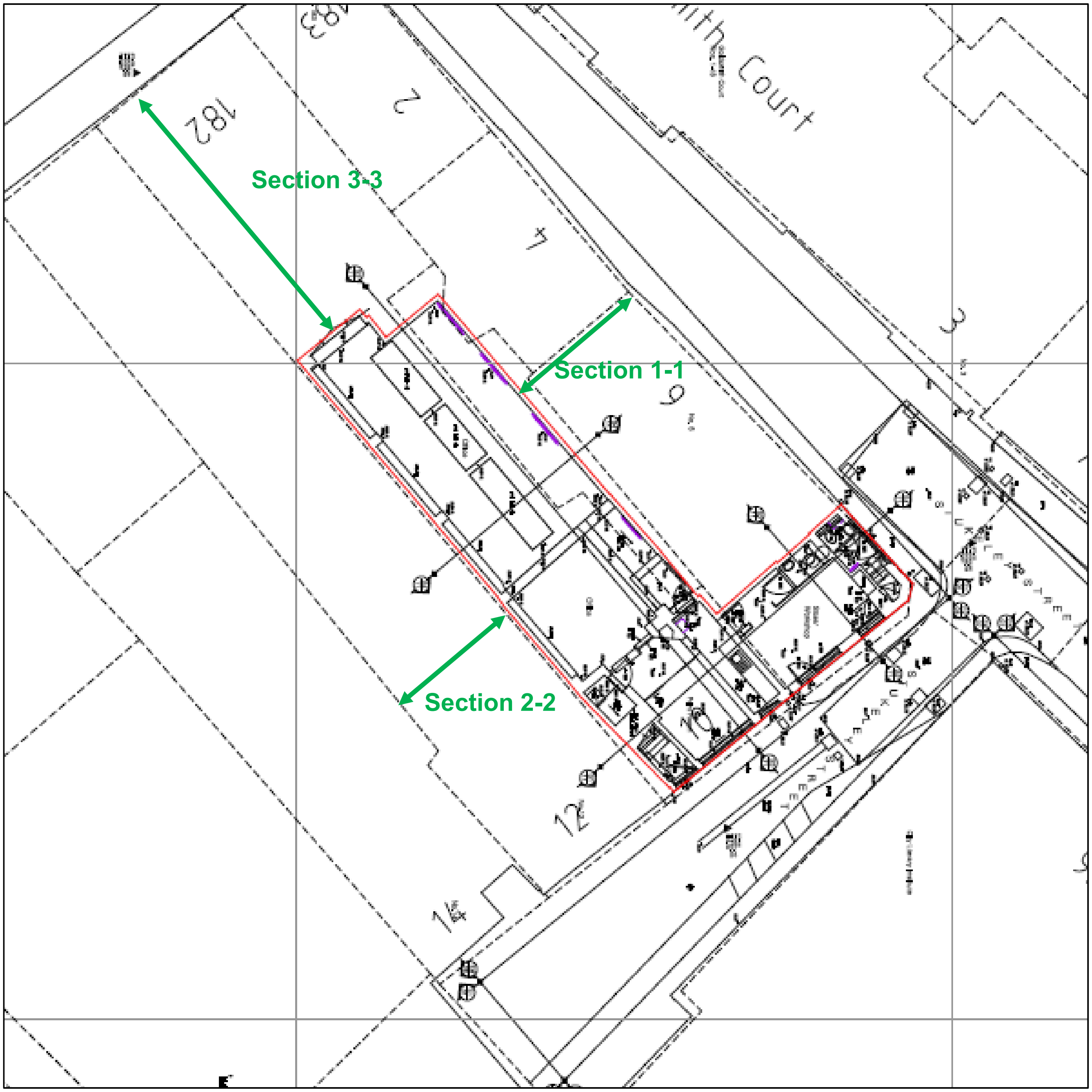
Any lateral deflection may result in a corresponding vertical settlement behind the underpin. Due to the difficulty in modelling the movement from lateral deflection in granular materials (CIRIA C580 2.5.2) and the dominant vertical movement being heave, this potential movement has conservatively not been included in the assessment.

In summary we have assumed that the underpin is a stiff member and the formwork will be fully supported, as are the underpins, until the basement slabs is cast and the wall load transferred to the underpins. We undertook a PDISP analysis a part of the GMA which showed very low net vertical movement at the basement underpin walls of up to 6 mm. Consequentially we have allowed a nominal lateral movement of 2 mm.

Yours sincerely

Julian Maund BSc PhD FGS CGeol MIMMM CEng | Geotechnical Director

G&J Geoenvironmental Consultants Ltd | 35-37 High Street, Barrow upon Soar, Loughborough, Leicestershire, LE12 8PY

