Attachment 12

(13 pages including this page)

Quantitative Slope Stability Assessment

Using the computer application *Galena*^{TM}: *Slope Stability Analysis System*, Version 5.1 (Clover Technology, 2006)

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1. Background notes on *Galena*

"*GALENA* is designed to be a simple, user-friendly yet very powerful, slope stability software system. It was originally developed to satisfy the requirements of BHP (now known as BHP Billiton) geotechnical engineers who realised there were many problems with other slope stability analysis software systems available. Geotechnical engineering very rarely gives one unique answer and extensive parametric studies are often required before realistic results are obtained. *GALENA* enables such parametric studies to be undertaken quickly and easily.

The *GALENA* system considers slope stability problems as they are largely encountered in the field. That is, the overall geology generally remains the same; it is the slope surface that requires change in many situations. In *GALENA*, the overall geology is defined for the model, including the material properties. The defined slope surface then cuts through this model, as a slope would be excavated in the real world. Material above the slope surface is ignored since this has been removed or mined out. In this way, *GALENA* enables a large number of analyses to be undertaken without the need to redefine the model each time.

In addition, a range of different constraints and methods of analysis can then be used on that same model. This enables parametric studies to be undertaken very easily. The program is structured such that parameters can be defined or input in almost any sequence, provided they follow basic rules as outlined in this Users' Guide - for example the slope surface need not be defined before the material profiles.

GALENA incorporates the Bishop Simplified, the Spencer-Wright and the Sarma methods of analysis to determine the stability of slopes and excavations. The Bishop method is used to determine the stability of circular failure surfaces, the Spencer-Wright method is applicable for circular and non-circular failure surfaces, and the Sarma method is used for problems where non-vertical slices are required, or is used for more complex stability problems.

It is possible to analyse multi-layered slopes with tension cracks, earthquake forces, externally distributed loads and forces, and water pressures from within or above the slope (e.g. dams and river banks) including phreatic surfaces and piezometric pressures. *GALENA* incorporates various techniques for locating the critical failure surface with user-supplied restraints. Back analyses can also be performed to obtain critical material strength parameters from known or assumed failure surfaces, and probability analyses performed to gauge the likelihood of Factors of Safety being below values of interest, based on expected material property variations.

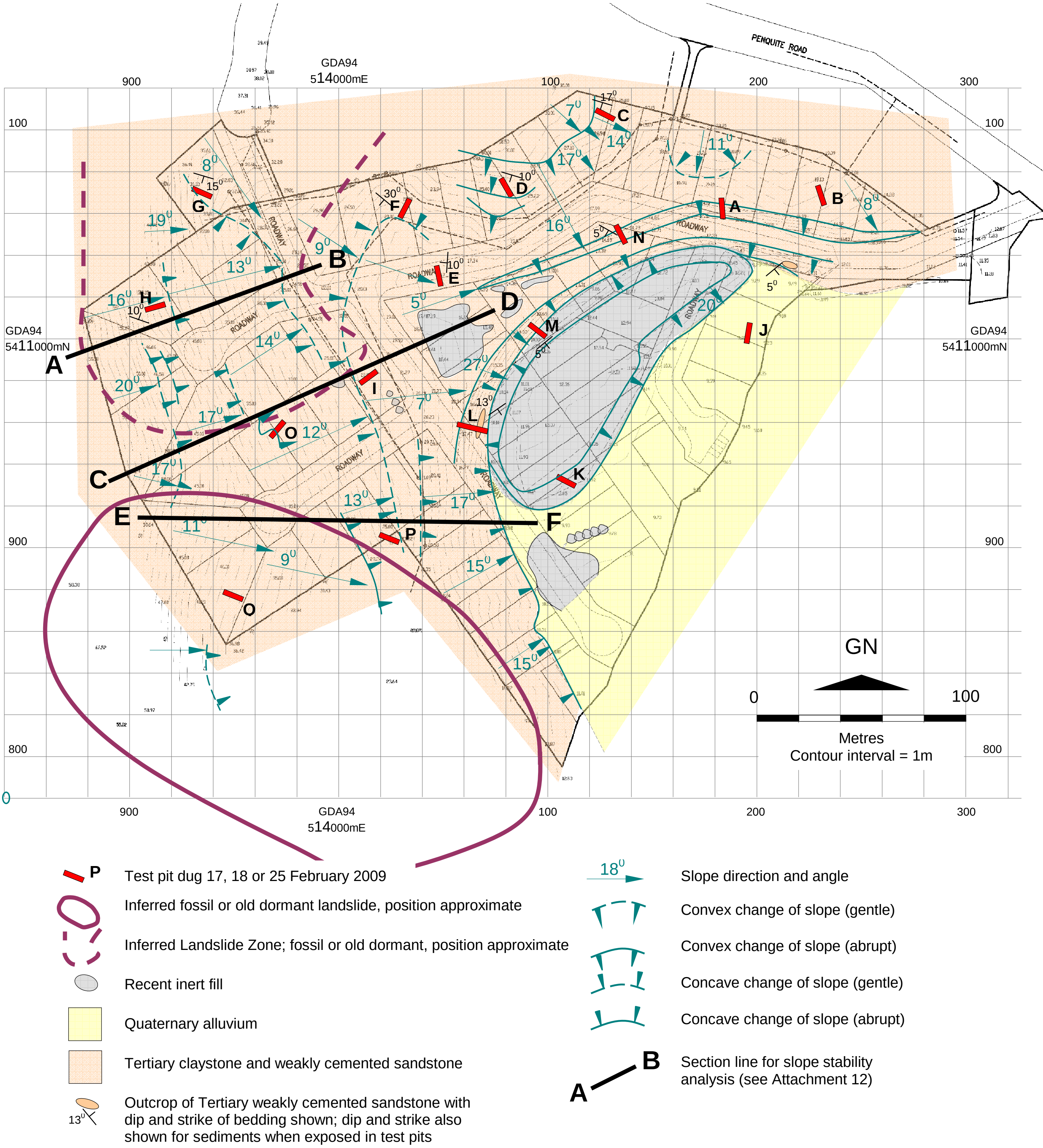
Either effective or total stresses may be used on any material layer. For the total stress case, the increase in undrained shear strength with depth can be simulated using Skempton's relationship by simply entering the value of the plasticity index for that material."

