

SMITHY BRIDGE ROAD, ROCHDALE

SLOPE STABILITY RISK ASSESSMENT

Job Number: LKC 22 1183

Date: August 2022

Client: Taylor Wimpey Strategic Land (North)



INCREASING LAND VALUE

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LK Consult Document Verification			
Site Address	Smithy Bridge Road, Littleborough, OL16 2RY		
Report Title	Slope Stability Risk Assessment		
Job Number	LKC 22 1183 (LKC 18 1005)	Document Ref.	CL-602-LKC 22 1183-01
Date of First Issue	22 nd April 2022	Report Version	R2
Prepared By	Garth Brownsword	Reviewed By	Colin Wardle

Revision Record			
Revision No.	Date	Nature of Revision	Approved By
1	01/07/2022	Report updated to reflect most recent development plan (Drawing No. P21-2628-003, rev. M1 dated 09/06/2022)	CC
2	31/08/2022	Report updated to reflect most recent development plan (Drawing No. P21-2628-003, rev. Q dated 31/08/2022)	CC

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1 Introduction

1.1 Background

Taylor Wimpey Strategic Land (North) (TWSLN) have commissioned LK Consult (LKC) to carry out a slope Stability Risk Assessment (SRA) for a proposed residential housing development of 166 plots in Greengate, off Smithy Bridge Road, Littleborough, OL16 2RY. The LKC Phase 2 Report (ref. CL-602-LKC 18 1005-02 R5, dated August 2022) should be read in conjunction with this report.

The site is approximately 500m long and varies in width between 200m and 130m. The development will be constructed on a gently sloping valley side to the north-west of the River Roch, (see Photograph 1.1). The elevation of the site is above the flood plain and is above (but in close proximity to) the steep sided river terrace (see Photograph 1.2).



Photograph 1.1, Panoramic View of Site from SW through to NE (photo taken 07Apr22).

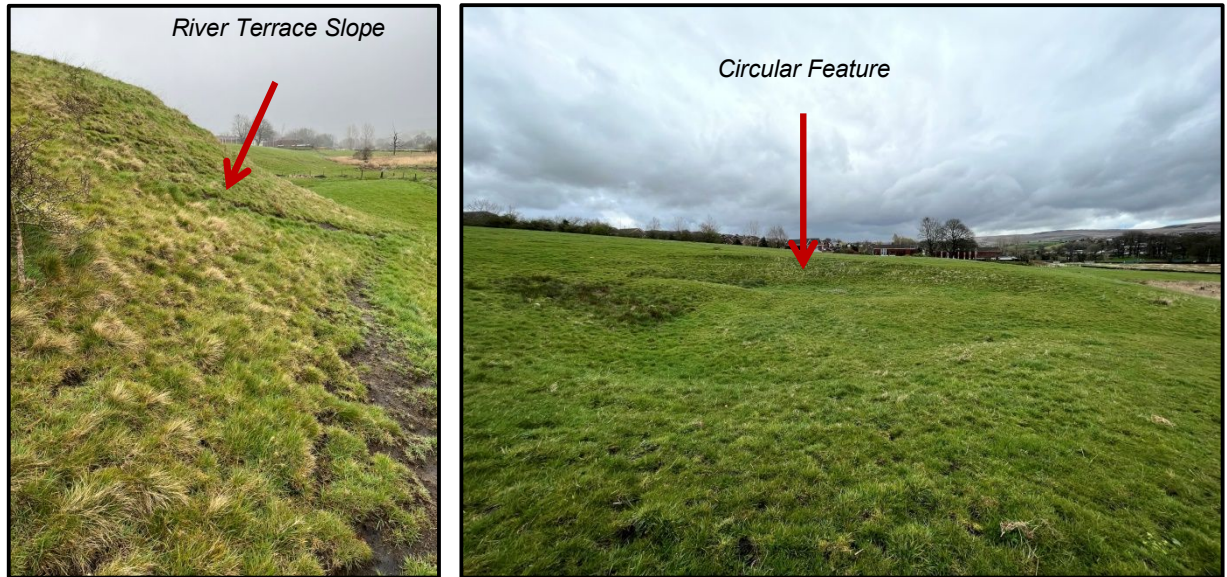
This SRA includes:

- » Results of a site reconnaissance carried out on by a suitably qualified and experienced Geotechnical engineer.
- » Slope stability modelling using the latest software.
- » A risk assessment of the proposed development site layout and slope stability.

1.2 Scope of this Stability Risk Assessment

The scope of this report is to follow the guidelines in carrying out a stability risk assessment as recommended on the official Government website <https://www.gov.uk/guidance/land-stability> with the purpose of assessing the proposed development for the risk of instability. With respect to the proposed layout, worst case conditions have been assessed for stability including (but not limited to):

1. Steepest gradient sections of existing slopes and steepest gradients of proposed final levels.
2. Ground upslope of crest areas adjacent to river terrace slopes with indications of observed instability such as backscarps and near-surface solifluction and/or soil creep downslope of sections of the proposed development.
3. A noticeable circular feature with steep side slopes as seen during the reconnaissance and visible on mapping (see photograph 1.3).
4. Pertaining to above slope areas, modelling of variable loads such as surcharge due to trafficking and proposed permanent building loads near to the crest of the steepest slopes such as the river terrace slope.
5. Only natural slopes and proposed 'fill to final earthwork levels' have been modelled (i.e. no slope stabilisation measures or retaining structures have been modelled).



Photographs 1.2 and 1.3, view of Steepest Slope at Site (river terrace slope) and view of Circular Feature.
(Photographs taken 07Apr22 looking NE).

1.3 Ground Investigations, Mapping and Previous Information

A Preliminary Risk Assessment (PRA) desk study report was undertaken by Betts Geo-Environmental in August 2017 (ref. 17TAY040/DS) and the results are also reported by LKC in their geo-environmental report issued August 2022 (ref. CL-602-LKC 22 1183-02 R5) titled *Phase 2 Geo-Environmental Investigation, Risk Assessment and Remediation Strategy*. It is recommended that the aforementioned reports are read in conjunction with this SRA report.

The above LKC report includes results of a site investigation carried out February-March 2018 involving 24no. window sampler boreholes, 27no. trial pits, 4no. follow-on dynamic probe holes, 15no. dynamic cone penetration holes, and a trial trench to assess the near-surface for a possible coal mine entry (mine shaft).

1.3.1 Mapping and Site History

The site has been mapped as open undeveloped fields since 1851 to the present day. It is worth noting the following aspects that may impact the stability of the site:

- » Natural springs are mapped in the near locality in similar elevations and geomorphological contexts as our site.
- » A stream (tributary to R. Roch) runs along the eastern site boundary and appears to be diverted, channelled or culverted to the north of the 'Old coal pit'.
- » An 'Old coal pit' and 'chimney' is mapped on the OS 1891 map within the site boundary but at the eastern extremity of the site, directly adjacent to Smithy Bridge Road. In the same location a coal shaft is mapped by the Coal Authority as presented in the Coal Authority's online Interactive Map, <https://mapapps2.bgs.ac.uk/coalauthority/home.html>, (location 'Smithy Bridge').
- » Numerous coal shafts, mine entries and collieries are noted in the surrounding parishes but are outside of the site's boundary. The site is not within the Coal Authority's *Development High Risk Area* and the nearest *Past Shallow Coal Mine*

Workings are approximately 70m to the north of the site's boundary in the proximity of streets named Wuerdle Place and Old Road.

» British Geological Survey (BGS) Sheet 76 (Rochdale) Bedrock and Superficial (published 2008), shows the proposed 'for-construction' development area is covered entirely by drift described as 'Till' (of glacial origin) and described as *clay to sandy clay, unsorted, with common pebbles, cobbles and some boulders*. The site is also located within a glacial channel. The solid geology map (sheet 76, Rochdale) shows the type of bedrock underlying the glacial till. The bedrock is described as Milnrow Sandstone (10 – 40m thickness) of the Lower Pennine Coal Measures. The sheet's key shows the existence of 2no. coal seams at the top of the Milnrow Sandstone formation, namely Cemetery Coal and Pasture Coal, but these seams are not shown as present on the map of the site area. The generalised dip of the Milnrow beds at the site is shown in the same direction as the valley side, i.e. NW to SE.

» With respect to the proposed 'for-construction' layout and depth to bedrock, LKC's ground investigation undertaken in 2018 reports the following bedrock information:

- West of the site – bedrock ranges between c.4.4mbgl and c.3.1mbgl. In terms of elevation bedrock reduces from 151.7mAOD to c.132mAOD. On the flood plain bedrock is c.1.9mbgl (c.129.3mAOD).
- Central part of the site (along line of section as presented in Plate 1.1) – bedrock ranges between c.3mbgl and c.7.4mbgl i.e. between 139mAOD and 134mAOD. On the flood plain bedrock is c.5.5mbgl (c.126.5mAOD).
- East of the site - bedrock ranges between c.2.3mbgl and c.7mbgl i.e. between c.147.3mAOD and c.133mAOD. On the flood plain bedrock is c.8.1mbgl (c.124.5mAOD).

» With respect to stability modelling, the site's ground conditions, soil type/strength, depth to water table and soil horizons are discussed section 3.2.

1.4 Site Boundary

The site boundary has been taken from AutoCAD drawing *Smithy Bridge Road Proposed Site Layout* ref. no. P21-2628-003 issued by Pegasus Group 19/10/21.

1.5 Slope Gradients, Surface Geometry and Associated Stability Hazards

The site area is approximately 11.7Ha with a perimeter of c.1,650m. The site and adjacent downslope areas are split into 5 distinct sections of gradient.

1. Flat area (flood plain):

- Downslope of the development area equating to the river valley bottom and flood plain. The river water level was surveyed at 131.56mAOD near Smithy Bridge Road, 130.44mAOD approximately halfway downstream and 129.48mAOD adjacent to the western site boundary of the river. The drop in river level is approximately 2.00m for the length of the site. The average flood plain elevation is roughly 1.50m above the river water level, for example adjacent to the steep river terrace shown in Photograph 2 the flood plain elevation is c.131.88mAOD. None of the stability of the development and construction layout is affected by this area.

2. Steepest slopes (river terraces):

- River terrace slopes follow the general alignment of the River Roch, the steepest slopes being in the middle of the site nearest the river, and shallower river terrace gradients are to be found in the eastern and western parts of the site. The steepest river terrace slopes are directly downslope of the development area at the proposed locations of plots 62 and 63 (as seen in Photograph 1.2). Here the slope gradient is 1v:1.9h with crest to toe elevations of c.141.00 to c.132.00mAOD, i.e. total vertical height of between 9m and 10m. The proposed southern access road is shown overlying 'filled' parts of the upper river terrace slope at this particular location. This slope is where the slope stability software modelling has been carried out (see line of section in Plate 1.1).
- The western river terrace slopes are of shallow gradients, lesser vertical height and the crest is at least 50.00m downslope of the proposed developments, and as such do not pose significant slope stability hazard. The steepest eastern river terrace slopes are downslope of plots 5 through 9 which are 1v:5h in gradient (c.10°) with vertical height of 6.00m to 7.00m. These plots are approximately 9.00m back from the crest (at the nearest point of the buildings). As such this slope geometry does not pose a significant slope stability hazard but a risk assessment is still required which takes into consideration the reconnaissance results and ground profiles.

3. Relatively gentle slope (river valley side):

- The proposed layout plan utilises the gentle slopes of the River Roch's valley for the actual residential and highways construction area. The uppermost elevation is c.156.00mAOD (in the NW of the site) and the lowest elevation is c.135.00mAOD (for the access road adjacent to Smithy Bridge Road). The slope gradient for all plots and roads inside the construction area is between 1v:11h and 1v:14h. At these gentle gradients the majority of the proposed site development has favourable slope stability, and as no instability was seen during the site reconnaissance, and bedrock is relatively shallow, there is no necessity to carry out slope modelling for the majority of the site.

4. Relatively steep short slopes (associated with tributary of River Roch):

- A steep but relatively short slope aligned approximately NW-SE and associated with a tributary of the River Roch runs along part of the eastern site boundary and has plots 16 through 27 located along the crest, (see Photograph 1.4). The steepest global slope is 1v:5h with a vertical height of c.4.50m as mapped on the given topographical data. Locally the slope may be 1v:3h but with vertical height in the range of 2.00m to 3.00m.

5. Relatively steep short slopes (associated with a circular feature):

- The development layout map as described in section 1.4 above shows that the circular feature (as shown in Photograph 1.3) will be backfilled and covered by the southern access highway adjacent to plots 49 and 50. The base of this feature has an elevation of 137.60mAOD and an upper crest of 141.46mAOD, i.e. a vertical drop nearly 4.00m and a steepest slope of approximately 1v:3h. As the feature will be backfilled to crest level the slope hazard will effectively be removed. However, as the feature may be representative of other possible stability hazards the risk assessment (in section 2.3) will include a further assessment of this feature, including assessment of the ground profile as encountered in the trial pits and window samples, and described in LK report and logs of boreholes. There may be a possibility of ground instability linked to the possibility of shallow coal

mining or other legacy of coal mining or quarrying. Further discussion and recommendations about this feature and potential hazards are presented in Section 3.



Photograph 1.4: Eastern site boundary - short relatively steep slope.

1.6 Lines of Sections for Slope Stability Modelling

An extract of the topographical site plan is presented in Plate 1.1 and the full site layout drawing is presented in Appendix (Figure 3). The site levels have been taken from the supplied topographical information.