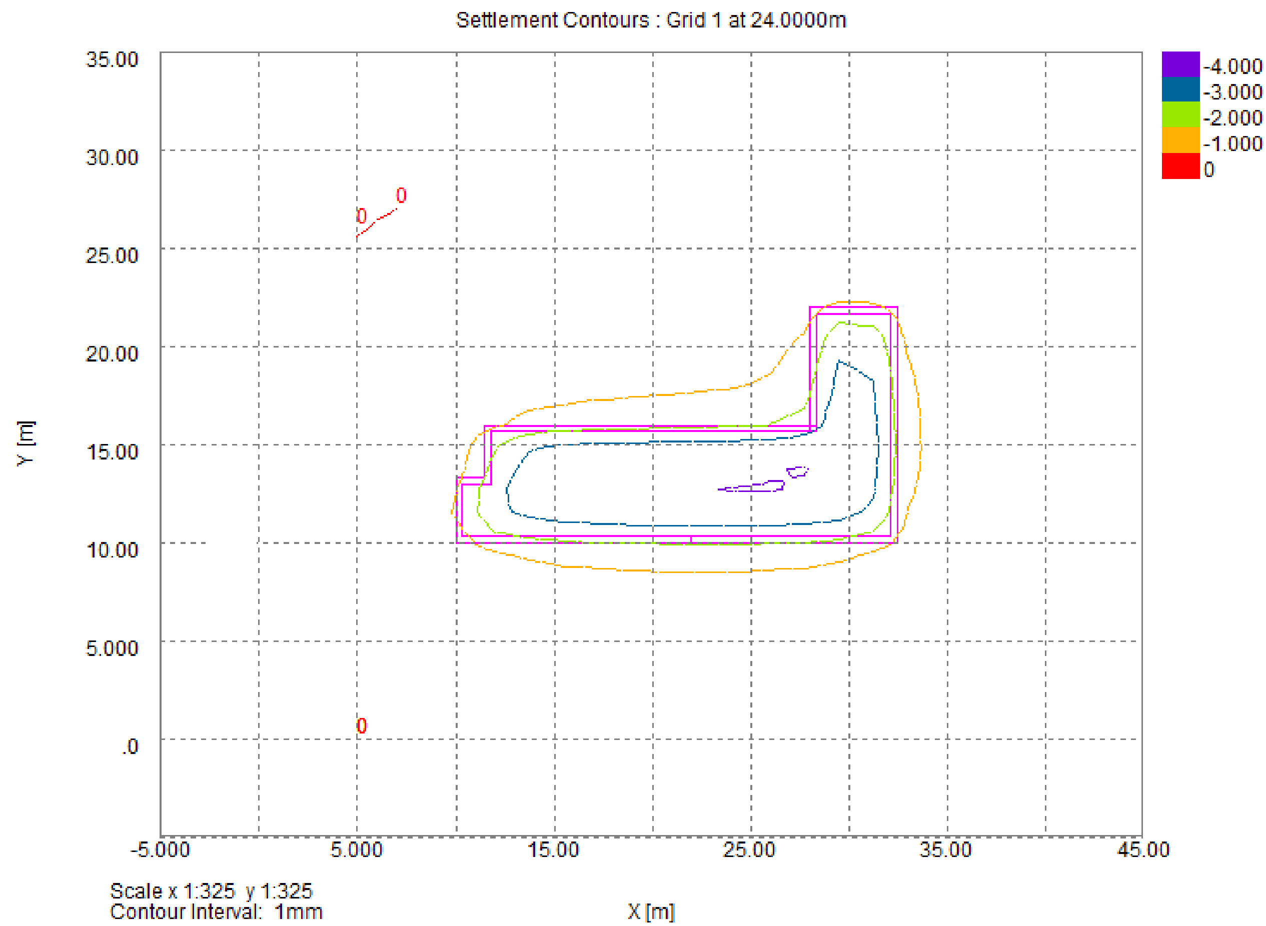


Section 1-1 GMA Plots

Client		Project
Croft Structural Engineers Ltd	MAUND GEO-CONSULTING	8 -10 Stukeley Street
Job No.	Title	Figure No.
MCG/16/25	Basement Outline and Surrounding Properties	1

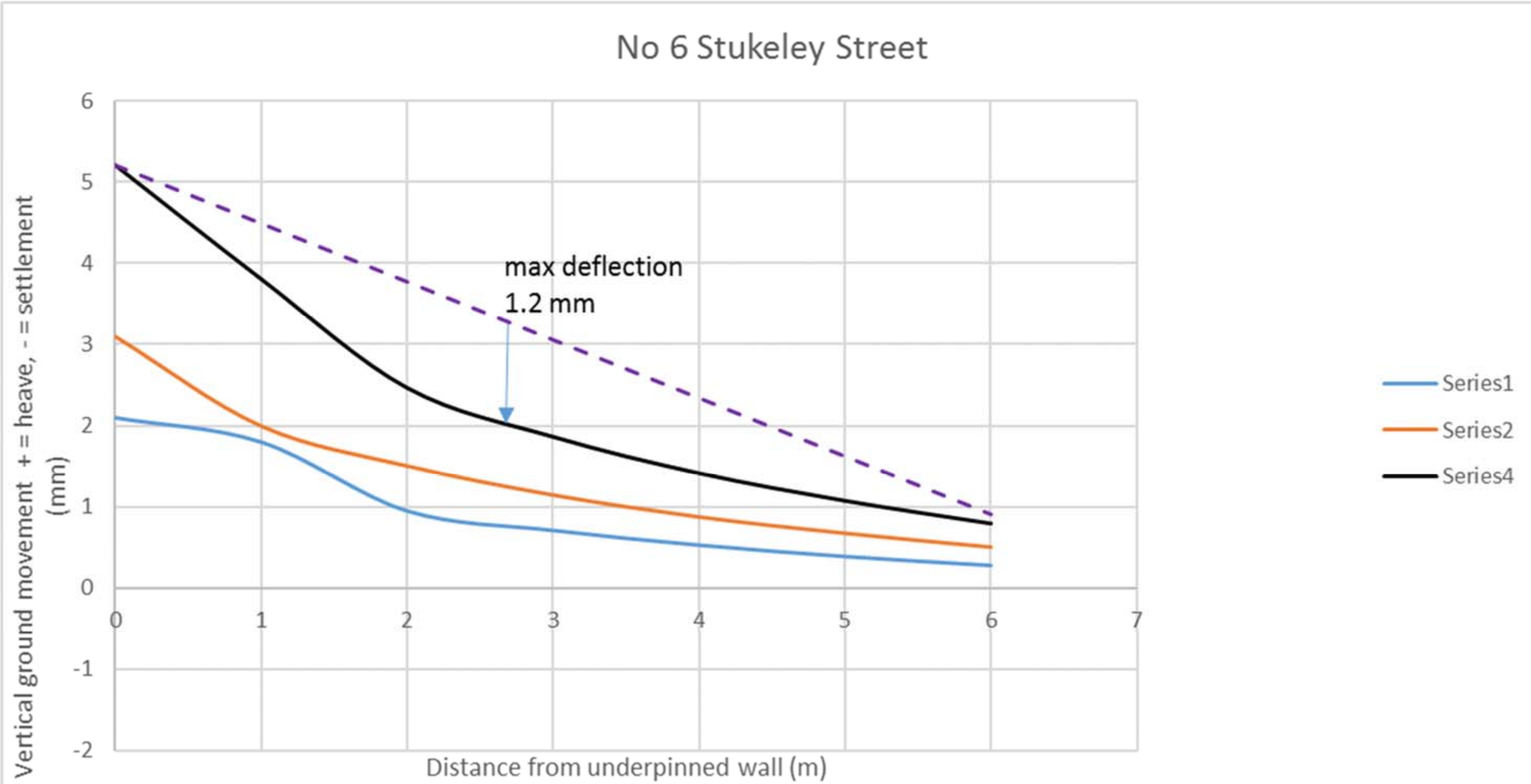
Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Short Term Undrained Vertical Ground Movement Contour Plot	2