Copied without change from the Summary page of the GALENA Users' Guide Version 5.0

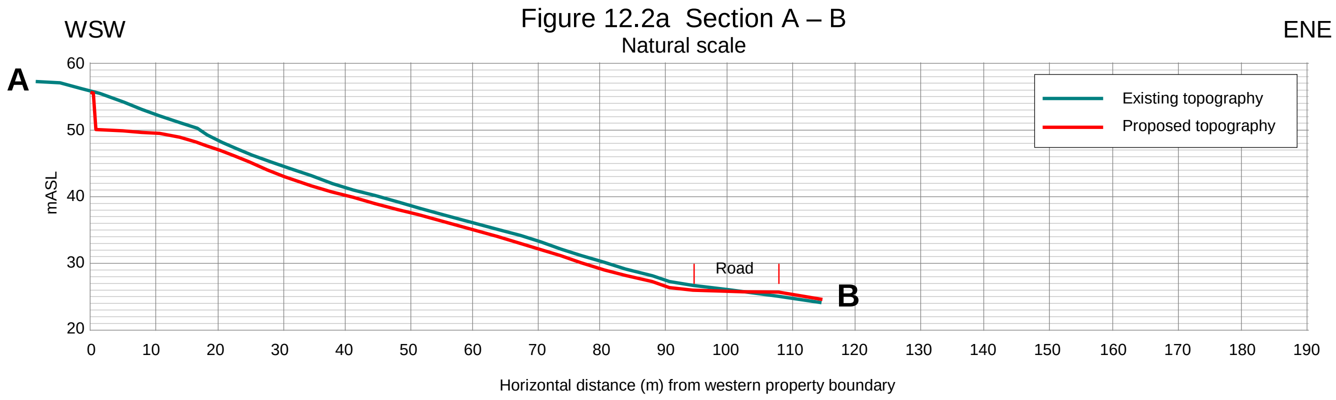
2. Interpreted hydrogeological cross sections through the western part of the proposed subdivision

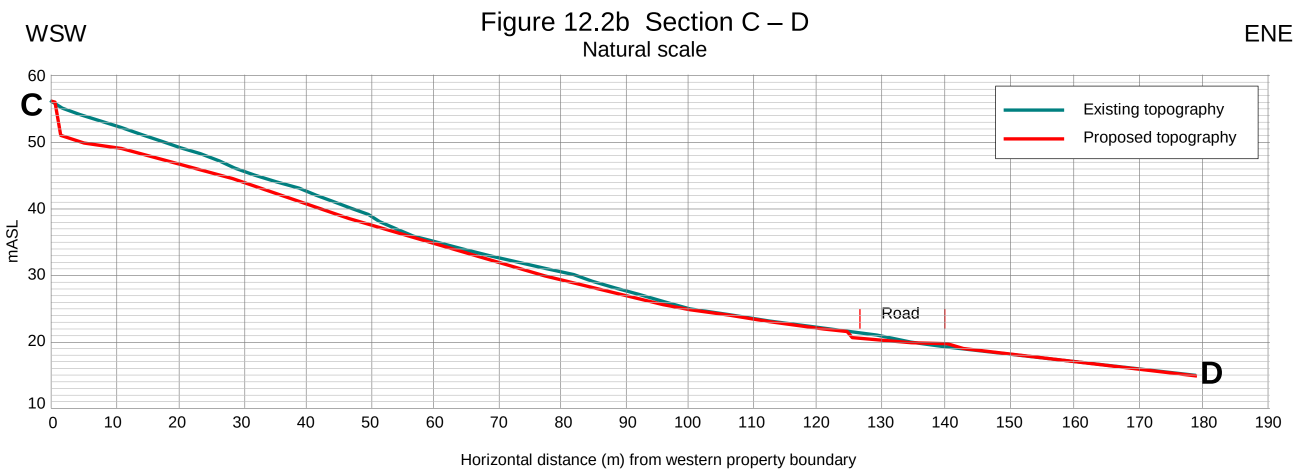
Figure 12.1 is reproduced from Attachment 7 and includes the locations of three section lines: A – B, C – D and E – F from the western property boundary down the slope to the east. Figures 12.2a, b and c are cross sections of the lines.

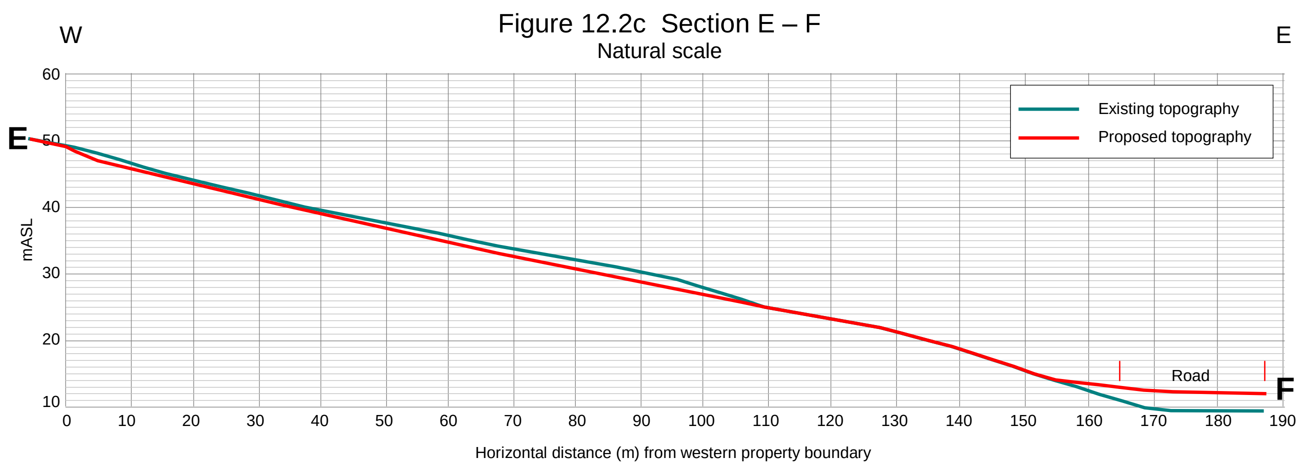
Figure 12.1 Geological interpretation map of the proposal showing cross section lines used in slope stability analysis
(reproduced from Attachment 7)



Figures 12.2a, b and c Cross sections A – B, C – D and E – F at natural scale
Proposed topography from Attachment 8







3. Comments on inputs to slope stability assessment on the proposed subdivision

Qualitative slope stability assessment requires:

- A slope surface
- A phreatic or piezometric surface
- Material types
- Material properties
- Material profiles in the subsurface
- Postulates of failure surfaces, and if appropriate,
- Modifications to the model

Comments on these follow.

Slope surface
Known sufficiently accurately from surveyed and contoured maps with 1m contours.

Phreatic or piezometric surface
Little is know of groundwater occurrence on the proposed subdivision. The only information we currently have is seepages into test pits J and L at depths around 6 – 8mASL. It is assumed that the groundwater in these pits is unconfined, and is present in Quaternary alluvium throughout the adjacent flood plain of Kings Meadows Rivulet. Whether or not it extends laterally into the older Tertiary rocks of the subdivision is uncertain. However, for the purposes of slope stability assessment, I have assumed that a water table (phreatic surface) rises to the west from elevations of around 6 – 8mASL near test pit L, but at a lesser angle than the land surface.

The elevation (and to a lesser extent, the profile) of the phreatic surface will change with climatic and other factors over varying time periods.

Material types
Interpreted from materials exposed in 16 test pits. No significant surface exposures. As a simplification, four material types are recognised beneath the western part of the subdivision (from the surface down): topsoil, subsoil, claystone and sandstone.