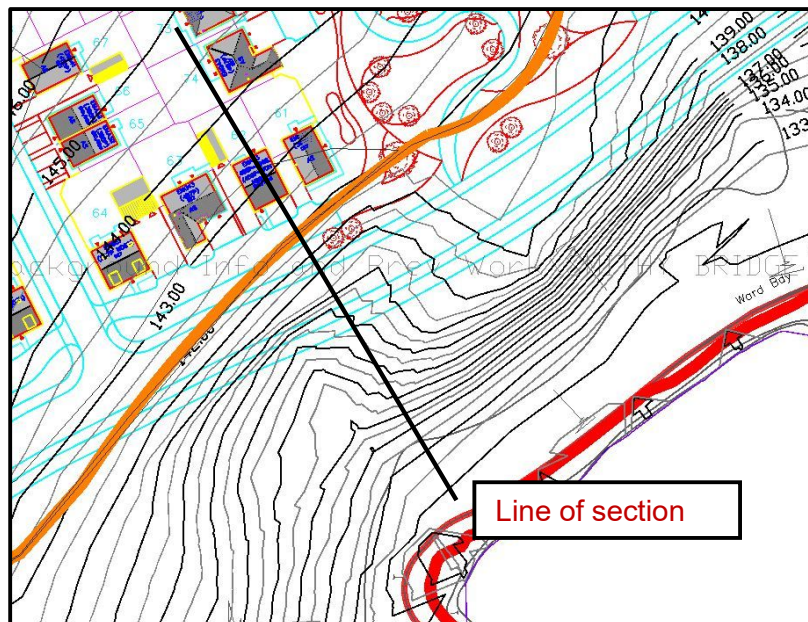


Plate 1.1: Line of Section Adjacent and Downslope of Plot 61 and Highway on crest of River Terrace: (Drawing source: Proposed Site Layout ref. no. P21-2628-003 Rev. M issued by Pegasus Group 09/06/22). Note the plot layout has not changed to Rev. Q.

2 Site Reconnaissance

2.1 Methodology.

A site visit and assessment of the existing slope and surroundings (including upslope and downslope of the proposed development) was carried out on Thursday 7th April 2022. The site reconnaissance was undertaken by suitably qualified and experienced geotechnical engineer Mr G. Brownsword, BSc, MSc, FGS. The general approach employed to reconnoitre the site was to methods described in the Design Manual of Roads and Bridges (DMRB), Volume 4, Section 1, CD622 (formerly HD22/08) *Managing Geotechnical Risk* and CS641 (formerly HD41/03) *Maintenance of Highway Geotechnical Assets*. Regarding the intrusive ground investigation carried out by LKC in February and March 2018, the engineers and technicians complied with the site investigation codes of practice BS10175:2011 and BS5930:2015 during the investigation.

2.2 Field Observations and Existing Site Condition.

The site was reconnoitred to inform the stability risk assessment and to understand the site in relation its geotechnical and geological setting and to examine the proposed development site (including downslope and upslope) for observable signs of past or current instability and potential for future instability and/or slope failure in relation to the proposed development.

The steepest and most significant slope to model for stability of the proposed development is above the crest of the river terrace as shown on Photograph 1.2 and the line of sections for plot 61 and the proposed highway as presented in Plate 1.1. An image available on public domain website taken in 2021 shows this slope exhibiting localised near-surface slippage features. Confirming this near-surface instability, soil creep and solifluction features were also observed during the site reconnaissance (see Photograph 2.1).



Photograph 2.1: Near-surface instability observed during site visit.

No other areas of slope instability, slumps, slippages, tension cracks, or ground movements were observed within the proposed development area (or upslope/downslope of the proposed development area). Additionally, (not including the 'circular feature') no other slopes within the site or directly adjacent to site were observed of a steepness to impact on the stability of the proposed development or to warrant further assessment by stability modelling.

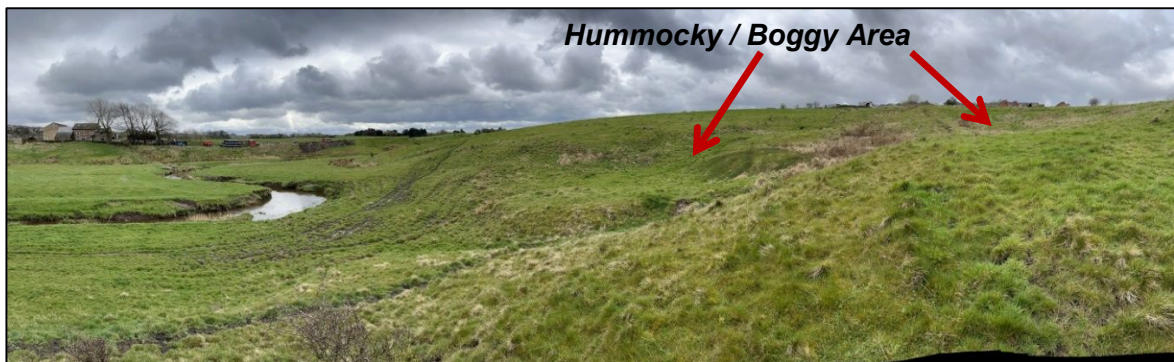
2.3 Circular Feature (Hollow).



Photograph 2.2: View North of Circular Feature and Steepest Slope to be modelled.

As seen in Photograph 2.2 above a circular 'hollow' was observed that could be either a natural or an anthropogenic feature but no evidence to verify its formation was forthcoming during the surveillance.

2.4 Hummocky and Boggy Area.



Photograph 2.3: Hummocky and boggy area. Photo taken in SW direction.

In the central lower part of the proposed site layout there is a hummocky and boggy area (see Photograph 2.3) that geomorphologically may be associated with a Quaternary period river meander cut into the hillside forming a 'semi-circular hollow' which may now exist as natural deposits consisting low strength soils. The proposed plots overlying this area are plots 68 through 72. Window sample borehole WS109 is located at the 'head' of the area but is above the hummocky/boggy ground therefore the makeup and nature of the soils in this locality are unknown. The proposed layout suggests that this area will be backfilled and as such it is recommended that during the construction period this area is excavated to remove the potential of compressible soft peaty organic clayey soils thus eliminating risk of unacceptable settlement to the aforementioned plots.

2.5 Site Stability Assessment (taken from site visit observations).

With the exception of the steeply sloping river terrace affecting plots 61 & 62 and the circular feature affecting plots 49 & 50 the overall assessment of the site reconnaissance is that the slopes and valley sides of the proposed development area are currently stable and that the proposed development will not impact the stability of the natural slopes (conditional on implementation of some minor mitigation and precautionary measures for the aforementioned plots and highway adjacent to plots 61 through 66).

3 Discussion Regarding Circular Feature

During LKC's ground investigation carried out in 2018 1no. trial pit (TP119) was excavated in the base of the hollow and 4no. window sampler boreholes sunk directly adjacent to the hollow (WS110, WS111, WS117 and WS118) as presented in Plate 3.1 below.

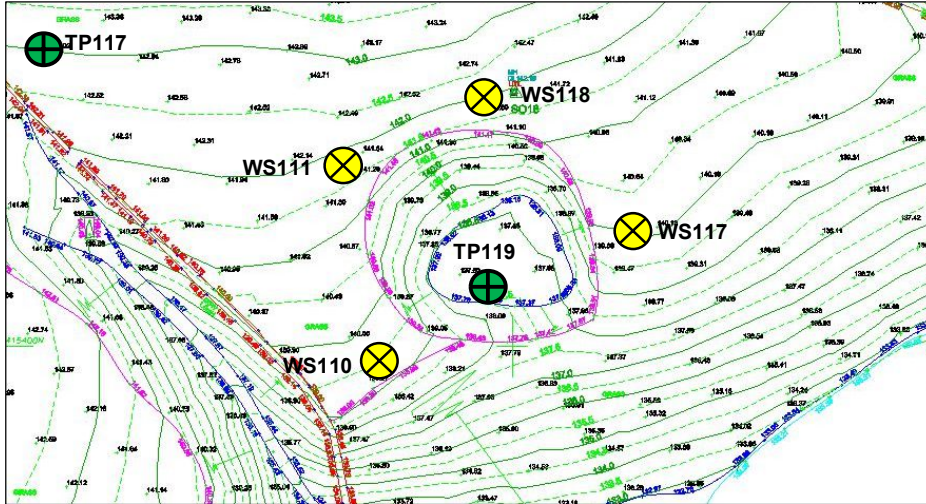


Plate 3.1: Contours of Circular Feature (extract from topographical survey entitled Topographical Survey of Land at Smithy Bridge, issued by Survey Operations, Skelmersdale, Sept 2017, ref. 17H112/004).

WS110 records firm clay to 2.90mbgl (137.08mAOD) with sand to 5.45mbgl (134.53mAOD). Water is encountered at 2.00mbgl (137.98mAOD). WS117 shows clay to 5.00mbgl (134.97mAOD) with the DP progressing to 10.00mbgl (129.97mAOD) without refusal.

WS111 records mudstone at 135mAOD (5.30mbgl) and WS118 records a DP value at 5.20mbgl (136mAOD) characteristic of bedrock. In WS118 below 4.60mbgl the formation was described as 'very iron stained'.

TP119 has 0.70m of made ground underlain by 1.70m of soft to firm sandy clay with sand present at the base of the pit at 2.50mbgl (135.20mAOD). Stagnant odours were noted in the lower part of the pit.

As mentioned in sections 1.5.5 and 2.3 this hollow in the ground could be either a natural or anthropogenic feature. If it is natural, then the soft wet clays in the hollow may be compressible and as such it is recommended during construction that the hollow is excavated to remove potentially compressible material and mitigate potential settlements.

However, before resorting to such measures it would be prudent to eliminate the possibility of anthropogenic origins such as unrecorded shallow coal mine workings (i.e. bell pits) or a mine entry (adit) or coal workings drainage tunnel. To eliminate the risks of shallow coal mine workings on site, a Mining Report has been undertaken by The Land Consultancy Limited (ref. Q316 SFK (TLC1004) rep CH rev. G, dated October 2019) and the LKC Access Road Remediation Strategy detailing recommended remedial works associated with the mineshaft off Smithy Bridge Road, letter dated 10th December 2019)

4 Stability Modelling and Results

4.1 Methodology

To characterise the site and derive the geotechnical parameters we have reviewed the results of the LKG site investigation and site reconnaissance, and reviewed geotechnical information including BGS borehole logs, historical maps, aerial photographs and geological maps.

Modelling of the site's pre-construction condition, temporary condition during construction and post development condition for global and localised slope and toe stability for the short & long term cases have been carried out to recognised optimised methods using GEO5© Geotechnical Engineering software (version 2019.63, hardware key 3676 / 1, operated by LK Consult Limited under licence from Fine Software, Czech Republic, www.finesoftware.eu).

The geometry and topography of the existing site and slopes were taken from the supplied geo-referenced topographical survey data and field measurements as outlined in section 1.4, topographical information.

Effective shear strength values for slope soils, made ground and natural soils underlying the site are based on findings of the LK site investigation, previous information, and site visits as outlined above.

Groundwater levels are interpreted from LK monitoring results and borehole/trial pit logs.

4.2 Ground Model and Geometry

The geometry and ground slope stability model is presented in Plate 4-1.

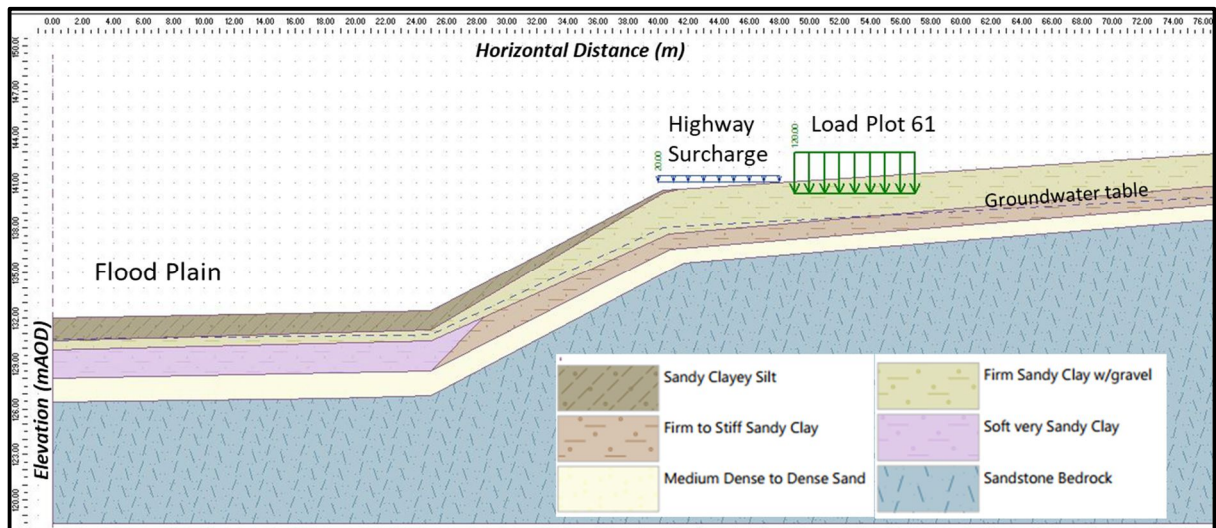


Plate 4-1: Ground model, worst case slope geometry and load cases. Line of section is presented in Plate 1.1.

The alignment of the cross section is shown in Plate 1.1 and the geometry is based on data in section 1.4 and drawings supplied to LKC. The worst case of the surface geometry (steepest slope and nearest road/plot to the crest edge) has been adopted. The ground model and geology are based on borehole logs and the site visit. The shear strength and density of individual strata used in the ground model are presented in section 4.3 below.

4.3 Parameters Used in Stability Calculations

Table 4.1 presents the parameters used in the stability calculations. The water table depth has been based on a moderately conservative site-wide variable level rising from

130.6mAOD (c.1.9mbgl) as recorded in WS114 on the flood plain, rising to 140.4mAOD (3.0mbgl) in borehole WS109.

Soil / Rock Type	Bulk Density kN/m ³	Saturated Density kN/m ³	Drained Shear Strength Values	
			ϕ°	c' kN/m ²
Sandy Clayey Silt	17.5	18.0	25	5
Firm sandy Clay with gravel	18.2	18.5	27	8
Soft very sandy Clay	17.5	18.2	24	2
Firm to Stiff sandy Clay	18.5	18.7	28	5
Medium Dense to Dense Sand	17.0	17.5	32	0.5
Sandstone Bedrock	19.5	20.0	35	30

Table 4.1: Parameters Used in Stability Modelling

Values for density for soils have been based on the conservative densities presented in British Standard BS 8004:2015 *Code of practice for foundations, Figures 1 and 2*.

As can be seen in Table 1 moderately conservative drained shear strength values for each strata type has been employed. The moderately conservative shear strength equates to middle values in the range of upper and lower bound strength envelopes interpreted from the GI information. Strength envelope values have been based on the following:

- » Triaxial Tests on cohesive samples recovered from investigations.
- » In-situ Hand Shear Vane and pocket penetrometer results in cohesive formation in trial pits and window samples.
- » In-situ SPT results from LK intrusive investigation and other GI data.
- » Interpretation of SPT values recorded in the ground investigations.
- » Angles of repose on observable stable slopes at the site.
- » Previous GI information at the site including laboratory data - relative density and 'stiffness' descriptions for local soil types in the area, including SPT information.
- » 'Realistic' modelling output results.