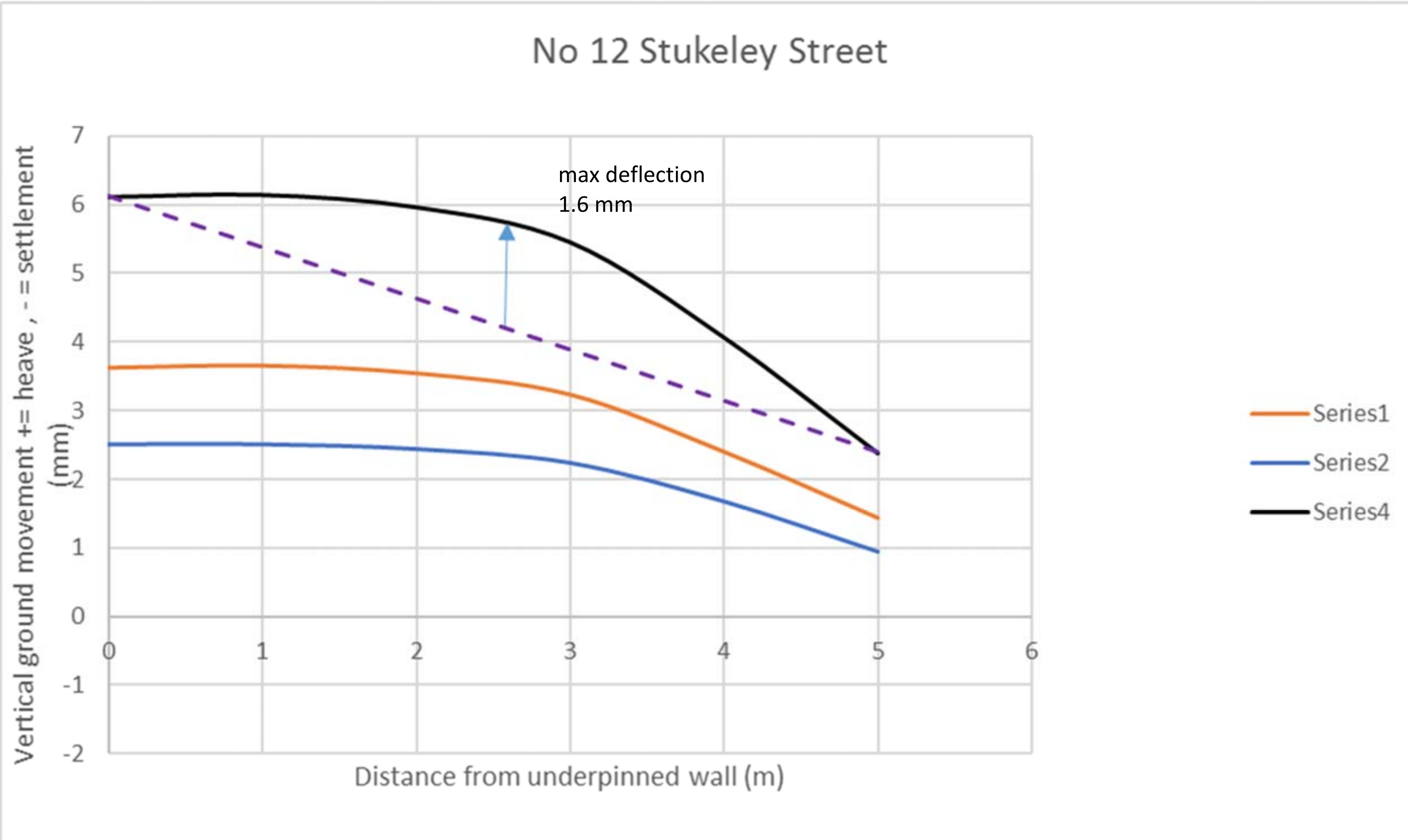
Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Long Term Drained Vertical Ground Movement Contour Plot	3



Client	MAUND GEO-CONSULTING	Project
Croft Structural Engineers Ltd.		8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Combined Vertical Movements Section 1-1 (No. 6 Stukeley St)	4