Material properties
Unit weight
Eight densities for subsoil clay, silty clay and sandy clay were obtained from shrink swell testing. Results are summarised in Table 12.1. The average of 1.9t/m^3 has been conservatively increased to 2.0t/m^3 and used for this material in slope stability analysis. Other values in the range 1.6 to 2.0t/m^3 have used for topsoil, claystone and sandstone. Density has been converted to unit weight (kN/m^3) by multiplying by the acceleration due to gravity (9.81m/sec^2; say 10m/sec^2).

Table 12.1 Unit weights of subsoil clayey materials

Pit	Sample depth (m)	Unit weight t/m^3	Material
B	1.2 - 1.5	1.9	Silty CLAY (CH): coarsely mottled grey and reddish orange; high plasticity
C	0.8 - 1.1	1.6	Silty CLAY (CH): mottled olive brown and olive; high plasticity
F	0.9 - 1.2	1.7	Sandy CLAY (CH), locally Clayey SAND (SC, CL): mottled orange red and grey
G	1.0 - 1.3	2.0	Sandy CLAY (SC, CL): bright orange and grey; low-mod plasticity
H	0 9 - 1.2	2.1	Silty CLAY (CH): dark brown; high plasticity
I	1.0 - 1.3	2.1	Silty CLAY (CH): dark brown flecked with red; high plasticity
P	1.2 - 1.5	2.2	Silty CLAY: brownish orange; some sand; mod plasticity
Q	0.9 - 1.2	2.1	CLAY (CH): orange and grey; high plasticity
	Average	**1.9**	

Cohesion and friction angle

Peak cohesion (12kPa) and friction angle (24^0) have been obtained from one subsoil sample from a depth of 0.9 – 1.2m in pit Q, submitted to Mineral Resources Tasmania. There was no evidence from the test pit that the subsoil sample had previously failed. However, residual cohesion and residual friction angle are currently being obtained from it.

Values of material properties used in slope stability analysis are summarised in Table 12.2.

Subsurface material profiles

These are least known. All subsurface profiles in this Attachment are approximate and inferred. However, all fit the observed geology in test pits.

Postulates of failure surfaces

Galena permits a large number of possible failure surfaces to be analysed. These are generated from a single selected failure surface, where its length and curvature are permitted to vary between chosen constraints. In the printouts from *Galena* which follow, about a thousand possible failure surfaces are calculated for most scenarios, with only the critical one (lowest Factor of Safety) shown in the diagrams.

Model modifications

The following modifications have been included in slope stability assessment for the western side of the proposed subdivision:

- slope modification (up to 5m of material is proposed to be removed from the higher western boundary; lesser amounts will be removed progressively downslope to the east)
- slope loading with a conservative 100kPa at possible house sites

Table 12.2 Material properties used in slope stability analysis

Underlined values are laboratory measurements

			Cohesion (c, kPa)		Friction angle (Φ^o)		
Unit	**Descriptor**	**Unit weight (ρ, kN/m^3)**	**Peak**	**Residual**	**Peak**	**Residual**	**Remarks**
1	Topsoil	16		0		20	Inferred age: Quaternary. Inferred origin: topsoil of locally colluvial origin (soil properties) Silty SAND (SP), Sandy SILT (SP, SM); Clayey SILT (CL); light grey, brown; hard setting, nonplastic to low plasticity Residual values used
2	Subsoil	<u>20</u>	<u>12</u>		<u>24</u>		Inferred age: Quaternary. Inferred origin: subsoil of locally colluvial origin (soil properties). CLAY (CH), Sandy CLAY (CL); brown, olive brown, olive grey, orange; high plasticity Peak values used (laboratory results for residual values pending)
3	Claystone	20		5		15	Inferred age: Tertiary. Sediments of the Launceston Beds. Includes silty mudstone. Soil properties. CLAY (CH); black, dark grey, olive grey; Hard Residual values used
4	Sandstone	18	0		35		Inferred age: Tertiary. Sediments of the Launceston Beds. Weakly cemented but remouldable if water added (soil properties) SAND (SP), Clayey SAND (SC), Silty SAND (SP); light yellow, brown, orange; Dense to Very Dense. Peak values used

4. Printouts from *Galena* showing Factors of Safety for slope stability scenarios for the proposed subdivision

Unless otherwise stated, the following printouts use the material properties listed in Table 12.1. The following interpretations are made for Factors of Safety:

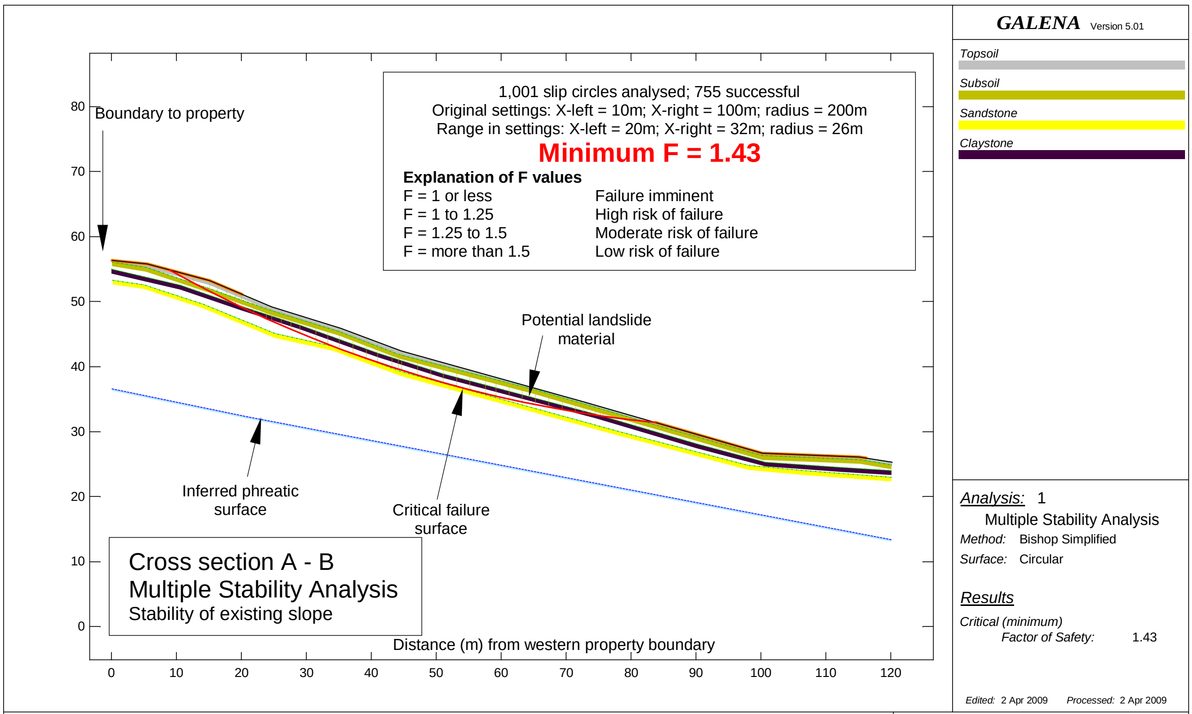
F = 1 or less	Failure imminent
F = 1 to 1.25	High risk of failure
F = 1.25 to 1.5	Moderate risk of failure
F = more than 1.5	Low risk of failure

Twelve scenarios are shown in Figures 12.3 to 12.14 in the following pages. Table 12.3 below (a copy of Table 1 in the report) summarises the main findings from each.