4.4 Model and Resistance/Load Cases

Long term 'drained' stability has been modelled. Model results and report sheets are presented in the Appendices. Slope stability modelling is an iterative process and modelling began by using the lower bound values. Increments in shear strength were employed where modelling outputs indicated 'unrealistic' factors of safety in relation to the observations made during the site visit and the overall stability of the site through the period since the 100+ years of Ordnance Survey mapping. Uniformly distributed loads and concentrated loads due to column and vehicle loads have been modelled. Localised, footprint stability and global slope stability were modelled for the 'existing condition' case.

The 'end of modelling' outputs and resultant factors of safety were based on the 'as interpreted' moderately conservative strength values for soils in the slopes demonstrating mobilised shear strength (and potential mobilised shear strength) without observable signs of long-term instability.

The slope stability risk assessment is based on realistic 'most likely' unfavourable modelled outputs as presented in Table 4.2. Highway surcharge is 20kN/m² and permanent footing loadings are 120kN/m².

4.5 Partial Factors and Limit State Factors of Safety.

The partial factors used are according to EC7 as presented in Appendix B. In parallel with EC7 utilisation outputs, limit state factors of safety have been calculated based on total

restoring forces divided by the destabilising forces. We have chosen the cut-off for unacceptability of slope stability as a factor of safety of <1.3 and EC7 utilisations of $>100\%$ after applying partial factors. The results of the slope stability modelling are presented in section 4.7.

4.6 Findings of Slope Stability Modelling

The summary of modelling results is presented in Table 4.2 overleaf and the detailed report sheets are presented in Appendix A.

Regarding the short- and long-term slope stability of the slope in its existing condition, the modelling results show an acceptable factor of safety for significant rotational and deep-seated potential slip surfaces.

Advisory information concerning 'digging at the toe' and 'stockpiling' during the construction phase and prevention of on-going minor natural slope slippages and soil are given in the 'recommendations' section overleaf.

Considering the representative groundwater table used, the modelling results show a satisfactory factor of safety for the case of short- and long-term global stability (significant and deep-seated slip circle).

Regarding the slope of interest, the site visit observations substantiate the results of the modelling and show that:

- » Its global stability (including upslope, downslope and lateral stability) is satisfactory.
- » The post development site and global stability (including upslope, downslope and lateral stability) is satisfactory.
- » The modelled factor of safety is satisfactory for medium and deep-seated slip surfaces.
- » Regarding the near-surface stability on the steepest slope, the modelled factor of safety is acceptable but as soil creep and small-scale slippages and back-scarps have been identified this slope's near-surface stability will be improved into the long term by installing slope drainage, for example as herringbone pattern perforated pipe/gravel filled drainage trenches. The risk assessment indicates that the marginal shallow stability can be mitigated to 'acceptable' status conditional on slope drainage measures being implemented.

4.7 Table 4.2 - Stability Report Summary

The results of the stability modelling are summarised in Table 4.2 and the full output sheets are presented in Appendix A. The results of the slope stability modelling are discussed in Section 4.6 on the previous page and the Slope Stability Risk Assessment is presented in Section 4.8.

Modelled Slip Circle and Depth	Depth of Potential Failure	Analysis Stage	Slip Surface Analysis	UDL Load kN/m ²	EC7 Combo DA/1	EC7 Combo DA/2	FoS (unfactored)	Acceptability
All potential slip surfaces	Near-Surface to 11m depth	Present Condition Existing Slope	Grid Search Multiple Slip Surfaces	none	-	-	1.84	Safe^①
Crest through to toe of slope	4.5m	Present Condition Existing Slope	Single Slip Surface	none	-	-	1.39	Safe
Crest through to toe of slope	5m	During Construction Access Road	Optimised (Multiple Slip Surfaces)	20 - Road	-	-	1.30	Safe
Near-surface to Deep i.e. Potential for Global Failure	Shallow and to 14m (into Bedrock)	Long Term (post construction) Access Road and Plot 61 built.	Optimised (Multiple Slip Surfaces)	20 - Road 120 - Foundations	91	96	1.30	Safe
Near-surface to Deep i.e. Potential for Global Failure	Shallow and to 14m (into Bedrock)	Long Term (post construction) Access Road and Plot 61 built.	Grid Search Multiple Slip Surfaces	20 - Road 120 - Foundations	-	-	1.55	Safe

Table 4.2: Results of Slope Stability Modelling based on Bishop Method.

Notes: FoS = Factor of Safety, UDL = Uniformly Distributed Load (i.e. surcharge from Access Road and Plot 61), Acceptability, ^① = Modelled with acceptable FoS but near-surface soil creep and slippages observed & past photo recorded. Moderately Conservative Groundwater Level has been modelled.

4.8 Slope Stability Risk Assessment

The slope stability risk assessment is summarised in Table 4.3.

Assessment Stage (i.e. site's existing condition / short term during construction / long term condition post construction) Size and Mode of Potential Slope Instability	Initial Stability Risk Assessment Condition	Measure to Mitigate Unacceptable Condition	Final Risk Assessment (after applying Mitigation Measures)
Construction Period and Long Term <u>Steep River Terrace Slope</u> Near-Surface Shallow Slippages and Soil Creep on slope surface	UNACCEPTABLE	Remove and re-profile areas of slippage with stone or reinforced earth (or soil nails) and install slope drainage and 'green' the slope with appropriate vegetation.	ACCEPTABLE
Long Term (Post Construction) <u>Steep River Terrace Slope</u> Potential Global Failure Potential Medium to Deep Failure	ACCEPTABLE	(NR)	ACCEPTABLE
During Construction <u>Steep River Terrace Slope</u> Shallow & Medium Depth Slope Failures	UNACCEPTABLE	No digging long deep trenches at slope toe. Leaving excavations open adjacent to the toe is not advisable. No Stockpiling at crest. No piling rigs or very heavy vibratory plant working at crest.	ACCEPTABLE
Construction Period and Long Term <u>Circular Feature</u> Potentially affecting Plots 49 and 50. Potential for unacceptable ground movements and settlements.	UNACCEPTABLE	Potential for Shallow Coal Mining Workings. Recommended to undertake geophysical and/or intrusive ground investigation to clarify existence or not of coal mining workings. Digging out of soft potentially compressible material.	ACCEPTABLE
Construction Period and Long Term <u>Hummocky / Boggy Area</u> Potentially affecting proposed Plots 63, 65, 66 and 67.	MARGINALLY UNACCEPTABLE	During construction period to excavate soft and potentially compressible material to mitigate potential settlement hazards.	ACCEPTABLE
Construction Period and Long Term <u>Short Steep Slope 1v:3h.</u> Plots 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26 and 27.	POTENTIALLY UNACCEPTABLE	Maintenance programme for upkeep of trees and shrubs which are needed for near-surface slope stability. Additional planting of grasses and ground stabilising vegetation where possible. Tree management & tree replacement with stability enhancing tree varieties. To enhance slope drainage any wet patches on the slope surface to be connected to site drainage by French drains or similar.	ACCEPTABLE

Table 4.3: Slope Stability Risk Assessment. (Notes: NR = Not Required).

5 Conclusions and Recommendations

5.1 Slope Stability

The site has been risk assessed for slope stability following official planning guidance and 'industry recognised' geotechnical assessment methods and slope stability software. The risk assessment takes into account the findings of on-site intrusive investigations and historical investigations, desk studies (including historical mapping, Coal Authority's website and BGS archives) and site reconnaissance by a suitably qualified and experienced geotechnical engineer.

The conclusion of this slope stability risk assessment (SRA) is that the majority of slopes at the site are generally of gentle gradient and will be inherently stable into the long term and safe to develop and build on.

There is one steep slope at the site (river terrace slope) of c.90m crest length with the potential to affect the stability of Plots 61 and 62 and the proposed highway running along the crest. In regard to this slope's medium depth and deep global stability, it has been assessed in this report as inherently stable into the long term (including road and building loads) with a factor of safety (unfactored) of 1.30 and an EC7 utilisation of 91% (DA/1) and 96% (DA/2). However, this slope has localised shallow near-surface marginal instability and it is recommended to remove and re-profile areas of localised slippage (back-scarps) with stone or reinforced earth (or soil nails) and install slope drainage and 'green' the slope with appropriate vegetation. This will ensure minimal maintenance of the slope in the long term and prevent continual on-going near-surface instability of the slope.

There is a 100m long crest of a 1v:3h short slope along the eastern border of the site which has the potential to affect the stability of plots 16 through 27 but this slope has been assessed with the proposed layout as having acceptable stability and does not warrant mitigation measures.

A hummocky and boggy area exists at the site with potentially soft compressible soils. To mitigate the potential settlement and ground movement risk, it is recommended during the construction period to remove soft and compressible material and replace with well compacted suitable granular material.

With regard to a 'circular feature' (hollow) to the east of the site that has the potential to affect the stability of Plots 49 and 50, this feature may be associated with unrecorded shallow coal mine workings, and it is strongly recommended to undertake further site and ground investigations to assess the ground conditions and risk of voids, shafts and/or thick deposits of potentially collapsible mine workings.

The recommendation of this SRA is that the following mitigation measures are carried out to mitigate on-going small scale shallow slippages:

- » Drainage of slopes, stoning slippage areas, re-profiling steepest slopes, soil nailing if necessary.
- » Maintenance programme for upkeep of trees and shrubs which are needed for near-surface slope stability.
- » Additional planting of grasses and ground stabilising vegetation where possible. 'Greening' of patches of bare earth.
- » Tree management & tree replacement with stability enhancing tree varieties.

- » Wet patches on the slopes and areas found to have high moisture contents are to be drained to enhance drainage of the near-surface soils. Installed slope drainage to be connected to site drainage.
- » Removal of soft and compressible material and replacement with suitable granular material.
- » It may be prudent to liaise with the Environment Agency and any other relevant bodies as to whether mitigation measures, such as the addition of rock armour or sacrificial gabions, may be required to prevent any future erosion of the toe of the slope by the River Roch either by meandering or flooding events.
- » Site visit and stability review at the start of site works.

5.2 Precautionary Advice during Construction Phase

The following informative advice is given:

- » Digging at the toe of the steepest slopes is not recommended.
- » Leaving excavations open at the toe of the steepest slopes is cautioned against.
- » Removal of vegetation on or close to the slope is not recommended.
- » Installation of drainage should be a priority.
- » No stockpiling and heavy operating plant at the crest of the steepest slopes.