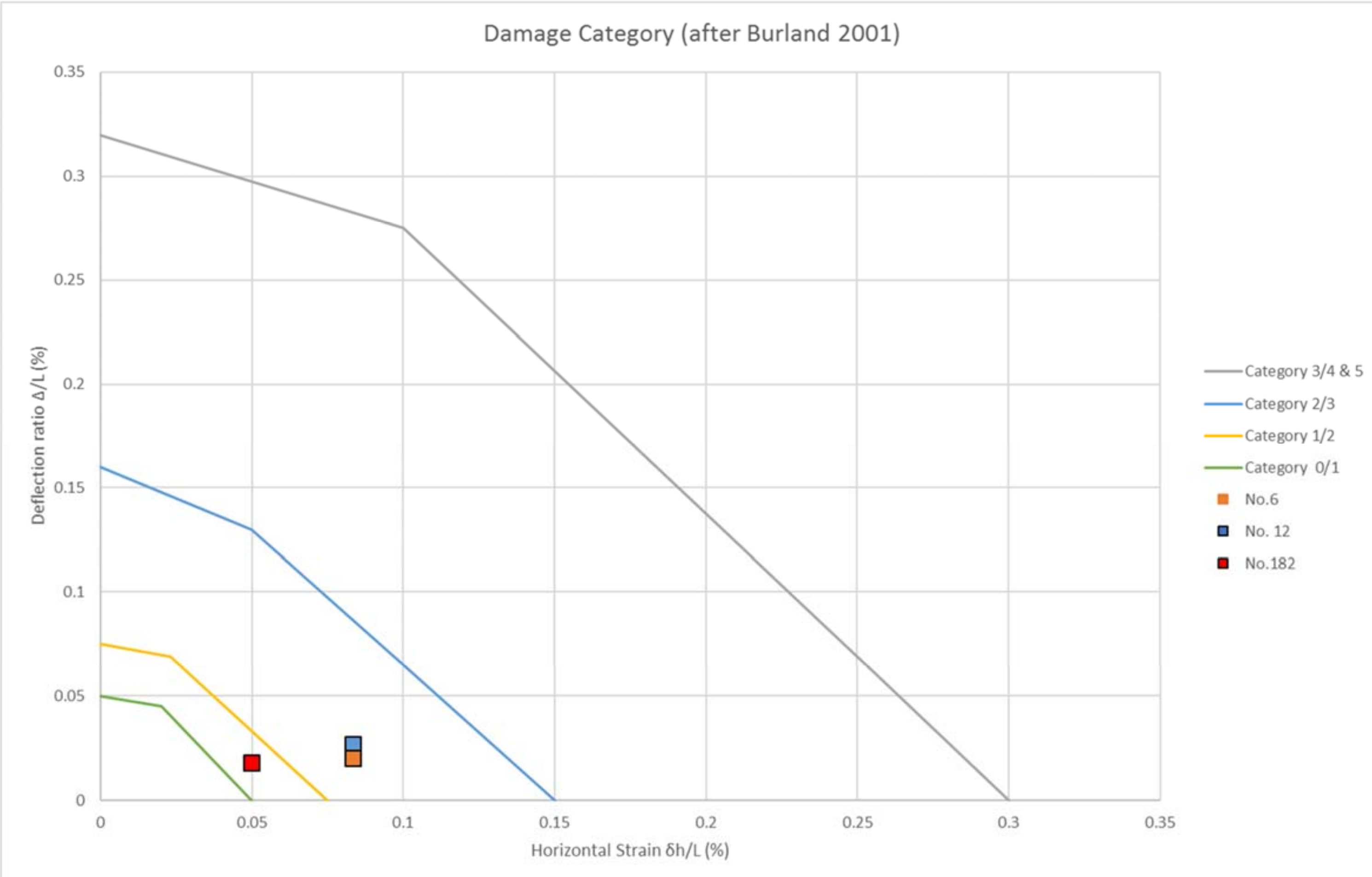


Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Combined Vertical Movements Section 2-2 (No. 12 Stukeley St)	5

Client	MAUND GEO-CONSULTING	Project
Croft Structural Engineers Ltd.		8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Combined Vertical Movements Section 3-3 (No. 182 Drury Lane)	6



Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Burland Damage Category Chart	7

RE: 8-10 Stukeley Street
Julian Maund
to:
LizBrown
14/10/2016 11:38
Cc:
James.Clark, camdenaudit, WilliamShaw, FiroozehMoghaddam, epappa, ymchan
Hide Details
From: "Julian Maund" <julian.maund@gmail.com> Sort List...
To: <LizBrown@campbellreith.com>
Cc: <James.Clark@camden.gov.uk>, <camdenaudit@campbellreith.com>, <WilliamShaw@campbellreith.com>, <FiroozehMoghaddam@campbellreith.com>, <epappa@croftse.co.uk>, <ymchan@benetonproperties.com>

2 Attachments

image003.jpg image004.jpg image005.jpg image006.jpg image007.jpg image008.png Figure 5 VM No 12 rev 3.pdf Figure 4 VM No 6 rev 3.pdf

Dear Liz

Further to our phone conversation today, 14/10/26, we have re-evaluated the horizontal distance to negligible movement to be 10 m. This results in the Damage Category being 1 for the adjoining properties as shown in the table below.

		Vertical Movements				Horizontal Movements			δh = 2 mm	δh = 5 mm			
Property	Building length - L (m)	maximum deflection in metres (from GMA charts, Figures 4 to 6)	Δ/L (%)	εlim	Δ/L/εlim	length (in m) to negligible horizontal movement	δh = 2 mm	δh = 5 mm	δh/L (%) = εh	δh/L (%) = εh	Building height - H (m)	L/H	Burland (2001) Damage Category (assuming 5 mm horizontal displacement)
No 6 Stukeley St	6	0.0012	0.0200	0.05	0.40	10.00	0.002	0.005	0.020	0.050	5	1.2	1
No 12 Stukeley St	5	0.0016	0.0320	0.05	0.64	10.00	0.002	0.005	0.020	0.050	8	0.625	1
No 182 Drury Lane	10	0.0018	0.018	0.05	0.36	10.00	0.002	0.005	0.020	0.050	8	1.25	1

I have made slight amendments to Figures 4 and 5 where I have added a key to explain the lines on the charts which were omitted in error previously.