Table 12.3 Summary of slope stability assessments

Figure	Scenario	Critical FS*	No. circles analysed	Comment
12.3	Cross section A – B. Stability of existing slope from the western property boundary to near the break of slope at about 100m distant. Multiple analysis.	1.43	755	Moderate risk of failure
12.4	Cross section A – B. Stability of modified slope from the western property boundary to near the break of slope at about 100m distant. Modifications include cut and fill as shown in Attachment 8. Multiple analysis.	1.53	755	Low risk of failure
12.5	Cross section A – B. Stability of existing slope from the western property boundary to near the break of slope at about 100m distant. Single analysis, with deep-seated failure surface.	2.77	1	Low risk of failure
12.6	Cross section C - D. Stability of existing slope from the western property boundary to near the break of slope at about 100m distant. Single analysis, with deep-seated failure surface.	2.52	1	Low risk of failure
12.7	Cross section C - D. Stability of existing slope from the western property boundary to near the break of slope at about 100m distant. Multiple analysis.	1.9	755	Low risk of failure
12.8	Cross section C - D. Stability of modified slope from the western property boundary to near the break of slope at about 100m distant. Modifications include cut and fill as shown in Attachment 8. Multiple analysis.	2.06	755	Low risk of failure
12.9	Cross section E - F. Stability of existing slope from the western property boundary to near the break of slope at about 170m distant. Multiple analysis.	2.82	755	Low risk of failure
12.10	Cross section E - F. Stability of modified slope from the western property boundary to near the break of slope at about 170m distant. Modifications include cut and fill as shown in Attachment 8. Sandstone assumed absent; hillside is Claystone only beneath subsoil. Multiple analysis.	1.14	755	High risk of failure
12.11	House site on 20^0 hillside. Natural slope. Multiple analysis.	2.20	807.	Low risk of failure
12.12	House site on 20^0 hillside. Modified slope (1.5m subvertical cut). Multiple analysis.	0.7	501	Lip of excavation has failed.
12.13	House site on 20^0 hillside. Modified slope (1.5m subvertical cut and fill). Multiple analysis.	2.6	1001	Low risk of failure in fill (lip of excavation has failed)
12.14	House site on 20^0 hillside. Modified slope (1.5m subvertical cut and fill; house built). Multiple analysis.	1.4	1001	Moderate risk of failure in fill (lip of excavation has failed)

*Critical FS = critical (minimum) Factor of Safety



Project: Proposed 76-lot subdivision, Penquite Road, Newstead

File: C:\CROMER\BILL\30. GALENA FILES\Newstead line AB.gmf

Figure 12.3

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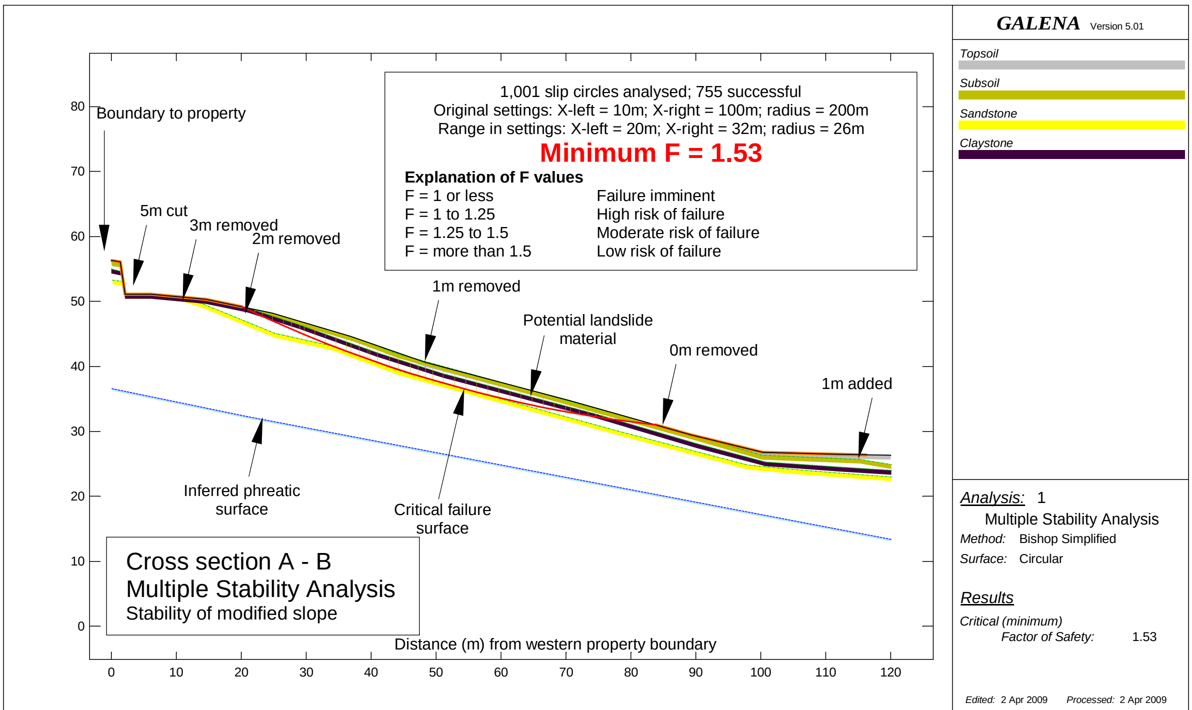

