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December 9 2010
Finalised (26/03/2013)

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1.0 Mandate

Martin Grenon Ph.D., ing. and John Hadjigeorgiou Ph.D., P.Eng., ing., were mandated by Agnico Eagle to undertake a preliminary stope stability analysis for the orebody of the Meliadine Gold Project. No site visit was undertaken and this analysis is strictly based on the available data reported in the report by Golder (2010). There was no access to the original geomechanical data so it was necessary to rely on the data as presented in the report.

2.0 Geology

Figure 1 illustrates the defined geology of the deposit. Based on the block model the mandate was to investigate the stability and potential dilution of stopes in all lodes. Table 1 summarizes the location and dimensions of analysed stope dimensions:

Table 1. Location and configuration of analysed stopes.

Lode	Height (m) (min/max)	Span (m) (min/max)	Length (m) (min/max)	Dip (°)	Depth (m)
1000	20/20	5/10	15/25	62	200
1015	20/20	5/10	15/25	62	400
1025	20/20	5/10	15/25	62	150
1050	20/20	5/10	15/25	62	100
1100	20/20	4/10	15/25	62	200
1152	20/20	5/10	15/25	62	250
1153	20/20	5/10	15/20	62	250
1154	20/20	15/30	15/20	62	200
1155	20/20	15/30	15/20	62	250
1252	20/20	15/30	15/20	62	350
1255	20/20	5/10	15/25	62	400

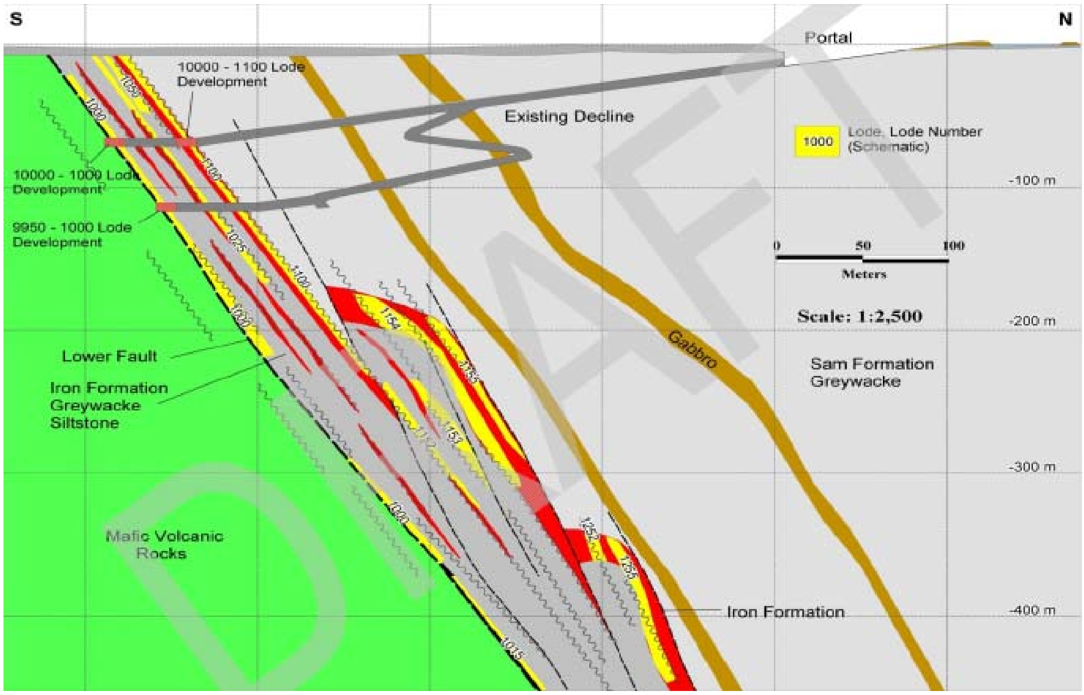

Figure 1. Schematic cross-section of underground geology and mineralisation of the Tiriganiaq deposit (looking West), reproduced from Golder Draft Report (2010).