Kind regards

Julian Maund

Julian Maund **BSc PhD FGS CGeol MIMMM CEng**
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From: LizBrown@campbellreith.com [mailto:LizBrown@campbellreith.com]
Sent: 12 October 2016 16:55
To: Julian Maund <julian.maund@gmail.com>
Subject: RE: 8-10 Stukeley Street

Julian

Apologies, I see what you have done and yes, I concur that it's conservative. The only thing I would say is that I think you have assumed that the horizontal movement reduces from 5mm to zero over the width of the building irrespective of the dimension. I'd say that you could assume the distance would be the same on all sides, so your horizontal strain would be the same for all three sections. This might make it better for Nos 6 and 12. Please let me know if I have misunderstood or Abbey Pynford have told you otherwise.

I think you have also assumed the same L/H for all three buildings which seems unlikely. I'm not sure if that will help or not. Can you confirm the dimensions for the various buildings and the damage categories.

Regards
Liz Brown
Partner

CampbellReith
consulting engineers
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From: "Julian Maund" <julian.maund@gmail.com>
To: <LizBrown@campbellreith.com>
Cc: "'Clark, James'" <James.Clark@camden.gov.uk>, <camdenaudit@campbellreith.com>, <WilliamShaw@campbellreith.com>, <FiroozehMoghaddam@campbellreith.com>, "'Eleni Pappa'" <epappa@croftse.co.uk>, "'Yumeng Chan'" <ymchan@benetonproperties.com>
Date: 28/09/2016 15:16
Subject: RE: 8-10 Stukeley Street

Dear Liz

We are responding to the two final outstanding queries remaining for the BIA / GMA for 8-10 Stukeley Street.

1. Horizontal Movement of the underpin walls.
I have contacted Abbey Pynford. A copy of the correspondence is attached which shows that lateral movement can be contained to within 2-5 mm.

2. Damage Assessment
The damage assessment profile has been re-evaluated on the basis of a section at 90 degrees to the underpin wall, and allows for a lateral movement of 5 mm. I trust you agree this is a conservative case. This shows a Burland Category 1 and 2 Damage Assessment.

Revised figures are attached for all the sections taking into account 5 mm lateral movement. Figure 1 now shows the sections on the plan to provide greater clarity.

Yours sincerely

Julian Maund

From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 23 September 2016 15:55
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

Dear Liz,

Further to our phone conversation this afternoon, I have summarised the actions we discussed.

Horizontal Movement of the underpin walls.
You were concerned about our assessment of the combined movement of 2 mm. I made this assessment on the basis of very low vertical movements shown in the analysis for the predominantly dense granular soil. Due to the difficulty in modelling this movement for underpins it was agreed that the actual movement would be down to the workmanship during construction. I will contact specialist contractors to get an estimate of expected movement and re-model on this basis.

Damage Assessment
Section 1-1 in the report is taken diagonally across the re-entrant corner, for the boundary with No. 6 Stukeley Street. PDISP does show the greatest vertical ground movement on the diagonal section so this was initially taken as a worst case. However, it is accepted that this will provide a longer section across No. 6 Stukeley Street. The section will be revised to show the damage assessment at 90 degrees to the underpin wall.

Undrained / drained analysis and the impact of the 26 kPa wall load.
This query was addressed in the email below, where it was agreed the difference is negligible.

I trust this captures the issues we discussed, and the way forward to resolve these issues. I hope to be able to respond early next week to the two outstanding items.

Kind regards
Julian Maund **BSc PhD FGS CGeol MIMMM CEng**
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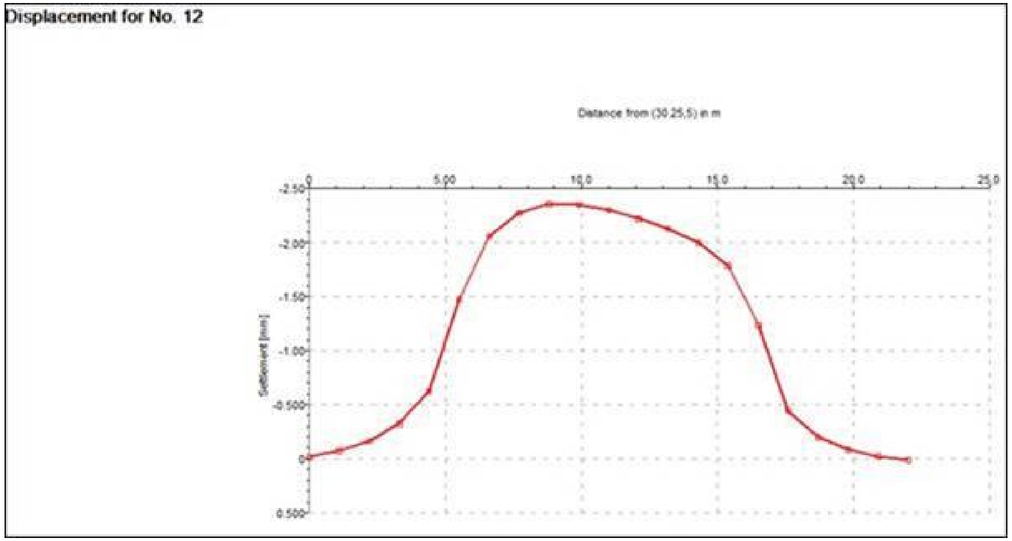
From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 21 September 2016 11:14
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