Project: Proposed 76-lot subdivision, Penquite Road, Newstead

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Figure 12.4

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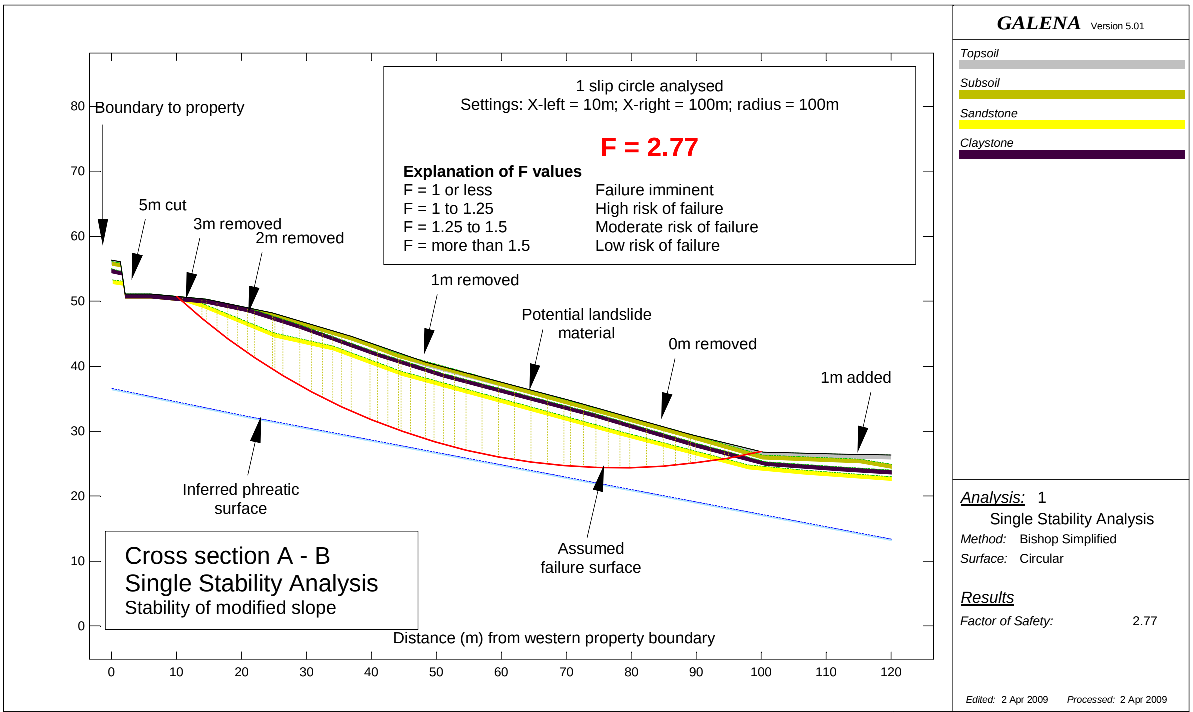

Project: Proposed 76-lot subdivision, Penquite Road, Newstead

Figure 12.5

File: C:\CROMER\BILL\30. GALENA FILES\Newstead line AB existing slope, with 5m cut.gmf

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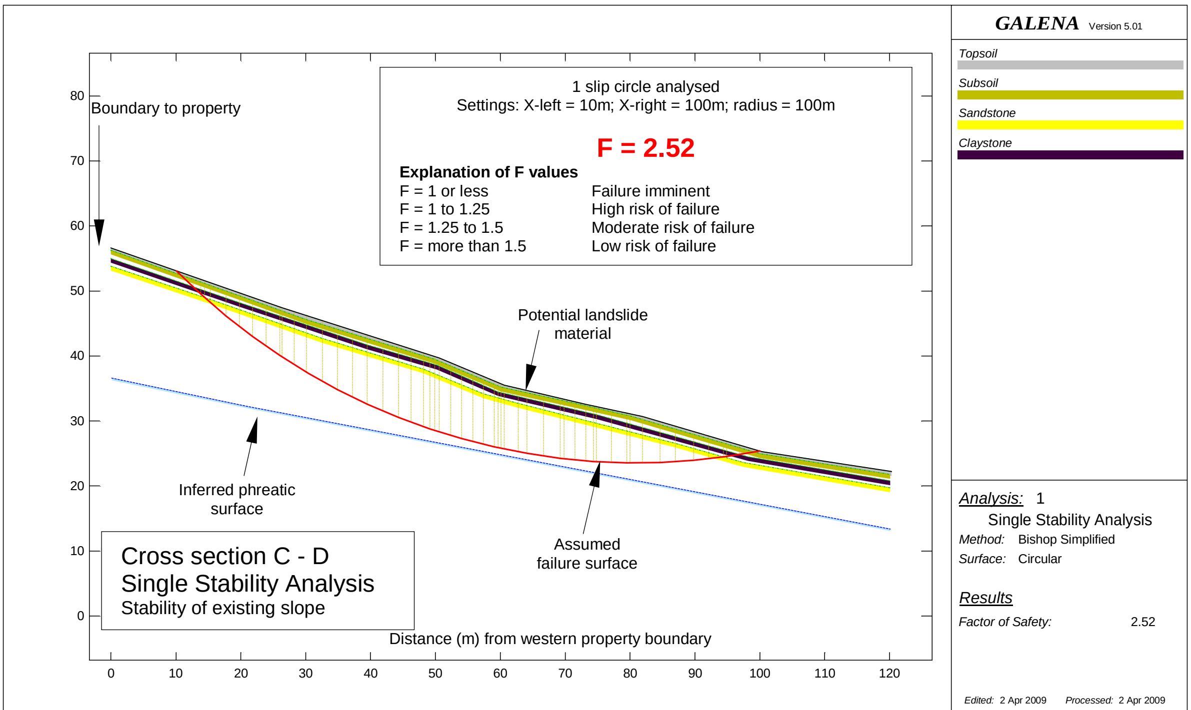

Project: Proposed 76-lot subdivision, Penquite Road, Newstead

Figure 12.6

File: C:\CROMER\BILL\30. GALENA FILES\Newstead line CD existing surface.gmf

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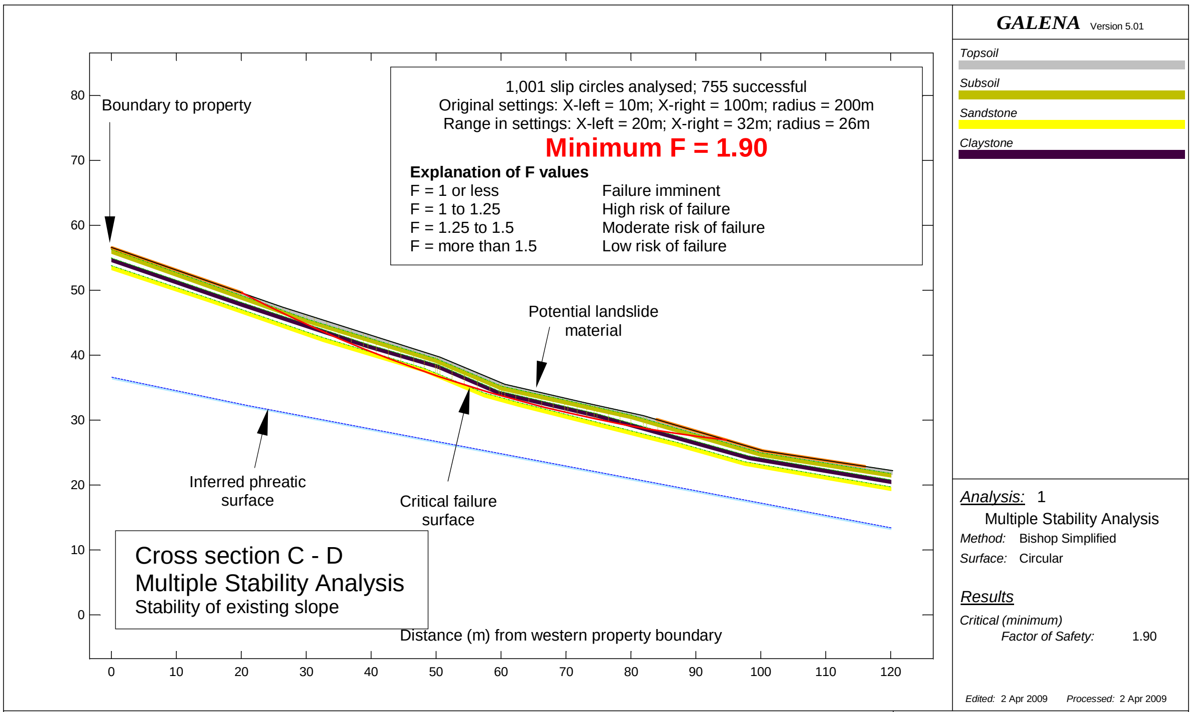