Figures

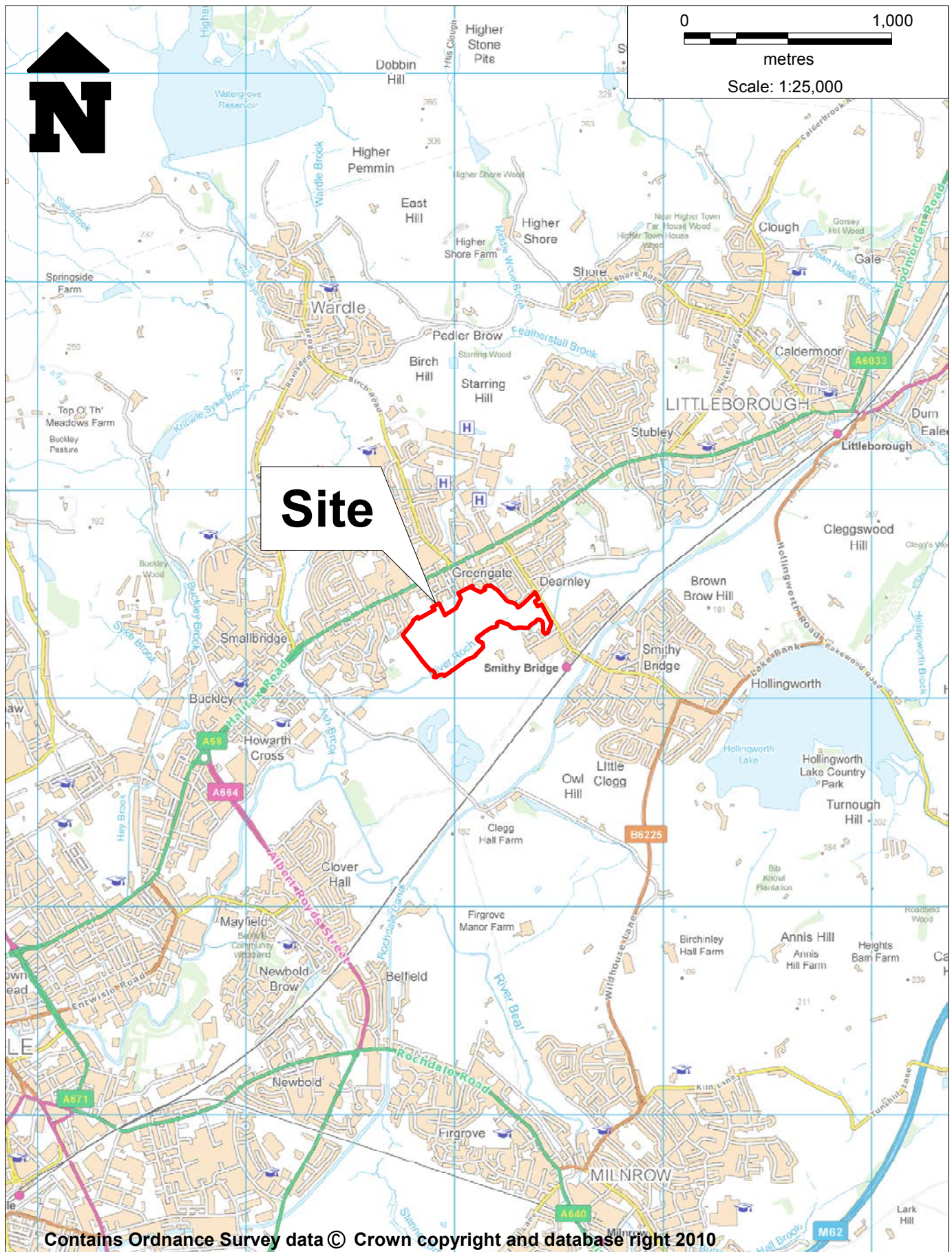
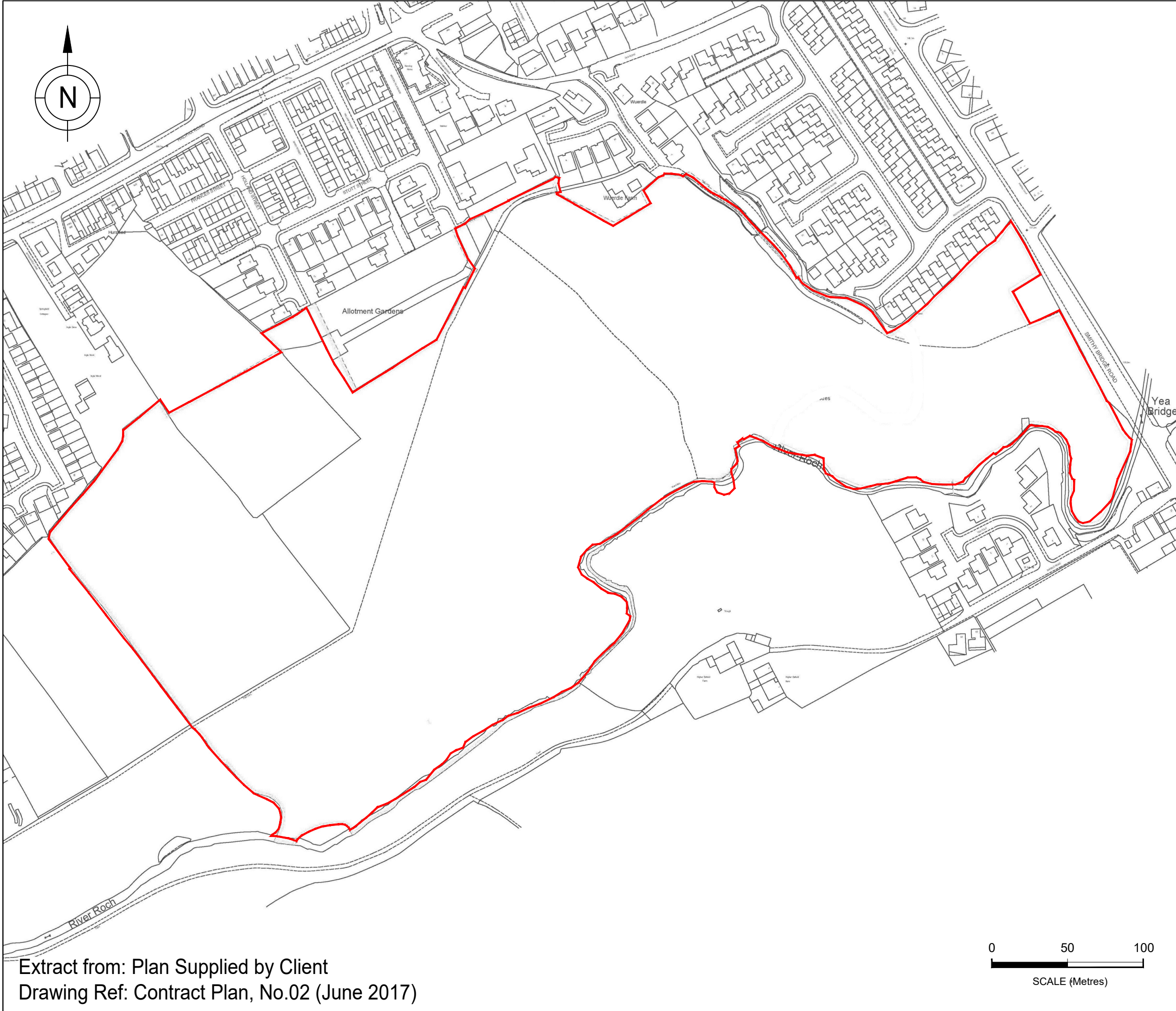


Figure 1: Site Location Plan, Smithy Bridge Road, Littleborough

Drawn: April 2018 Scale: 1:25,000 @ A4 (see scale bar)



KEY

 Site Boundary

Sampling Locations and features annotated by LK Consult Ltd are approximate and are based upon observed measurements unless otherwise stated. Do not scale from this drawing and work from marked dimensions only. All dimensions and features should be confirmed on site by the Contractor. Where this drawing includes information provided to LK Consult Ltd by others, LK Consult Ltd gives no warranty, representation or assurance as to the accuracy of such information.



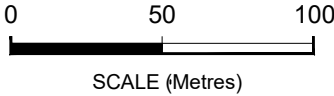
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Taylor Wimpey Strategic Land (North)

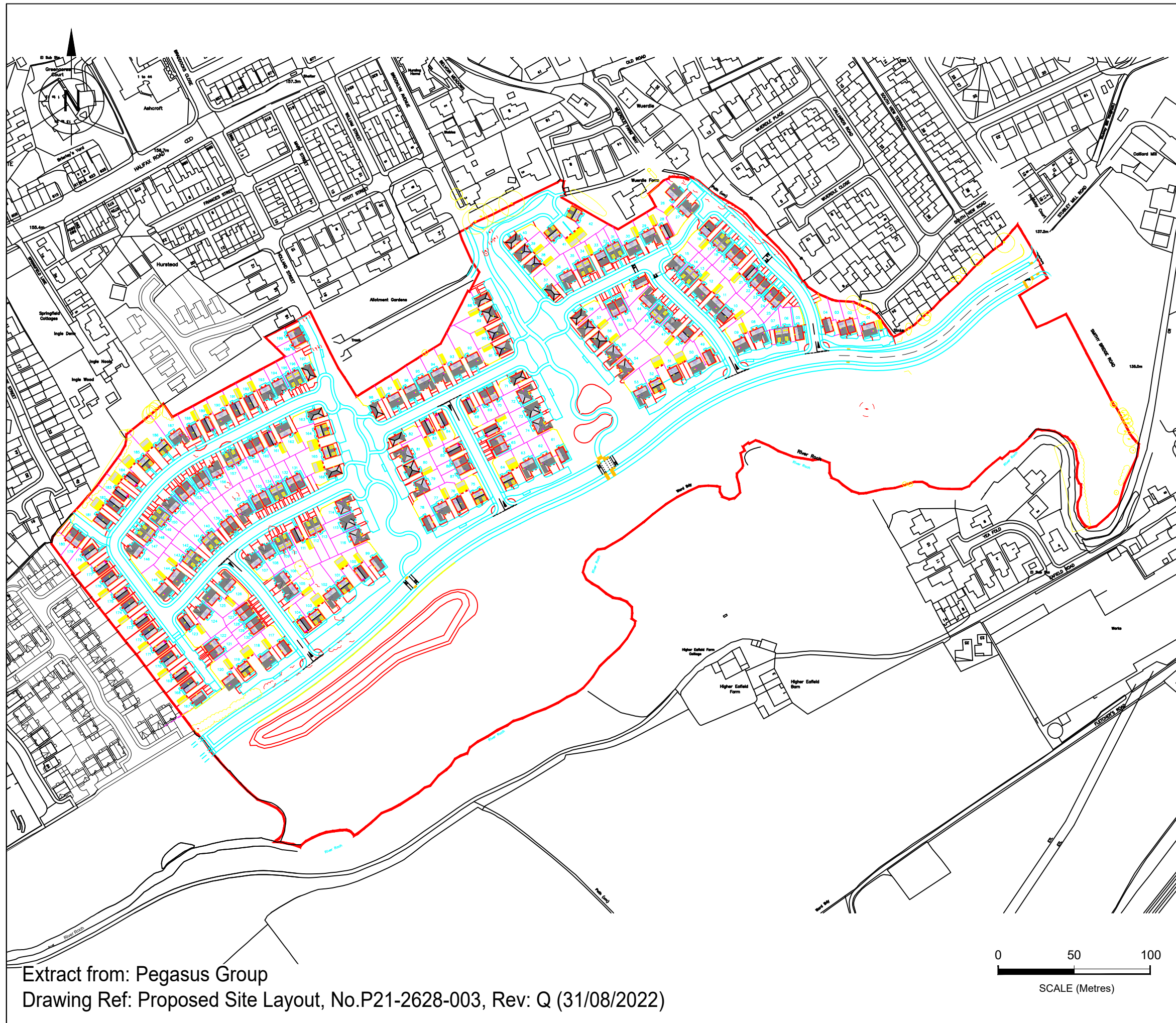
Site:
Smithy Bridge Road, Littleborough

Title:
Site Boundary Plan

Job No.:	Scale (See Scale Bar):	Figure:	Revision:
LKC 22 1183	1:2500 @ A3	2	
Drawn By:	Checked By:	Drawn:	
AC	EK	Jun 2022	

Extract from: Plan Supplied by Client
Drawing Ref: Contract Plan, No.02 (June 2017)





KEY

 Site Boundary

Sampling Locations and features annotated by LK Consult Ltd are approximate and are based upon observed measurements unless otherwise stated. Do not scale from this drawing and work from marked dimensions only. All dimensions and features should be confirmed on site by the Contractor. Where this drawing includes information provided to LK Consult Ltd by others, LK Consult Ltd gives no warranty, representation or assurance as to the accuracy of such information.



Client:
Taylor Wimpey Strategic Land (North)

Site:
Smithy Bridge Road, Littleborough

Title:
Proposed Development Plan

Job No.: LKC 22 1183	Scale (See Scale Bar): 1:2500 @ A3	Figure: 3	Revision: 1
Drawn By: CC	Checked By: EK	Drawn: Aug 2022	

Extract from: Pegasus Group
Drawing Ref: Proposed Site Layout, No.P21-2628-003, Rev: Q (31/08/2022)

0 50 100
SCALE (Metres)

Appendix A

Slope Analysis Report Sheets

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

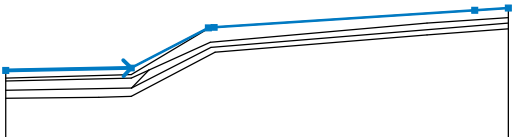
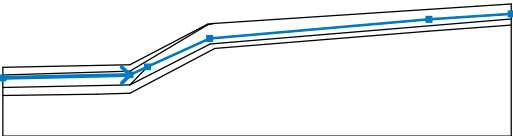
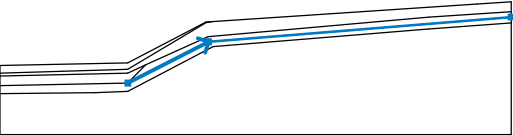
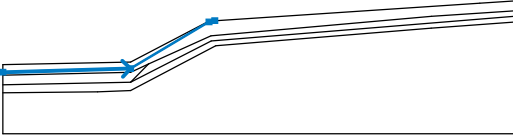
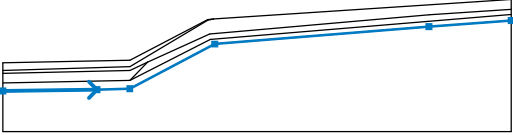
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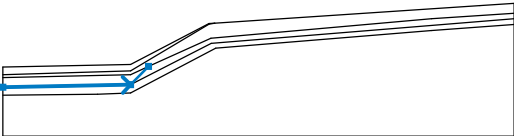
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

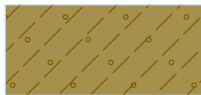
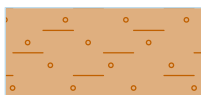
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

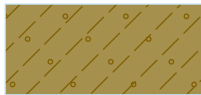
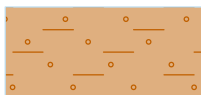
No.	Interface location	Coordinates of interface points [m]					
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		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

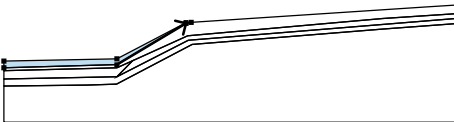
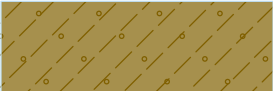
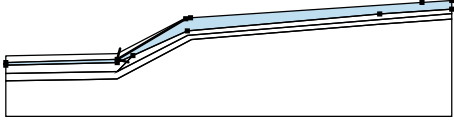
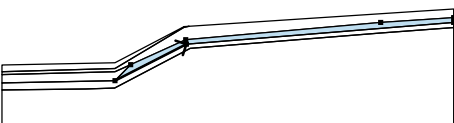
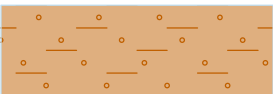
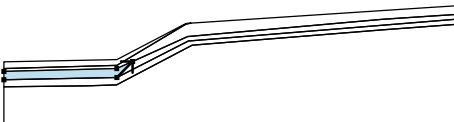
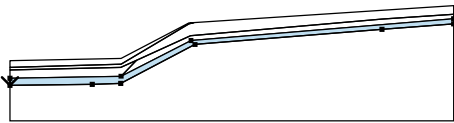
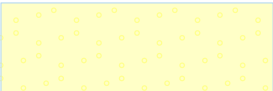
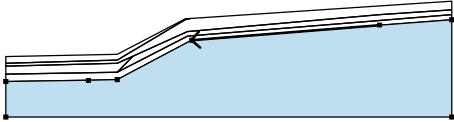
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil	
		x	z	x	z		
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt	
		41.45	140.58	40.30	140.50		
		25.00	132.50	0.00	132.00		
		0.00	130.50				
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel	
		0.00	130.50	0.00	129.90		
		24.99	130.50	28.48	132.08		
		40.70	137.63	83.83	141.41		
		100.00	142.49	100.00	144.44		
		93.30	144.00	41.45	140.58		
3		25.01	128.52	40.80	136.59	Firm to Stiff Sandy Clay	
		100.00	141.46	100.00	142.49		
		83.83	141.41	40.70	137.63		
		28.48	132.08				
4		25.01	128.52	28.48	132.08	Soft very Sandy Clay	
		24.99	130.50	0.00	129.90		
		0.00	128.04				
5		0.00	128.04	0.00	126.45	Medium Dense to Dense Sand	
		18.53	126.68	24.98	126.88		
		41.67	135.67	83.81	139.09		
		100.00	140.29	100.00	141.46		
		40.80	136.59	25.01	128.52		
6		83.81	139.09	41.67	135.67	Sandstone Bedrock	
		24.98	126.88	18.53	126.68		
		0.00	126.45	0.00	118.45		
		100.00	118.45	100.00	140.29		

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters					
Center :	x =	28.64 [m]	Angles :	α_1 =	-17.82 [°]
	z =	147.84 [m]		α_2 =	63.70 [°]
Radius :	R =	16.14 [m]			
The slip surface after optimization.					