3.0 Geotechnical Data

The available geotechnical data are summarised in Golder (2010). These data include core data, mapping data, laboratory tests and structural data. Although it would appear that there are classification data using the Q system, developed by Barton et al. (1974) the reported data are in the form of the RMR system and in particular the 1976 version as presented by Bieniawski (1976). Traditionally open Stope stability analysis is based on the Q system; therefore it was necessary to convert the RMR_{76} data to Q ratings. This was done based on the site specific conversion proposed in the Golder report. It is however strongly recommended that the raw data be used to calculate Q in all subsequent analyses. Table 2 summarizes the median RMR_{76} values estimated from borehole data.

Table 2. Median RMR_{76} values estimated from borehole data, reproduced from Golder (2010).

Lode	HW	Proximal HW	Stope	Proximal FW	FW
1000	74	60	68.5	57	75
1015	83		82		77
1025	74	57	74	53	73
1050	73	34	68	52	76
1100	71	45	67		71
1152	80		84		74
1153	78		79		84
1154	75		78		76
1155	78		77		78
1252	80		81		81
1255	81		80		80

The inherent variations in the recorded RMR_{76} are illustrated in Figure 2 for the 1000 lode for the hanging wall (HW), Stope and foot wall (FW). These graphs provide a range of RMR_{76} values that can be used for preliminary design. As there were no DDH classification values for the proximal footwall the analysis used RMR_{76} = 50 value, based on mapping results by Golder (2010).

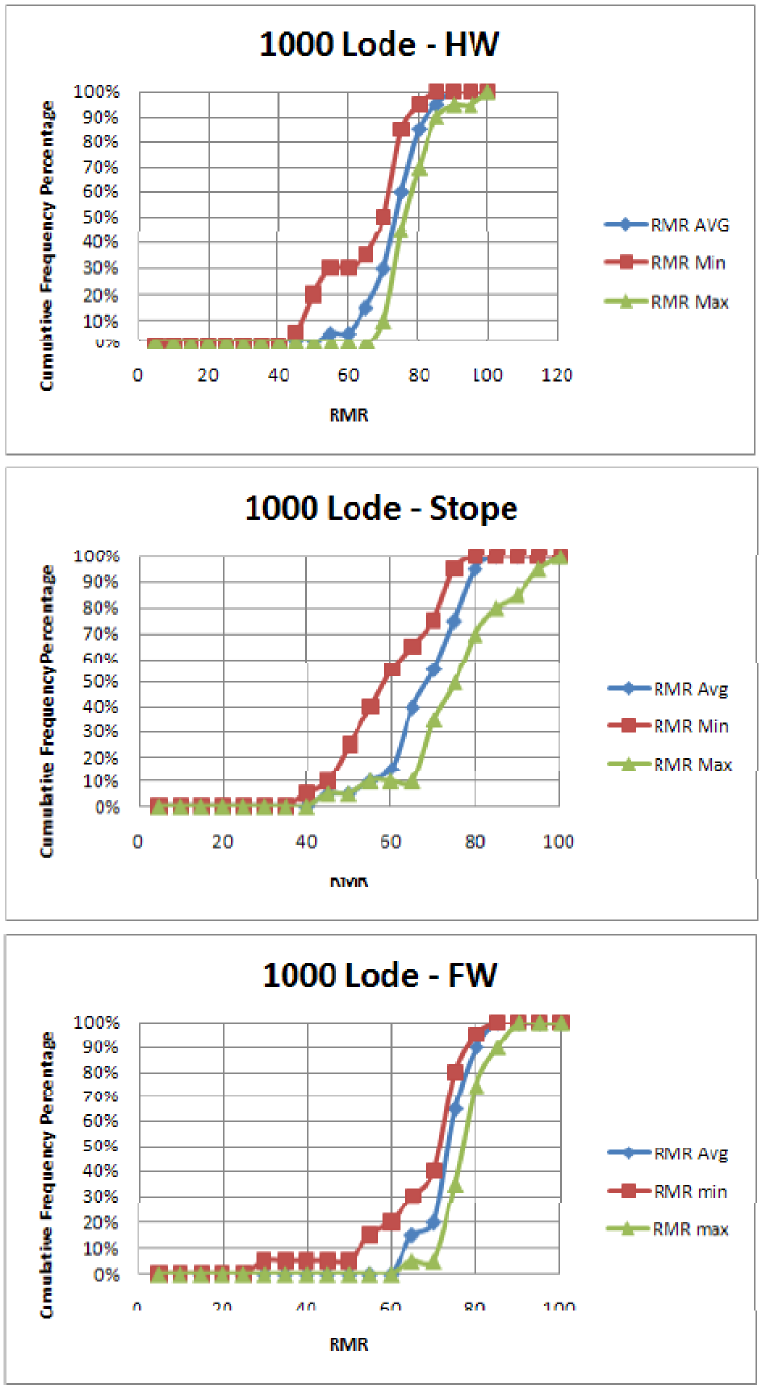

Figure 2. Recorded RMR_{76} for the 1000 Lode, after Golder (2010).