Project: Proposed 76-lot subdivision, Penquite Road, Newstead

Figure 12.7

File: C:\CROMER\BILL\30. GALENA FILES\Newstead line CD existing surface.gmf

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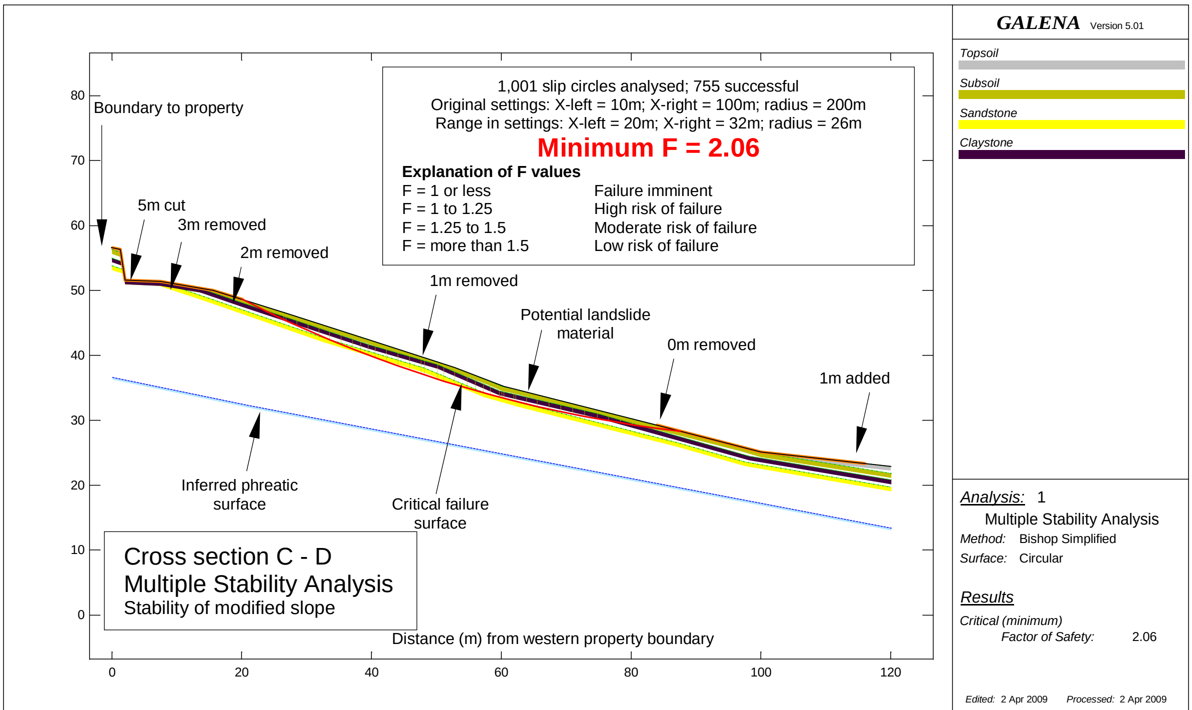

Project: Proposed 76-lot subdivision, Penquite Road, Newstead

Figure 12.8

File: C:\CROMER\BILL\30. GALENA FILES\Newstead line CD modified surface.gmf

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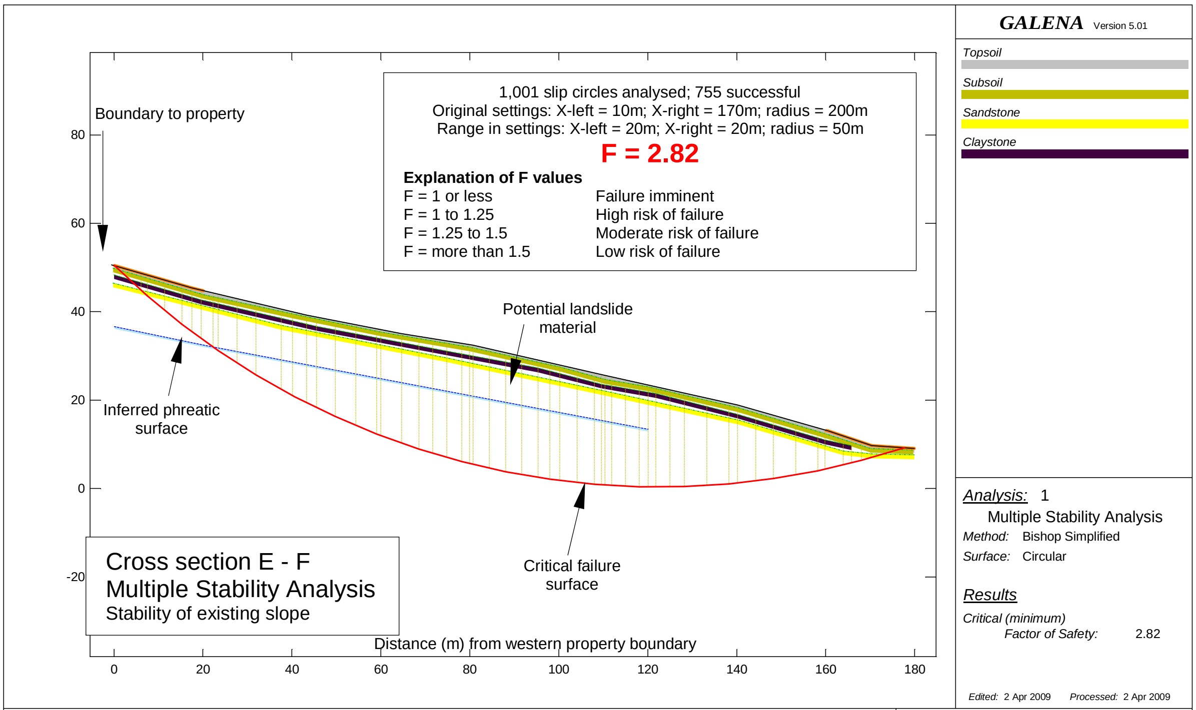

Project: Proposed 76-lot subdivision, Penquite Road, Newstead
Cross section A-B
File: C:\CROMER\BILL\30. GALENA FILES\Newstead line EF existing surface.gmf