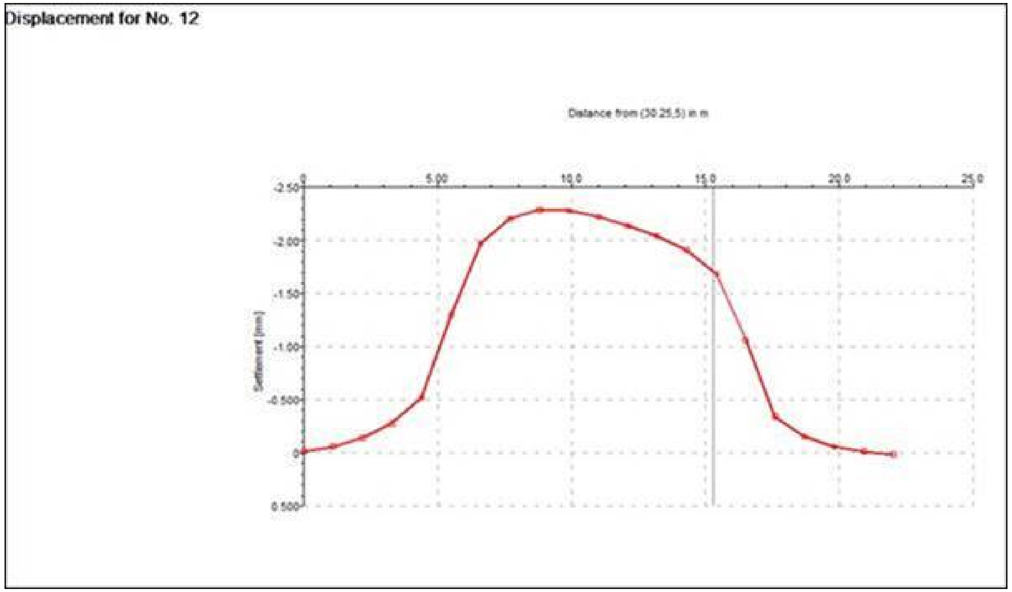
Dear Liz

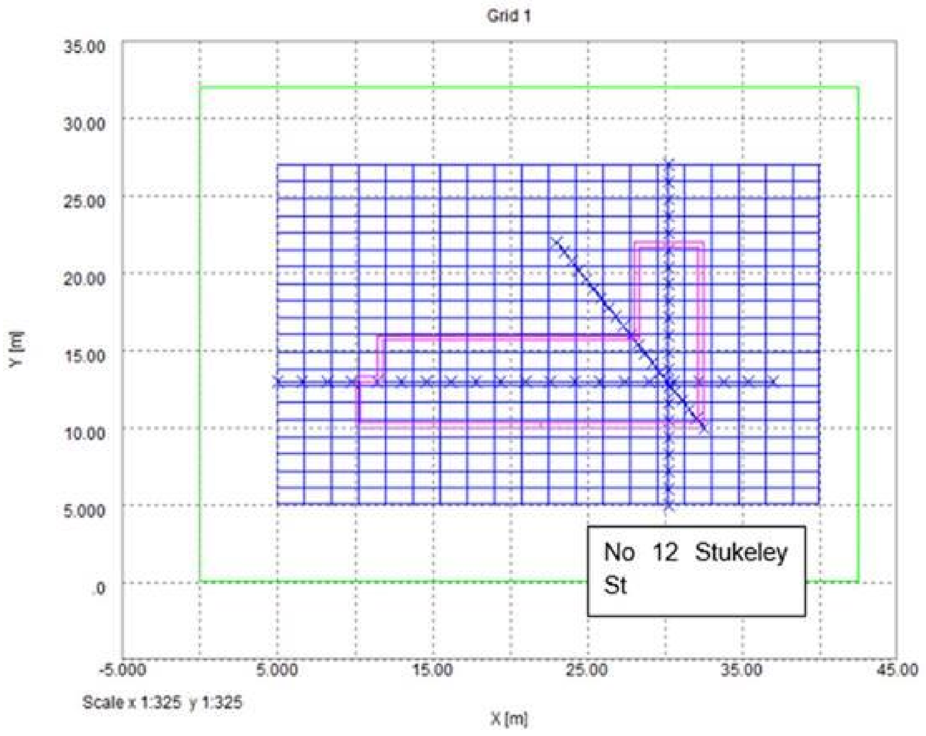
Further to my last email I have attached a sketch with screen shots to show that the wall load of 26 kPa makes almost no discernible difference (there is a very, very slight steepening of the displacement profile) . All movements are well within construction tolerance. The sections are across the basement and adjacent properties.

Undrained - no wall load



Undrained 26 kPa wall load


Displacement for No. 12
Distance from (30,25,5) in m
Settlement [mm]
0
5.00
10.0
15.0
20.0
25.0
-2.50
-2.00
-1.50
-1.00
-0.500
0
0.500



Kind regards

Julian Maund

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From: Julian Maund [mailto:julian.maund@gmail.com]

Sent: 20 September 2016 18:32
To: LizBrown@campbellreith.com
Cc: 'Clark, James' <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com; 'Eleni Pappa' <epappa@croftse.co.uk>; 'Yumeng Chan' <ymchan@benetonproperties.com>
Subject: RE: 8-10 Stukeley Street

Dear Liz,
I am sorry to have missed your call. I did try to call you back this afternoon. I will be available all day Wednesday 21st. I have responded with comments below but I think a phone call to discuss may be a preferable way forward?

Kind regards

Julian Maund

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From: LizBrown@campbellreith.com [mailto:LizBrown@campbellreith.com]
Sent: 20 September 2016 11:34
To: Julian Maund <julian.maund@gmail.com>
Cc: Clark, James <James.Clark@camden.gov.uk>; camdenaudit@campbellreith.com; WilliamShaw@campbellreith.com; FiroozehMoghaddam@campbellreith.com
Subject: 8-10 Stukeley Street

Dear Julian

I have just tried to call and was unable to leave a message, so I thought I would summarise the current situation in an email.

We can confirm that we now consider the soil parameters adopted in the PDisp analysis to be appropriate and have received clarification of the assumptions regarding building dimensions and geometry.