Slope stability verification (Bishop)Sum of active forces : $F_a = 414.13$ kN/mSum of passive forces : $F_p = 575.21$ kN/mSliding moment : $M_a = 6684.09$ kNm/mResisting moment : $M_p = 9283.96$ kNm/m

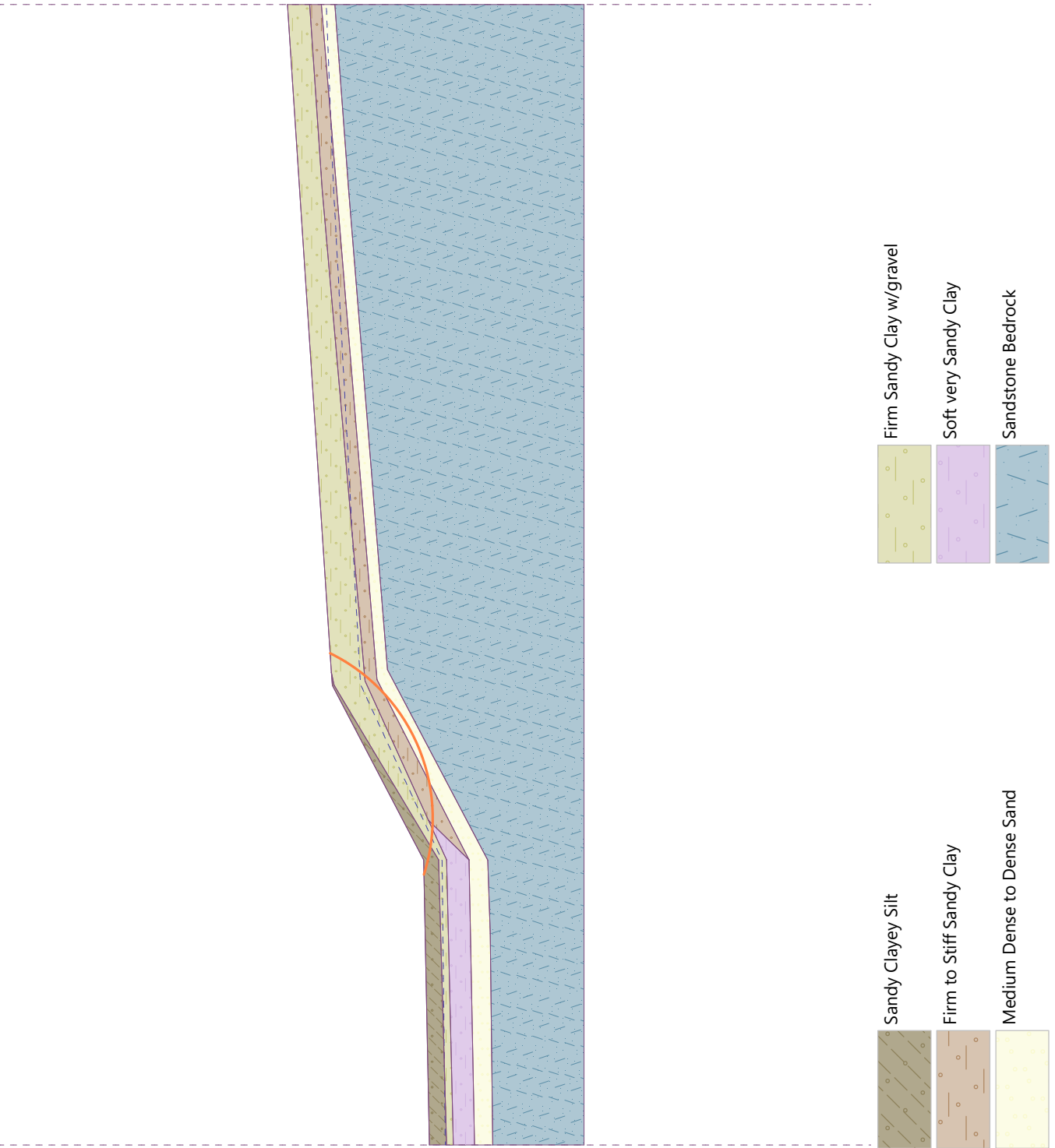
Factor of safety = 1.39 > 1.30

Slope stability ACCEPTABLE

G Brownsword

Name :

Stage - analysis : 1 - 1



The slip surface after optimization.

Slope stability verification (Bishop)

Sum of active forces : $F_a = 414.13 \text{ kN/m}$

Sum of passive forces : $F_p = 575.21 \text{ kN/m}$

Sliding moment : $M_a = 6684.09 \text{ kNm/m}$

Resisting moment : $M_p = 9283.96 \text{ kNm/m}$

Factor of safety = $1.39 > 1.30$

Slope stability ACCEPTABLE

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

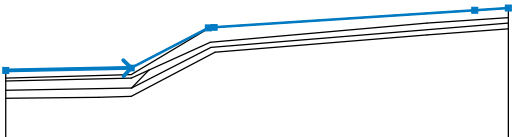
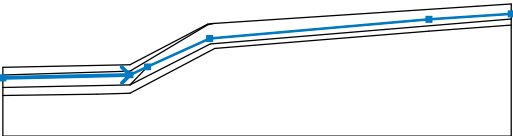
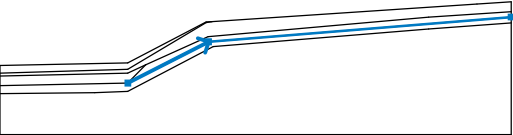
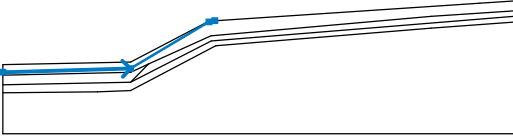
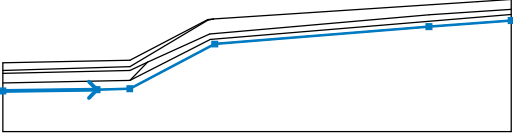
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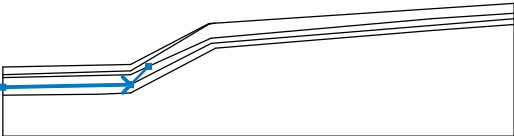
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

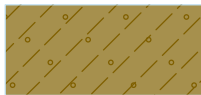
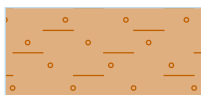
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

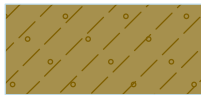
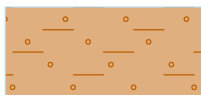
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
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		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

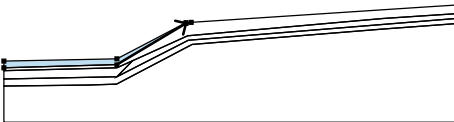
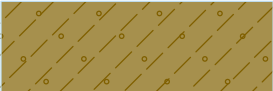
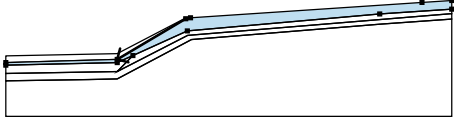
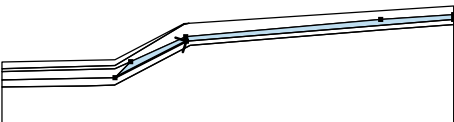
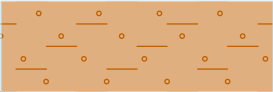
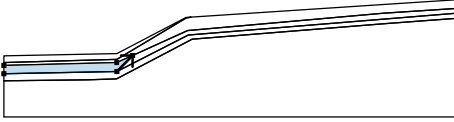
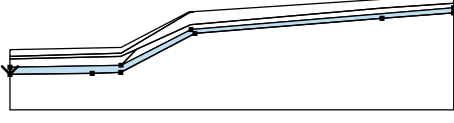
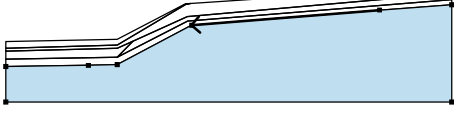
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil	
		x	z	x	z		
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt	
		41.45	140.58	40.30	140.50		
		25.00	132.50	0.00	132.00		
		0.00	130.50				
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel	
		0.00	130.50	0.00	129.90		
		24.99	130.50	28.48	132.08		
		40.70	137.63	83.83	141.41		
		100.00	142.49	100.00	144.44		
		93.30	144.00	41.45	140.58		
3		25.01	128.52	40.80	136.59	Firm to Stiff Sandy Clay	
		100.00	141.46	100.00	142.49		
		83.83	141.41	40.70	137.63		
		28.48	132.08				
4		25.01	128.52	28.48	132.08	Soft very Sandy Clay	
		24.99	130.50	0.00	129.90		
		0.00	128.04				
5		0.00	128.04	0.00	126.45	Medium Dense to Dense Sand	
		18.53	126.68	24.98	126.88		
		41.67	135.67	83.81	139.09		
		100.00	140.29	100.00	141.46		
		40.80	136.59	25.01	128.52		
6		83.81	139.09	41.67	135.67	Sandstone Bedrock	
		24.98	126.88	18.53	126.68		
		0.00	126.45	0.00	118.45		
		100.00	118.45	100.00	140.29		

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters							
Center :	x =	21.70	[m]	Angles :	α_1 =	4.03	[°]
	z =	189.27	[m]		α_2 =	31.88	[°]
Radius :	R =	56.55	[m]				
Slip surface after grid search.							

Slope stability verification (Bishop)Sum of active forces : $F_a = 378.79$ kN/mSum of passive forces : $F_p = 697.44$ kN/mSliding moment : $M_a = 21422.09$ kNm/mResisting moment : $M_p = 39442.91$ kNm/m

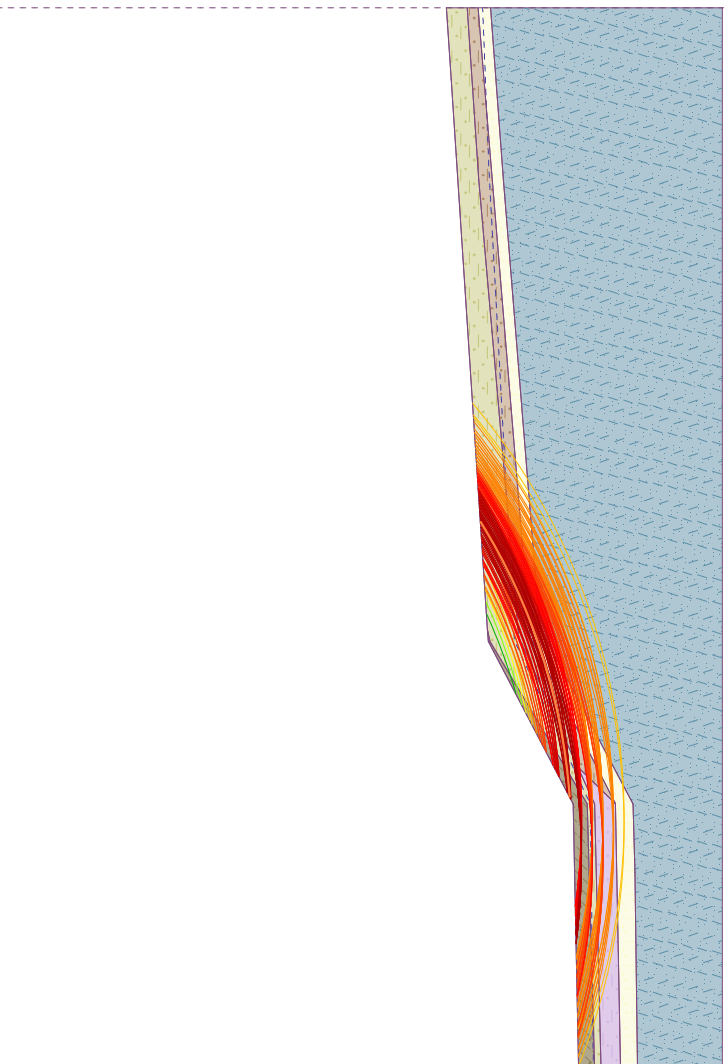
Factor of safety = 1.84 > 1.30

Slope stability ACCEPTABLE

Name :

Stage - analysis : 1 - 1

1.84
2.00
2.20
2.40
2.60
2.80
3.00
3.20
3.40
3.60
3.80
3.93



Firm Sandy Clay w/gravel



Soft very Sandy Clay



Sandstone Bedrock



Sandy Clayey Silt



Firm to Stiff Sandy Clay



Medium Dense to Dense Sand



Slip surface after grid search.