Figure 12.9
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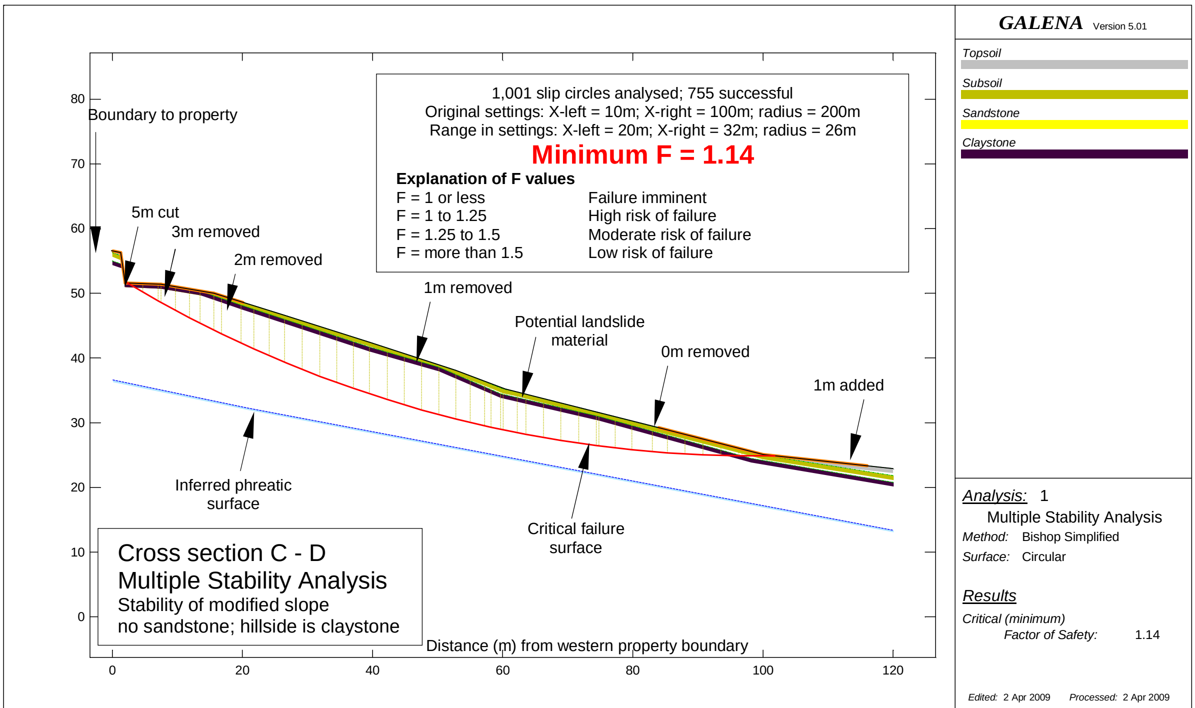

Project: Proposed 76-lot subdivision, Penquite Road, Newstead
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Figure 12.10
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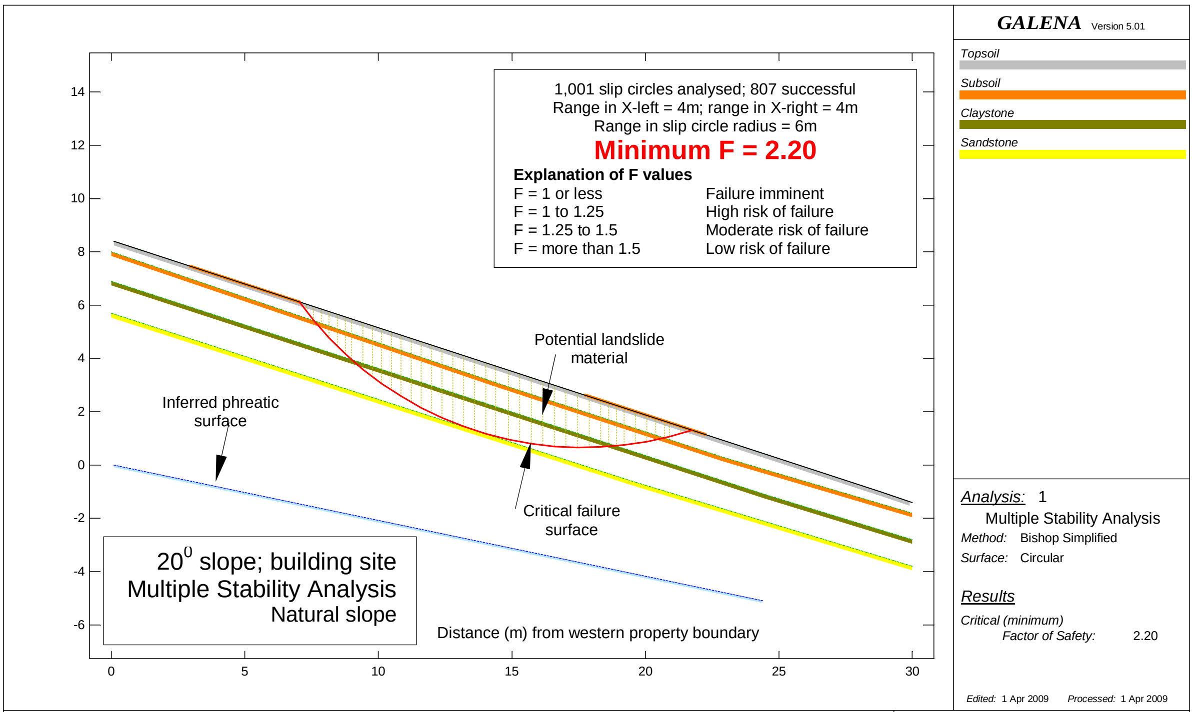

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Figure 12.11

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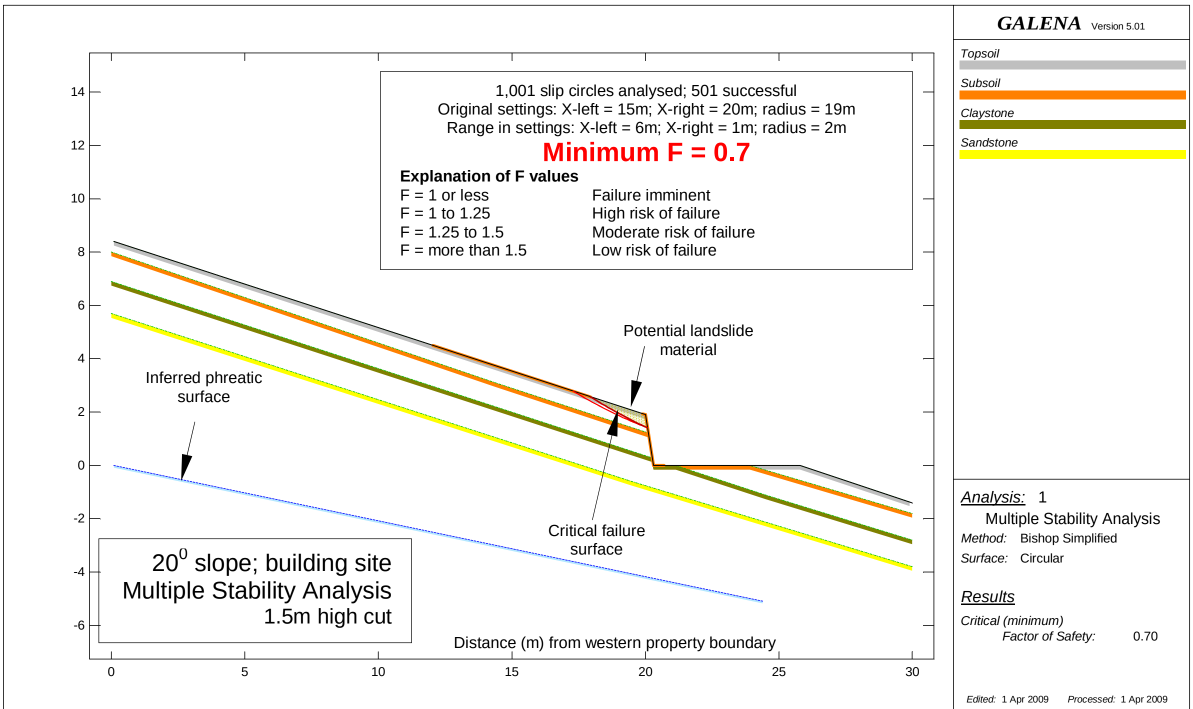