There are three queries remaining however, which can broadly be described as follows:

Estimation of horizontal movements
With respect to CIRIA C580, the reason there is no curve for horizontal ground movement resulting from excavation is due to a lack of data and not because it is assumed that no movement occurs. Whilst we concur that CIRIA C580 may not be strictly applicable, there does need to be recognition of the potential for horizontal ground movement associated with excavation, especially around the re-entrant corner. In our previous correspondence we confirmed our opinion that the estimated horizontal movement associated with wall installation is appropriate but requested consideration of horizontal movement due to excavation.
The method statement shows that excavation and installation is a single process. I have allowed 2 mm of movement during this combined process.
This is an approach which has been taken by other GMAs for Camden in the past for underpins. I have no issue with referring to C580 per se and we have adopted the general approach of C580. I believe we have taken a sensible approach for the specific ground conditions and construction methodology. I would be very happy to discuss this approach.

PDisp
We note that a downward vertical load of 26kN/m2 has been applied in both the undrained and permanent drained cases. It is our understanding that the undrained case is intended to look at the situation during construction and therefore before any meaningful construction loads are applied. This will affect the magnitude of immediate and long term vertical movements.
Undrained looks at short term movement and drained looks at long term movements due to pore-water pressure changes in the cohesive materials. At the same time the excavation of the granular materials (Lynch Hill Gravel) will not be effected by undrained or undrained movements to any significant amount. The analysis is already conservative, as excavation assumes that all the soil mass is removed at a single point in time. However the central soil mass will be used to prop against (to minimise the lateral movements from the excavation and construction of the underpin walls). It is only when the underpinned walls have been completed that the central soil mass is removed.
I would reiterate that due to the soil types present the magnitude of the immediate and long term movements are extremely small with total combined movements in the order of 6 mm. This maximum movement is within the centre of the basement which is furthest from adjacent buildings. Movements at the boundary walls is much less due to the heave and settlement virtually cancelling each other out.

Building damage assessment
The damage assessment should be carried out for the walls at risk rather than some theoretical structure case.
There may be some misunderstanding here. I have taken the actual dimensions of the sections for each adjoining property. These are not theoretical.

I hope that clarifies the situation, but if you have any further queries, please let me know.

Regards,

Elizabeth Brown
Partner

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----- Message from "Tim Casalis de Pury" <timcasalis@abbeypynford.co.uk> on Wed, 28 Sep 2016 11:04:50 +0100 -----

To: <julian.maund@gmail.com>
cc: "Paul Bailey" <paulbailey@abbeypynford.co.uk>, <epappa@croftse.co.uk>
Subject: RE: Anticipated Ground Movement from lateral deflection for underpinned basement walls

Good morning Julian,

Further to our earlier conversation, we write to confirm that in our experience the potential lateral movement of a reinforced concrete underpin wall could be between 2 and 5mm.

Clearly the amount of movement experienced depends upon the quality of the work undertaken on site, however the steps which have been highlighted below will go a long way to ensuring that the potential movement is minimised.

I hope that this is of assistance and if we can provide any further information please do not hesitate to contact me.

Kind Regards

Tim Casalis de Pury MEng (Hons) | Estimating Manager | Abbey Pynford Basement Engineering Specialists

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Abbey Pynford Geo Structures 1st Floor, West Wing, 575-599 Maxted Road, Hemel Hempstead, HP2 7DX
p: 01442 898314 | dd: 01442 898349 | m: 07971 572924 | e: timcasalis@abbeypynford.co.uk | w: www.abbeypynford.co.uk

From: Paul Bailey
Sent: 27 September 2016 18:06
To: Tim Casalis de Pury <timcasalis@abbeypynford.co.uk>
Subject: FW: Anticipated Ground Movement from lateral deflection for underpinned basement walls

From: Julian Maund [mailto:julian.maund@gmail.com]
Sent: 27 September 2016 13:53
To: Paul Bailey <paulbailey@abbeypynford.co.uk>
Cc: 'Eleni Pappa' <epappa@croftse.co.uk>
Subject: FW: Anticipated Ground Movement from lateral deflection for underpinned basement walls

Dear Paul

Further to my phone call today regarding the anticipated movement for an underpinned wall, I have provided an outline of the project below. At this stage can you please provide a general response which assumes that all reasonable steps are taken to reduce movement during construction and the construction will be fully monitored.

I have taken a section of the report for a site in LB Camden for you to comment on rather than providing the full report:

The basement will be constructed using traditional underpinning techniques with pins excavated in a hit and miss sequences in bays of 1.0 m width. Temporary propping and trench sheeting will be installed to the excavations at the top, bottom and middle of the underpin bays. The underpins will be supported in the long term by the basement and first floor slabs. The full details of the construction are included in the Basement Method Statement by Croft (ref. 140906 November 2015).
Ground movements resulting from underpinning are not well documented, and there is no specific method for assessing their magnitude. It should be noted that CIRIA C580, which is often used as a reference for ground movement assessments, is for embedded retaining walls and not concrete underpins. Therefore, although this assessment makes reference to C580, the assessment can only refer to empirical data.
When underpinning is carried out in a well-controlled manner, movements are typically small. The ground conditions at Stukeley Street is predominantly a granular fill over a very dense granular Lynch Hill Gravel, which appears to be above the groundwater level. The response to changes in load are anticipated to be short term in these ground conditions. The quality of workmanship and on site monitoring are key factors in minimising ground movements.
In common with other submissions relating to GMA and to provide some basis of estimating likely movements and damage resulting from excavating the basement in front of the underpinning, and in the absence of underpinning-specific guidance, the underpinned sections of the new basement are considered as stiff members. It has been assumed that the movements resulting from excavation in front of the underpins also incorporate the movements resulting from the construction of the underpins as (unlike for the piles for example), the construction process requires an excavation prior to the pins being formed.