Slope stability verification (Bishop)

Sum of active forces : $F_a = 378.79 \text{ kN/m}$

Sum of passive forces : $F_p = 697.44 \text{ kN/m}$

Sliding moment : $M_a = 21422.09 \text{ kNm/m}$

Resisting moment : $M_p = 39442.91 \text{ kNm/m}$

Factor of safety = 1.84 > 1.30

Slope stability ACCEPTABLE

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

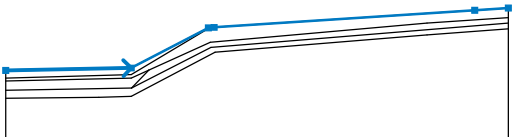
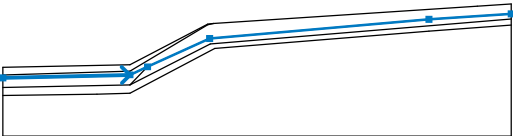
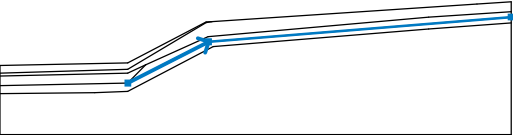
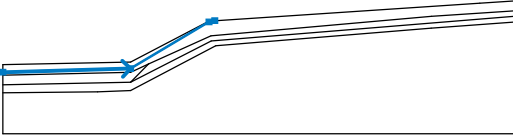
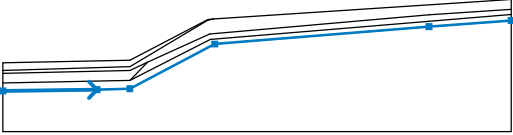
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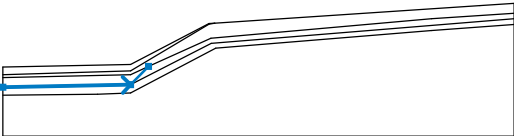
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

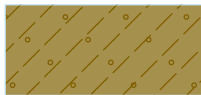
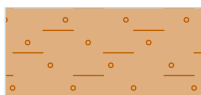
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

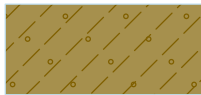
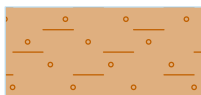
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0.00	132.00	25.00	132.50	40.30	140.50
		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

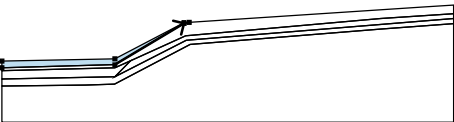
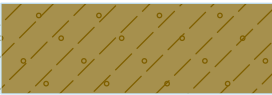
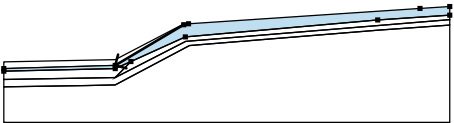
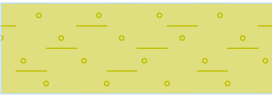
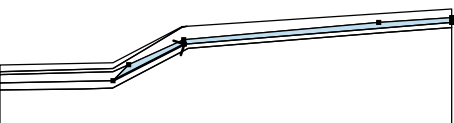
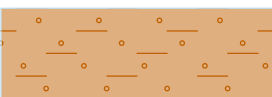
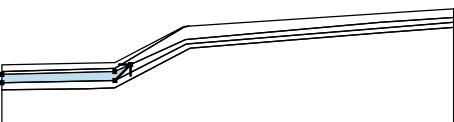
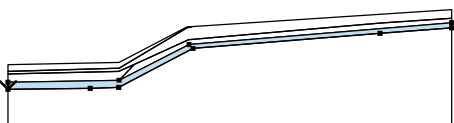
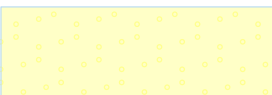
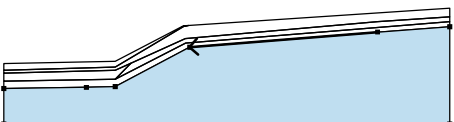
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt 
		41.45	140.58	40.30	140.50	
		25.00	132.50	0.00	132.00	
		0.00	130.50			
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel 
		0.00	130.50	0.00	129.90	
		24.99	130.50	28.48	132.08	
		40.70	137.63	83.83	141.41	
		100.00	142.49	100.00	144.44	
3		93.30	144.00	41.45	140.58	Firm to Stiff Sandy Clay 
		25.01	128.52	40.80	136.59	
		100.00	141.46	100.00	142.49	
		83.83	141.41	40.70	137.63	
4		28.48	132.08			Soft very Sandy Clay 
		25.01	128.52	28.48	132.08	
		24.99	130.50	0.00	129.90	
5		0.00	128.04			Medium Dense to Dense Sand 
				0.00	126.45	
		18.53	126.68	24.98	126.88	
		41.67	135.67	83.81	139.09	
		100.00	140.29	100.00	141.46	
6		40.80	136.59	25.01	128.52	Sandstone Bedrock 
		83.81	139.09	41.67	135.67	
		24.98	126.88	18.53	126.88	
		0.00	126.45	0.00	118.45	
		100.00	118.45	100.00	140.29	

Surcharge

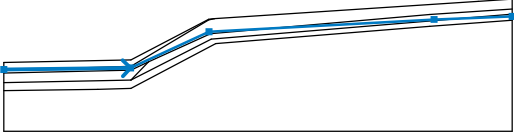
No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
								q, q ₁ , f, F	q ₂	unit
1	strip	permanent	on terrain	x = 40.00	l = 11.00		0.00	20.00		kN/m ²

Surcharges

No.	Name
1	Highway Surcharge

Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		0.00	130.61	24.96	130.89	40.37	138.04
		84.64	140.44	100.00	141.04		

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters					
Center :	x =	28.60 [m]	Angles :	α_1 =	-16.49 [°]
	z =	148.90 [m]		α_2 =	61.50 [°]
Radius :	R =	17.13 [m]			
Slip surface after grid search.					

Slope stability verification (Bishop)Sum of active forces : $F_a = 479.90$ kN/mSum of passive forces : $F_p = 624.66$ kN/mSliding moment : $M_a = 8220.69$ kNm/mResisting moment : $M_p = 10700.44$ kNm/m

Factor of safety = 1.30 > 1.30

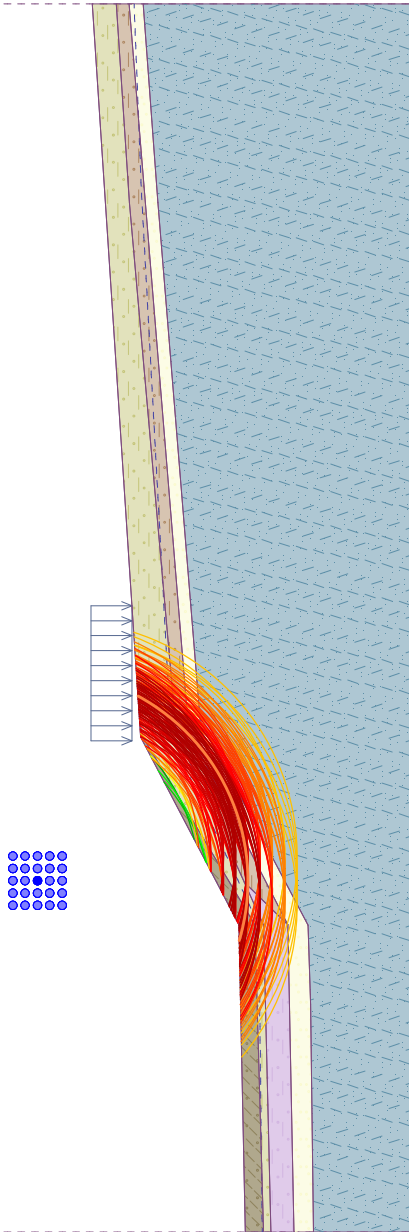
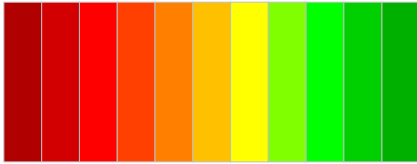
Slope stability ACCEPTABLE

G Brownsword

Name :

Stage - analysis : 1 - 1

1.30
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
3.00
3.20
3.26



Slip surface after grid search.

Slope stability verification (Bishop)

Sum of active forces : $F_a = 479.90 \text{ kN/m}$

Sum of passive forces : $F_p = 624.66 \text{ kN/m}$

Sliding moment : $M_a = 8220.69 \text{ kNm/m}$

Resisting moment : $M_p = 10700.44 \text{ kNm/m}$

Factor of safety = $1.30 > 1.30$

Slope stability ACCEPTABLE

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

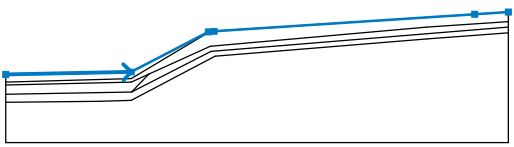
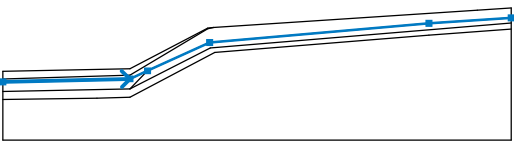
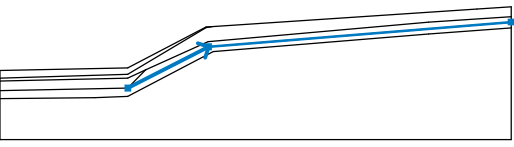
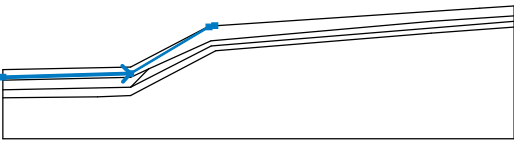
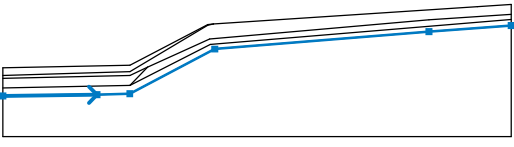
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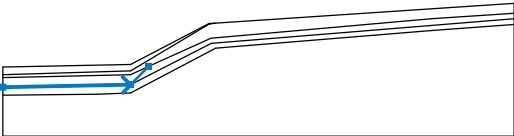
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

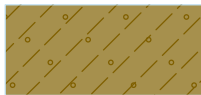
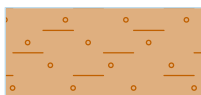
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

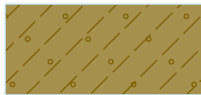
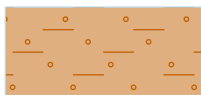
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0.00	132.00	25.00	132.50	40.30	140.50
		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

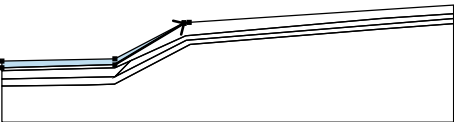
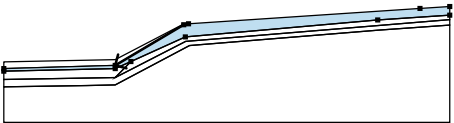
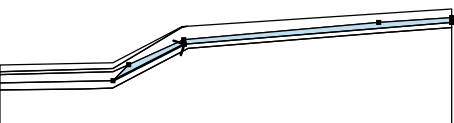
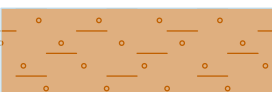
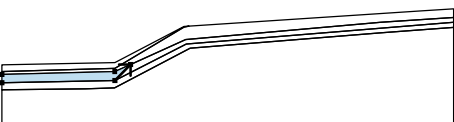
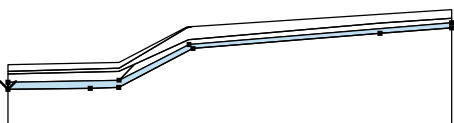
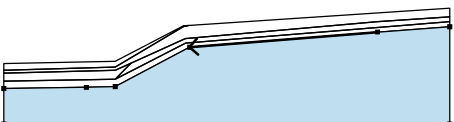
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt 
		41.45	140.58	40.30	140.50	
		25.00	132.50	0.00	132.00	
		0.00	130.50			
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel 
		0.00	130.50	0.00	129.90	
		24.99	130.50	28.48	132.08	
		40.70	137.63	83.83	141.41	
		100.00	142.49	100.00	144.44	
3		93.30	144.00	41.45	140.58	Firm to Stiff Sandy Clay 
		25.01	128.52	40.80	136.59	
		100.00	141.46	100.00	142.49	
		83.83	141.41	40.70	137.63	
4		28.48	132.08			Soft very Sandy Clay 
		25.01	128.52	28.48	132.08	
		24.99	130.50	0.00	129.90	
5		0.00	128.04			Medium Dense to Dense Sand 
				0.00	126.45	
		18.53	126.68	24.98	126.88	
		41.67	135.67	83.81	139.09	
		100.00	140.29	100.00	141.46	
6		40.80	136.59	25.01	128.52	Sandstone Bedrock 
		83.81	139.09	41.67	135.67	
		24.98	126.88	18.53	126.68	
		0.00	126.45	0.00	118.45	
		100.00	118.45	100.00	140.29	

Surcharge

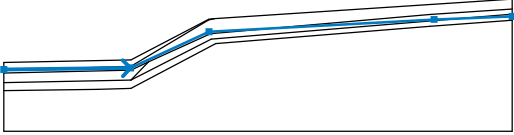
No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
								q, q ₁ , f, F	q ₂	unit
1	strip	permanent	on terrain	x = 40.00	l = 11.00		0.00	20.00		kN/m ²

Surcharges

No.	Name
1	Highway Surcharge

Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		0.00	130.61	24.96	130.89	40.37	138.04
		84.64	140.44	100.00	141.04		

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters					
Center :	x =	28.60 [m]	Angles :	$\alpha_1 =$	-16.49 [°]
	z =	148.90 [m]		$\alpha_2 =$	61.50 [°]
Radius :	R =	17.13 [m]			
The slip surface after optimization.					

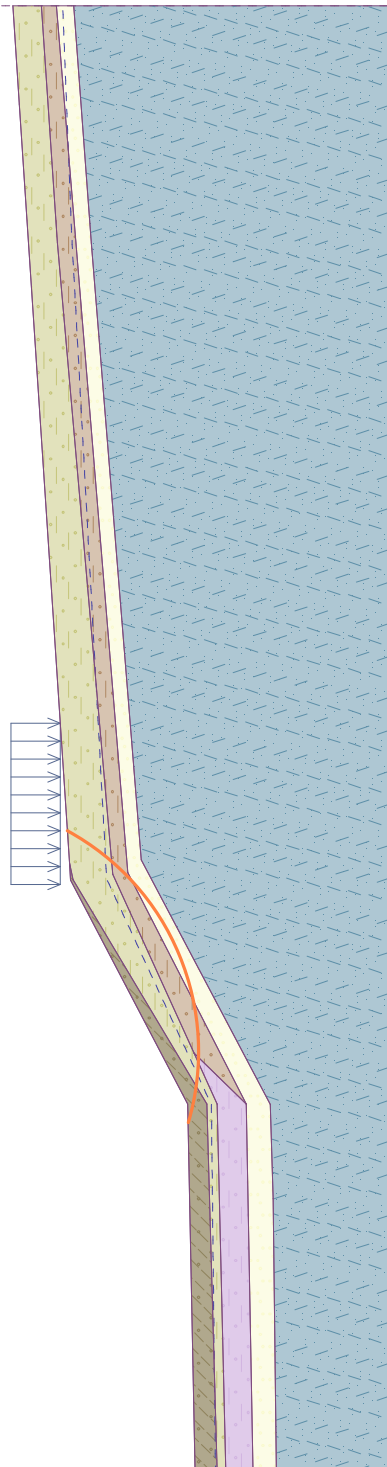
Slope stability verification (Bishop)Sum of active forces : $F_a = 479.90$ kN/mSum of passive forces : $F_p = 624.66$ kN/mSliding moment : $M_a = 8220.69$ kNm/mResisting moment : $M_p = 10700.44$ kNm/m

Factor of safety = 1.30 > 1.30

Slope stability ACCEPTABLE

Name :

Stage - analysis : 1 - 1



The slip surface after optimization.