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Figure 12.12

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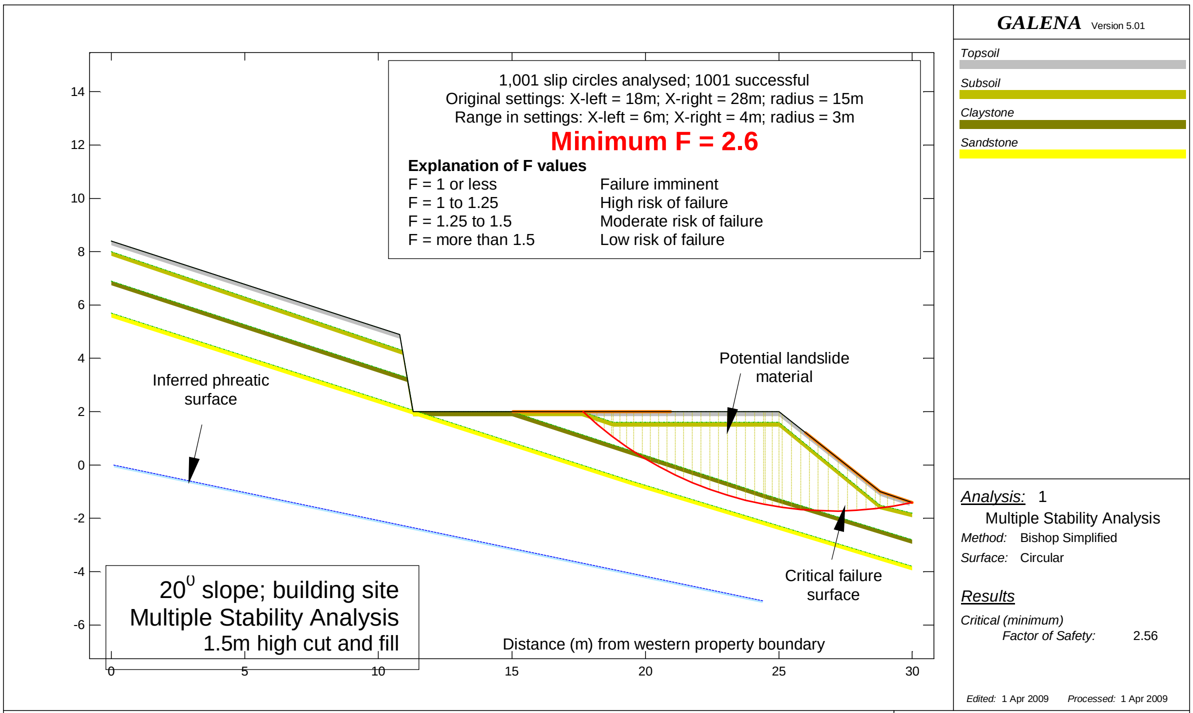

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Figure 12.13

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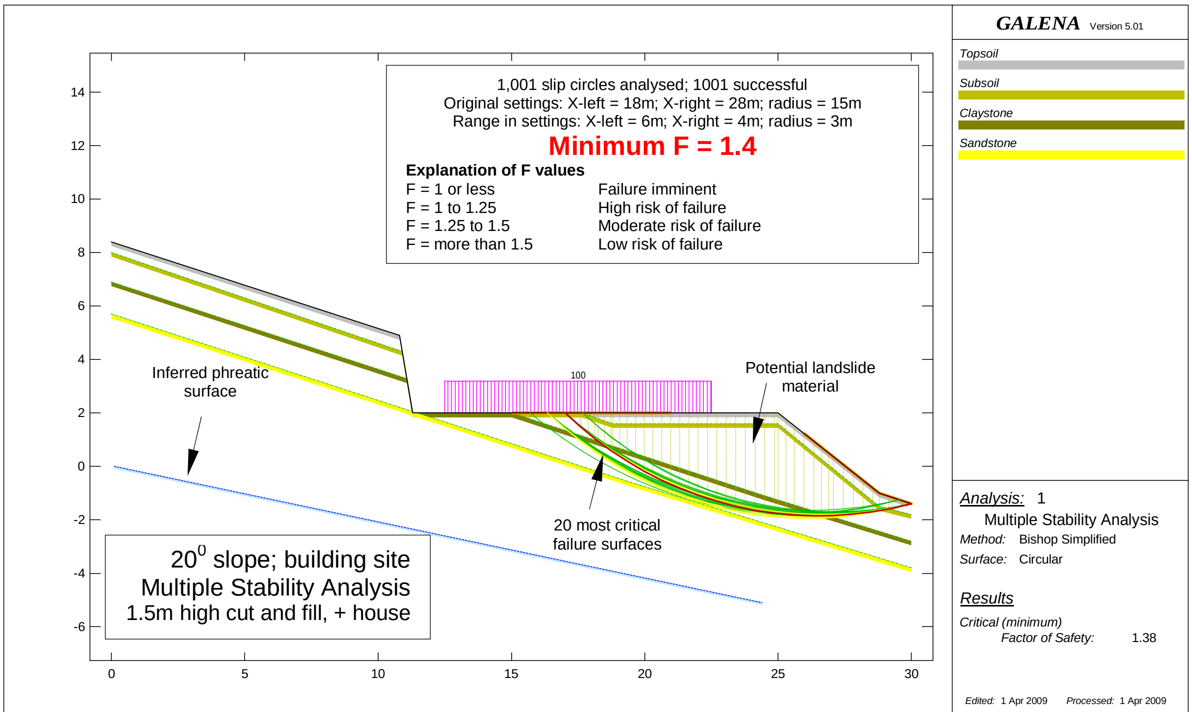

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Figure 12.14

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