The basement depth of 3.7 m and the high stiffness of the reinforced concrete underpins will result in long term deflection from the underpins themselves being negligible (< 2 mm) on the basis of records of similar basement construction using this type of method.
As shown in the Basement Method Statement lateral displacements will be resisted by propping of the underpinned foundations until such a time when the lateral loading will be transferred to the reinforced basement and ground floor slabs. For purposes of deriving a Damage Category Assessment a lateral deflection from the underpin installation is taken as 2 mm.
Any lateral deflection may result in a corresponding vertical settlement behind the underpin. Due to the difficulty in modelling the movement from lateral deflection in granular materials (CIRIA C580 2.5.2) and the dominant vertical movement being heave, this potential movement has conservatively not been included in the assessment.

In summary we have assumed that the underpin is a stiff member and the formwork will be fully supported, as are the underpins, until the basement slabs is cast and the wall load transferred to the underpins. We undertook a PDISP analysis a part of the GMA which showed very low net vertical movement at the basement underpin walls of up to 6 mm. Consequentially we have allowed a nominal lateral movement of 2 mm.

Yours sincerely

Julian Maund BSc PhD FGS CGeol MIMMM CEng | Geotechnical Director

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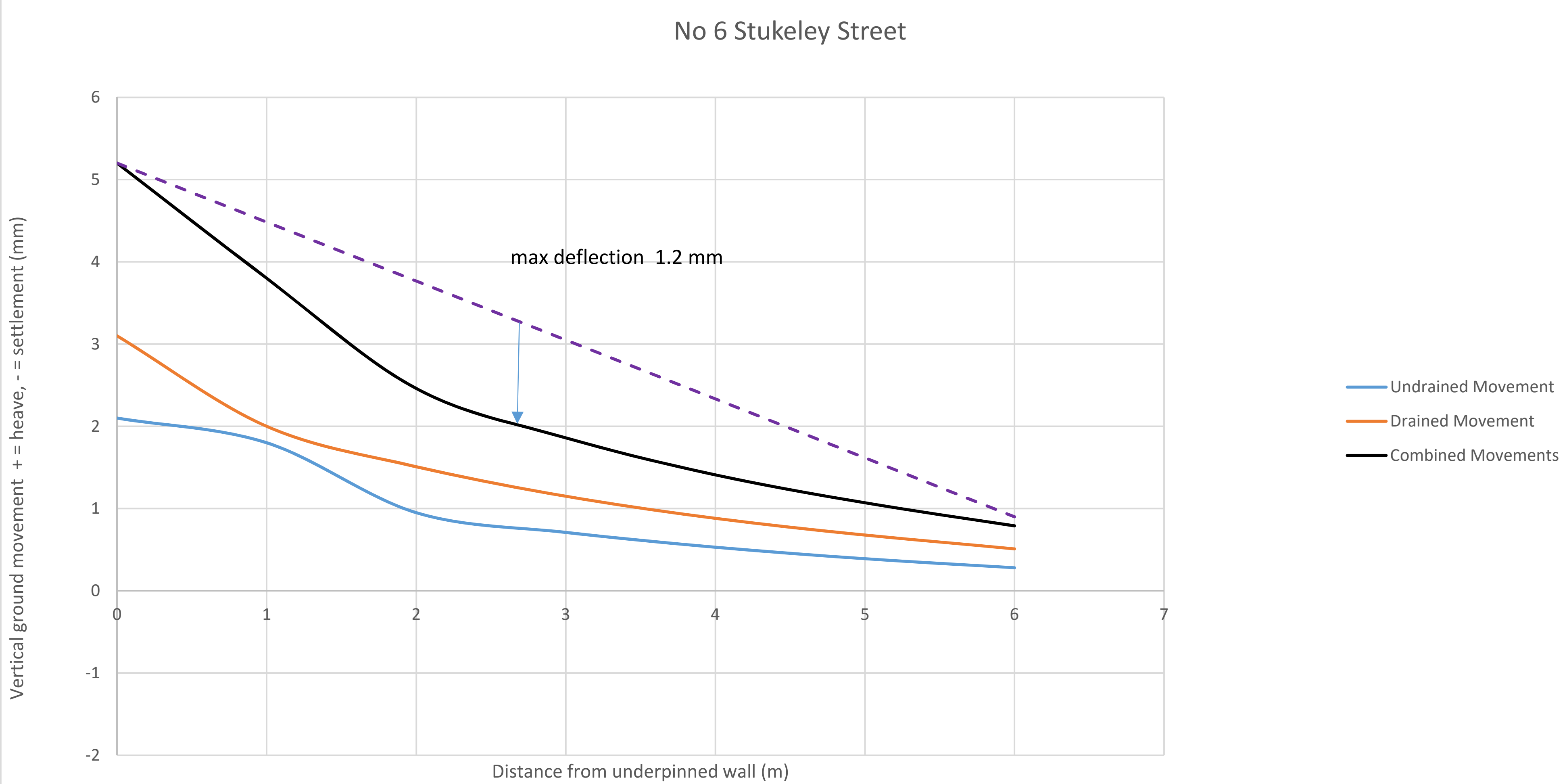
[attachment "Figure 2 Short term undrained rev 1.pdf" deleted by Liz Brown/CRH] [attachment "Figure 3 Long term drained rev.pdf" deleted by Liz Brown/CRH] [attachment "Figure 4 VM No 6 rev 2.pdf" deleted by Liz Brown/CRH] [attachment "Figure 5 VM No 12 rev 2.pdf" deleted by Liz Brown/CRH] [attachment "Figure 6 VM No 182 rev.pdf" deleted by Liz Brown/CRH] [attachment "Figure 7 Burland Damage Category rev 2.pdf" deleted by Liz Brown/CRH] [attachment "Figure 1 Basement Outline and Surrounding Properties including GMA sect....pdf" deleted by Liz Brown/CRH]



Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Combined Vertical Movements Section 1-1 (No. 6 Stukeley St)	4

Client		Project
Croft Structural Engineers Ltd.	MAUND GEO-CONSULTING	8-10 Stukeley St.

Job No.	Title	Figure
MGC/16/24	Combined Vertical Movements Section 2-2 (No. 12 Stukeley St)	5

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