Slope stability verification (Bishop)Sum of active forces : $F_a = 479.90 \text{ kN/m}$ Sum of passive forces : $F_p = 624.66 \text{ kN/m}$ Sliding moment : $M_a = 8220.69 \text{ kNm/m}$ Resisting moment : $M_p = 10700.44 \text{ kNm/m}$ Factor of safety = $1.30 > 1.30$ **Slope stability ACCEPTABLE**

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

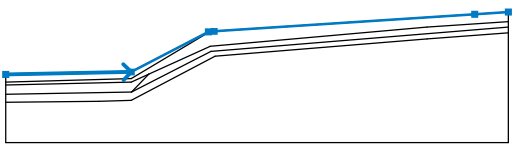
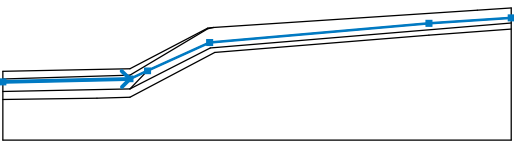
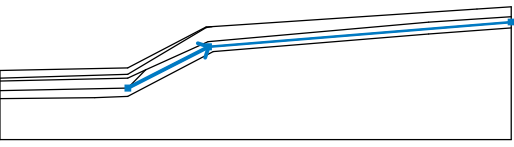
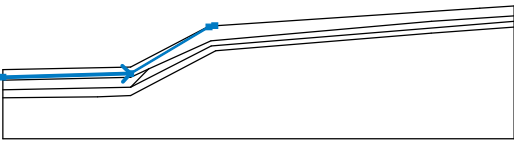
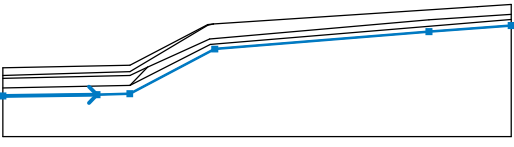
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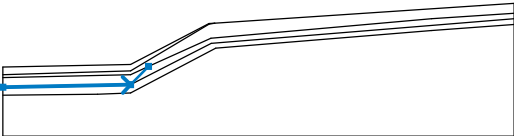
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

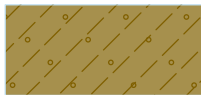
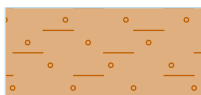
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

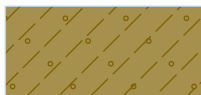
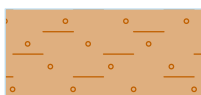
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0.00	132.00	25.00	132.50	40.30	140.50
		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

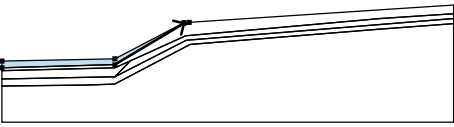
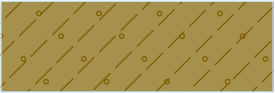
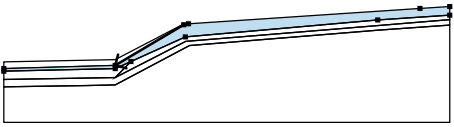
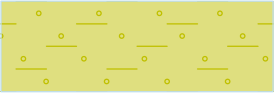
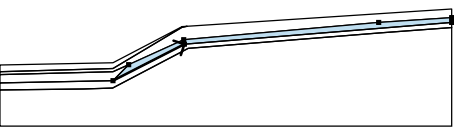
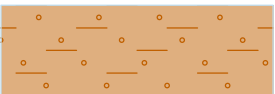
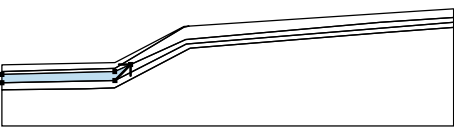
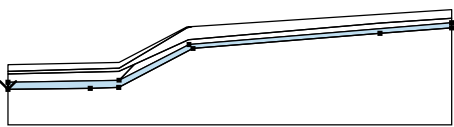
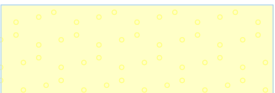
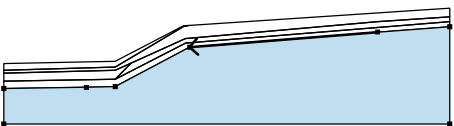
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt 
		41.45	140.58	40.30	140.50	
		25.00	132.50	0.00	132.00	
		0.00	130.50			
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel 
		0.00	130.50	0.00	129.90	
		24.99	130.50	28.48	132.08	
		40.70	137.63	83.83	141.41	
		100.00	142.49	100.00	144.44	
3		93.30	144.00	41.45	140.58	Firm to Stiff Sandy Clay 
		25.01	128.52	40.80	136.59	
		100.00	141.46	100.00	142.49	
		83.83	141.41	40.70	137.63	
4		28.48	132.08			Soft very Sandy Clay 
		25.01	128.52	28.48	132.08	
		24.99	130.50	0.00	129.90	
5		0.00	128.04			Medium Dense to Dense Sand 
				0.00	126.45	
		18.53	126.68	24.98	126.88	
		41.67	135.67	83.81	139.09	
		100.00	140.29	100.00	141.46	
6		40.80	136.59	25.01	128.52	Sandstone Bedrock 
		83.81	139.09	41.67	135.67	
		24.98	126.88	18.53	126.68	
		0.00	126.45	0.00	118.45	
		100.00	118.45	100.00	140.29	

Surcharge

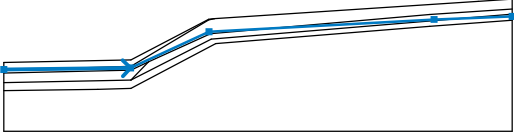
No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
								q, q ₁ , f, F	q ₂	unit
1	strip	permanent	on terrain	x = 40.00	l = 8.00		0.00	20.00		kN/m ²
2	strip	permanent	z = 140.25	x = 49.00	l = 8.00		0.00	120.00		kN/m ²

Surcharges

No.	Name
1	Highway Surcharge
2	Plot 61 foundation load

Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		0.00	130.61	24.96	130.89	40.37	138.04
		84.64	140.44	100.00	141.04		

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters					
Center :	x =	26.34 [m]	Angles :	α_1 =	-1.37 [°]
	z =	173.44 [m]		α_2 =	37.79 [°]
Radius :	R =	40.77 [m]			
Slip surface after grid search.					

Slope stability verification (Bishop)Sum of active forces : $F_a = 586.71$ kN/mSum of passive forces : $F_p = 907.72$ kN/mSliding moment : $M_a = 23917.44$ kNm/mResisting moment : $M_p = 37003.57$ kNm/m

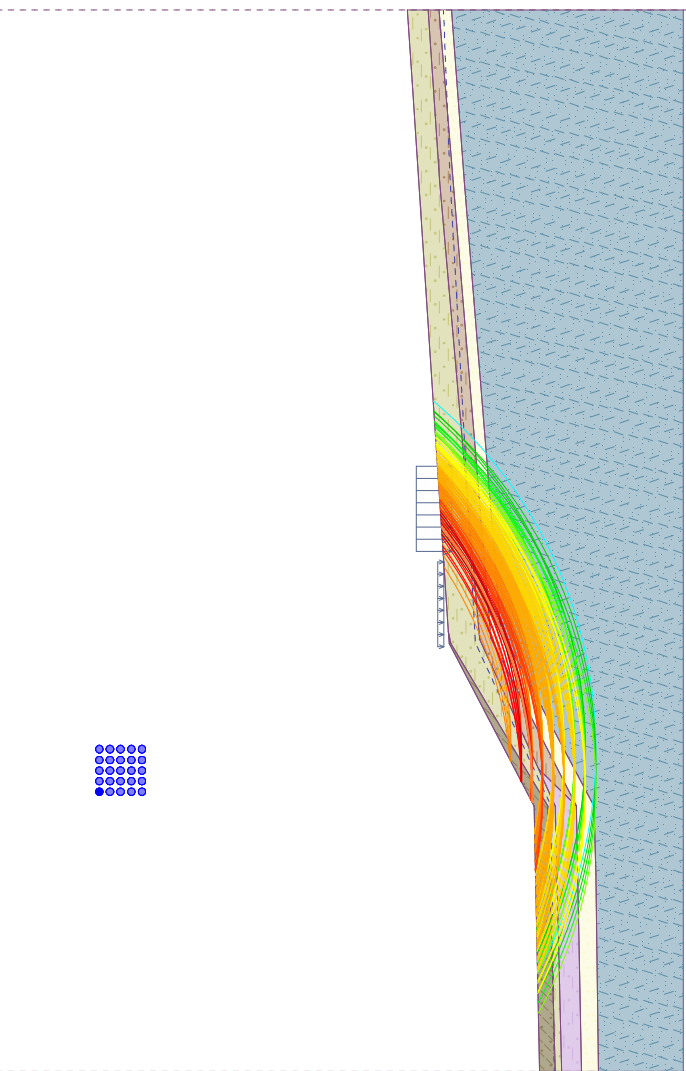
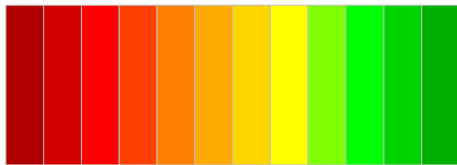
Factor of safety = 1.55 > 1.30

Slope stability ACCEPTABLE

Name :

Stage - analysis : 1 - 1

1.55
1.60
1.68
1.76
1.84
1.92
2.00
2.08
2.16
2.24
2.32
2.40
2.45



Firm Sandy Clay w/gravel

Soft very Sandy Clay

Sandstone Bedrock

Sandy Clayey Silt

Firm to Stiff Sandy Clay

Medium Dense to Dense Sand

Slip surface after grid search.

Slope stability verification (Bishop)

Sum of active forces : $F_a = 586.71$ kN/m

Sum of passive forces : $F_p = 907.72$ kN/m

Sliding moment : $M_a = 23917.44$ kNm/m

Resisting moment : $M_p = 37003.57$ kNm/m

Factor of safety = $1.55 > 1.30$

Slope stability ACCEPTABLE

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

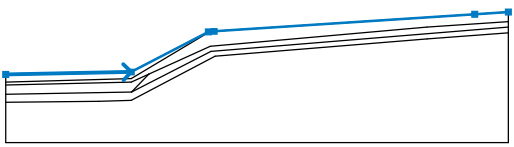
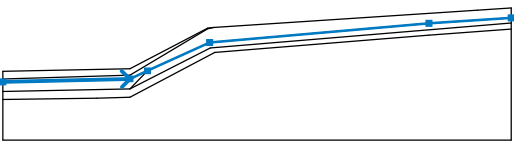
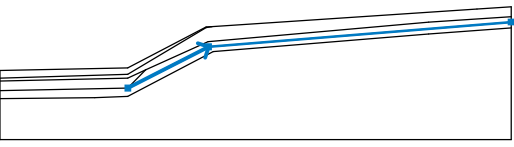
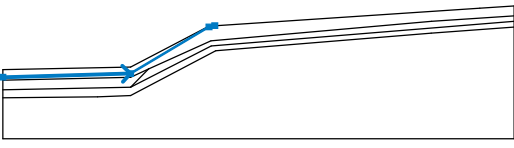
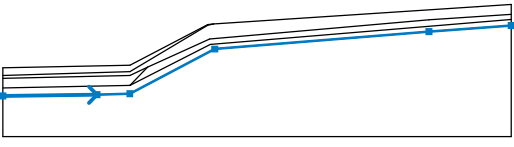
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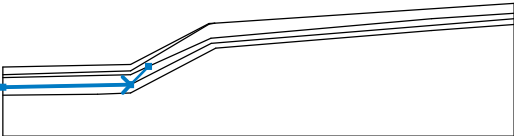
Stability analysis

Earthquake analysis : Standard
 Verification methodology : Safety factors (ASD)

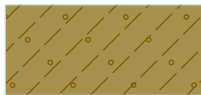
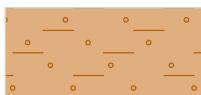
Safety factors			
Permanent design situation			
Safety factor :	$SF_s =$	1.30	[-]

Interface

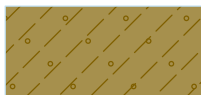
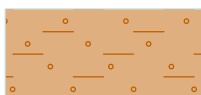
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0.00	132.00	25.00	132.50	40.30	140.50
		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
		41.45	140.58				
5		0.00	126.45	18.53	126.68	24.98	126.88
		41.67	135.67	83.81	139.09	100.00	140.29

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [–]
6	Medium Dense to Dense Sand		17.50		

Soil parameters**Sandy Clayey Silt**

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 25.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 27.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 24.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 28.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 18.70 \text{ kN/m}^3$

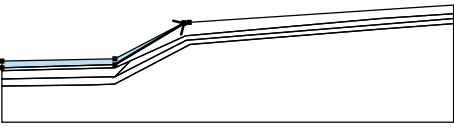
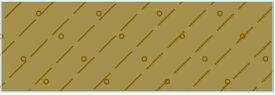
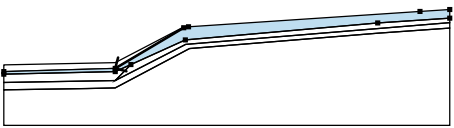
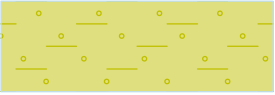
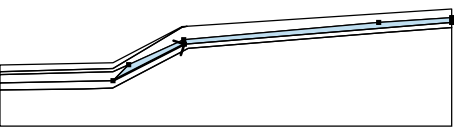
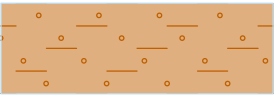
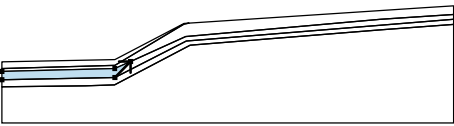
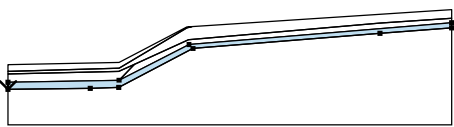
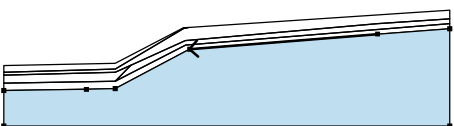
Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\phi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt 
		41.45	140.58	40.30	140.50	
		25.00	132.50	0.00	132.00	
		0.00	130.50			
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel 
		0.00	130.50	0.00	129.90	
		24.99	130.50	28.48	132.08	
		40.70	137.63	83.83	141.41	
		100.00	142.49	100.00	144.44	
3		93.30	144.00	41.45	140.58	Firm to Stiff Sandy Clay 
		25.01	128.52	40.80	136.59	
		100.00	141.46	100.00	142.49	
		83.83	141.41	40.70	137.63	
4		28.48	132.08			Soft very Sandy Clay 
		25.01	128.52	28.48	132.08	
		24.99	130.50	0.00	129.90	
5		0.00	128.04			Medium Dense to Dense Sand 
				0.00	126.45	
		18.53	126.68	24.98	126.88	
		41.67	135.67	83.81	139.09	
		100.00	140.29	100.00	141.46	
6		40.80	136.59	25.01	128.52	Sandstone Bedrock 
		83.81	139.09	41.67	135.67	
		24.98	126.88	18.53	126.68	
		0.00	126.45	0.00	118.45	
		100.00	118.45	100.00	140.29	

Surcharge

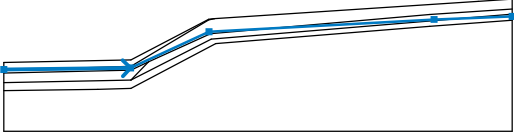
No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
								q, q ₁ , f, F	q ₂	unit
1	strip	permanent	on terrain	x = 40.00	l = 8.00		0.00	20.00		kN/m ²
2	strip	permanent	z = 140.25	x = 49.00	l = 8.00		0.00	120.00		kN/m ²

Surcharges

No.	Name
1	Highway Surcharge
2	Plot 61 foundation load

Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		0.00	130.61	24.96	130.89	40.37	138.04
		84.64	140.44	100.00	141.04		

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)**Analysis 1****Circular slip surface**

Slip surface parameters					
Center :	x =	28.57 [m]	Angles :	α_1 =	-16.11 [°]
	z =	149.23 [m]		α_2 =	60.85 [°]
Radius :	R =	17.44 [m]			
The slip surface after optimization.					

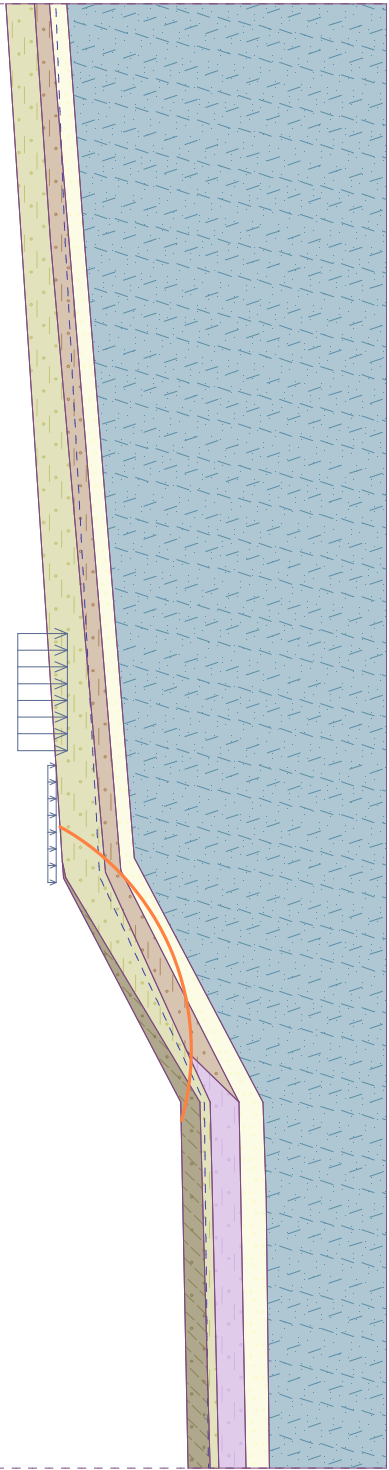
Slope stability verification (Bishop)Sum of active forces : $F_a = 483.71$ kN/mSum of passive forces : $F_p = 629.33$ kN/mSliding moment : $M_a = 8435.84$ kNm/mResisting moment : $M_p = 10975.47$ kNm/m

Factor of safety = 1.30 > 1.30

Slope stability ACCEPTABLE

Name :

Stage - analysis : 1 - 1



Firm Sandy Clay w/gravel

Soft very Sandy Clay

Sandstone Bedrock

Sandy Clayey Silt

Firm to Stiff Sandy Clay

Medium Dense to Dense Sand

The slip surface after optimization.

Slope stability verification (Bishop)

Sum of active forces : $F_a = 483.71 \text{ kN/m}$

Sum of passive forces : $F_p = 629.33 \text{ kN/m}$

Sliding moment : $M_a = 8435.84 \text{ kNm/m}$

Resisting moment : $M_p = 10975.47 \text{ kNm/m}$

Factor of safety = 1.30 > 1.30

Slope stability ACCEPTABLE

Slope stability analysis

Input data

Project

Task : Slope Stability
 Part : Highway Modelling
 Description : Smithy Bridge
 Customer : Taylor Wimpey Strategic Land (North)
 Author : G Brownsword
 Date : 21/04/2022
 Project ID : LKC 18 1005

Settings

United Kingdom - EN 1997

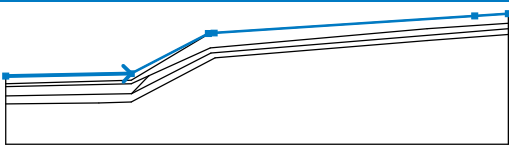
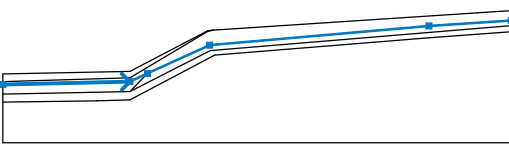
Stability analysis

Earthquake analysis : Standard
 Verification methodology : according to EN 1997
 Design approach : 1 - reduction of actions and soil parameters

Partial factors on actions (A)					
Permanent design situation					
		Combination 1		Combination 2	
		Unfavourable	Favourable	Unfavourable	Favourable
Permanent actions :	$\gamma_G =$	1.35 [-]	1.00 [-]	1.00 [-]	1.00 [-]
Variable actions :	$\gamma_Q =$	1.50 [-]	0.00 [-]	1.30 [-]	0.00 [-]
Water load :	$\gamma_w =$	1.35 [-]		1.00 [-]	

Partial factors for soil parameters (M)			
Permanent design situation			
		Combination 1	Combination 2
Partial factor on internal friction :	$\gamma_\phi =$	1.00 [-]	1.25 [-]
Partial factor on effective cohesion :	$\gamma_c =$	1.00 [-]	1.25 [-]
Partial factor on undrained shear strength :	$\gamma_{cu} =$	1.00 [-]	1.40 [-]

Interface

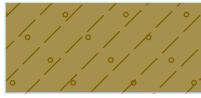
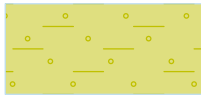
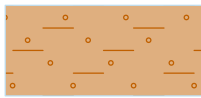
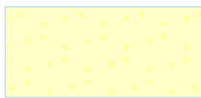
No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
1		0.00	132.00	25.00	132.50	40.30	140.50
		41.45	140.58	93.30	144.00	100.00	144.44
2		0.00	129.90	24.99	130.50	28.48	132.08
		40.70	137.63	83.83	141.41	100.00	142.49

No.	Interface location	Coordinates of interface points [m]					
		x	z	x	z	x	z
3		25.01	128.52	40.80	136.59	100.00	141.46
4		0.00	130.50	25.00	131.20	40.32	140.34
5		0.00	126.45	18.53	126.68	24.98	126.88
6		0.00	128.04	25.01	128.52	28.48	132.08

Soil parameters - effective stress state

No.	Name	Pattern	ϕ_{ef} [°]	c_{ef} [kPa]	γ [kN/m ³]
1	Sandy Clayey Silt		25.00	5.00	17.50
2	Firm Sandy Clay w/gravel		27.00	8.00	18.20
3	Soft very Sandy Clay		24.00	2.00	17.50
4	Firm to Stiff Sandy Clay		28.00	5.00	18.50
5	Sandstone Bedrock		35.00	30.00	19.50
6	Medium Dense to Dense Sand		32.00	0.50	17.00

Soil parameters - uplift

No.	Name	Pattern	γ_{sat} [kN/m ³]	γ_s [kN/m ³]	n [-]
1	Sandy Clayey Silt		18.00		
2	Firm Sandy Clay w/gravel		18.50		
3	Soft very Sandy Clay		18.20		
4	Firm to Stiff Sandy Clay		18.70		
5	Sandstone Bedrock		20.00		
6	Medium Dense to Dense Sand		17.50		

Soil parameters

Sandy Clayey Silt

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{ef} = 25.00^\circ$
 Cohesion of soil : $c_{ef} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 18.00 \text{ kN/m}^3$

Firm Sandy Clay w/gravel

Unit weight : $\gamma = 18.20 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{ef} = 27.00^\circ$
 Cohesion of soil : $c_{ef} = 8.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 18.50 \text{ kN/m}^3$

Soft very Sandy Clay

Unit weight : $\gamma = 17.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{ef} = 24.00^\circ$
 Cohesion of soil : $c_{ef} = 2.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 18.20 \text{ kN/m}^3$

Firm to Stiff Sandy Clay

Unit weight : $\gamma = 18.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{ef} = 28.00^\circ$
 Cohesion of soil : $c_{ef} = 5.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{sat} = 18.70 \text{ kN/m}^3$

Sandstone Bedrock

Unit weight : $\gamma = 19.50 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{\text{ef}} = 35.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 30.00 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 20.00 \text{ kN/m}^3$

Medium Dense to Dense Sand

Unit weight : $\gamma = 17.00 \text{ kN/m}^3$
 Stress-state : effective
 Angle of internal friction : $\varphi_{\text{ef}} = 32.00^\circ$
 Cohesion of soil : $c_{\text{ef}} = 0.50 \text{ kPa}$
 Saturated unit weight : $\gamma_{\text{sat}} = 17.50 \text{ kN/m}^3$

Assigning and surfaces

No.	Surface position	Coordinates of surface points [m]				Assigned soil
		x	z	x	z	
1		25.00	131.20	40.32	140.34	Sandy Clayey Silt
		41.45	140.58	40.30	140.50	
		25.00	132.50	0.00	132.00	
		0.00	130.50			
2		40.32	140.34	25.00	131.20	Firm Sandy Clay w/gravel
		0.00	130.50	0.00	129.90	
		24.99	130.50	28.48	132.08	
		40.70	137.63	83.83	141.41	
		100.00	142.49	100.00	144.44	
3		93.30	144.00	41.45	140.58	Firm to Stiff Sandy Clay
		25.01	128.52	40.80	136.59	
		100.00	141.46	100.00	142.49	
		83.83	141.41	40.70	137.63	
		28.48	132.08			
4		25.01	128.52	28.48	132.08	Soft very Sandy Clay
		24.99	130.50	0.00	129.90	
		0.00	128.04			
5		0.00	128.04	0.00	126.45	Medium Dense to Dense Sand
		18.53	126.68	24.98	126.88	
		41.67	135.67	83.81	139.09	
		100.00	140.29	100.00	141.46	
		40.80	136.59	25.01	128.52	
6		83.81	139.09	41.67	135.67	Sandstone Bedrock
		24.98	126.88	18.53	126.88	
		0.00	126.45	0.00	118.45	
		100.00	118.45	100.00	140.29	

Surcharge

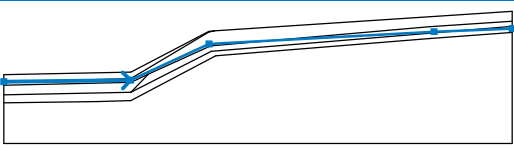
No.	Type	Type of action	Location z [m]	Origin x [m]	Length l [m]	Width b [m]	Slope α [°]	Magnitude		
1	strip	permanent	on terrain	x = 40.00	l = 8.00		0.00	q, q ₁ , f, F	q ₂	unit
2	strip	permanent	z = 140.25	x = 49.00	l = 8.00		0.00	20.00	120.00	kN/m ²

Surcharges

No.	Name
1	Highway Surcharge
2	Plot 61 foundation load

Water

Water type : GWT

No.	GWT location	Coordinates of GWT points [m]					
		x	z	x	z	x	z
1		0.00	130.61	24.96	130.89	40.37	138.04
		84.64	140.44	100.00	141.04		

Tensile crack

Tensile crack not input.

Earthquake

Earthquake not included.

Settings of the stage of construction

Design situation : permanent

Results (Stage of construction 1)

Analysis 1

Circular slip surface

Slip surface parameters					
Center :	x =	28.36 [m]	Angles :	α_1 =	-15.57 [°]
	z =	149.58 [m]		α_2 =	60.12 [°]
Radius :	R =	17.76 [m]			
The slip surface after optimization.					

Slope stability verification (Bishop)

Combination 1

Sum of active forces : F_a = 650.79 kN/mSum of passive forces : F_p = 714.88 kN/mSliding moment : M_a = 10490.78 kNm/mResisting moment : M_p = 11523.94 kNm/m

Utilization : 91.0 %

Slope stability ACCEPTABLE

Combination 2

Sum of active forces : F_a = 477.23 kN/mSum of passive forces : F_p = 496.96 kN/m

G Brownsword

Sliding moment : $M_a = 8475.52 \text{ kNm/m}$
Resisting moment : $M_p = 8826.01 \text{ kNm/m}$
Utilization : 96.0 %

Slope stability ACCEPTABLE

Optimized slip surface for : Combination 2