The intact rock strength is based on field assessment of the core based on the ISRM guidelines, Table 3 and is summarised in Table 4.

Table 3. ISRM guidelines for field identification of the approximate range of uniaxial compressive strength, after ISRM(1981).

Grade	Description	Field Identification	Approx. Range of Uniaxial Compressive Strength (MPa)
R0	Extremely weak rock	Indented by thumbnail	0.25-1.0
R1	Very weak rock	Crumbles under firm blows with point of geological hammer, can be peeled by a pocket knife	1.0-5.0
R2	Weak rock	Can be peeled by a pocket knife with difficulty, shallow indentations made by firm blow with point of geological hammer	5.0-25
R3	Medium strong rock	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with single firm blow of geological hammer	25-50
R4	Strong Rock	Specimen requires more than one blow of geological hammer to fracture it	50-100
R5	Very strong rock	Specimen requires many blows of geological hammer to fracture it	100-250
R6	Extremely strong rock	Specimen can be only chipped with geological hammer	>250

Table 4. Average estimated Intact Rock Strength for stopes in Lodes, reproduced from Golder (2010).

Lode	HW	Proximal HW	Stope	Proximal FW	FW
1000	R3	R3	R3	R3	R3
1015	R3		R3		R3
1025	R3	R3	R3	R3	R3
1050	R3	R3	R3	R4	R3
1100	R3	R3	R3		R3
1152	R4		R4		R4
1153	R4		R4		R4
1154	R4		R4		R4
1155	R4		R4		R4
1252	R4		R4		R4
1255	R4		R4		R4

It can be seen in Table 4 that the estimated strength falls in only two categories: R3 medium strong rock (25 to 50 MPa) and R4 strong rock (50 to 100 MPa). For Lodes 1000 and 1100 both mapping and diamond drilling results were used. In the absence of DDH results, data from the underground mapping were used for the proximal foot wall Lode 1100.

There have been no in-situ stress measurements made at the project site. Golder (2000) assumed that the maximum horizontal stress will be oriented approximately perpendicular to the trend of the Tiriganiaq Shear, or in an approximately north-south direction.

Golder (2010) reported that in 2008 they undertook underground mapping in the decline, ramp and the 1000 and 1100 drifts. The results of the mapping suggested the presence of three joint sets and two subordinate joints sets are reproduced in Table 5. Another important observation reported was the presence of a reduced rock mass quality zone in the margins of the 1000 and 1100 Lodes mineralisation. This was defined as the proximal hanging wall or footwall and was around 0.5 m thick. This is an area of concern for stability purposes.

Table 5. Joint set data from the underground mapping, reproduced from Golder (2010).

Type	Average Dip	Average Dip Direction	Typical Joint Spacing (cm)	Typical Joint Continuity (m)	Large Scale Amplitude	Shape
Dominant Joint Sets						
Joint set parallel to foliation	61^0	005^0	5-20	3.5 (up to 20 m)	1 cm	Mostly planar, undulating in some cases
Joint set orthogonal to foliation	32^0	185^0	10-60	6.5 (up to 15 m)	6 cm	Stepped and undulating
Joint set	85^0	95^0 or 275^0	10-40	3.5	< 1 cm	Planar, undulating in some cases < 1 cm
Subordinate Joint Sets						
Joint set	50^0	96^0	15-50	2.5	< 1 cm	Mostly planar, undulating in some cases
Joint Set	85^0	135^0	80-120	2.5	< 1 cm	Planar

4.0 Stability Analysis

The stability-graph method accounts for the major factors influencing the stability of open stopes. A stability index for each stope surface is traced against its dimensions. A series of empirically derived guidelines allow for predictions on the overall stability of a stope, Figure 3.

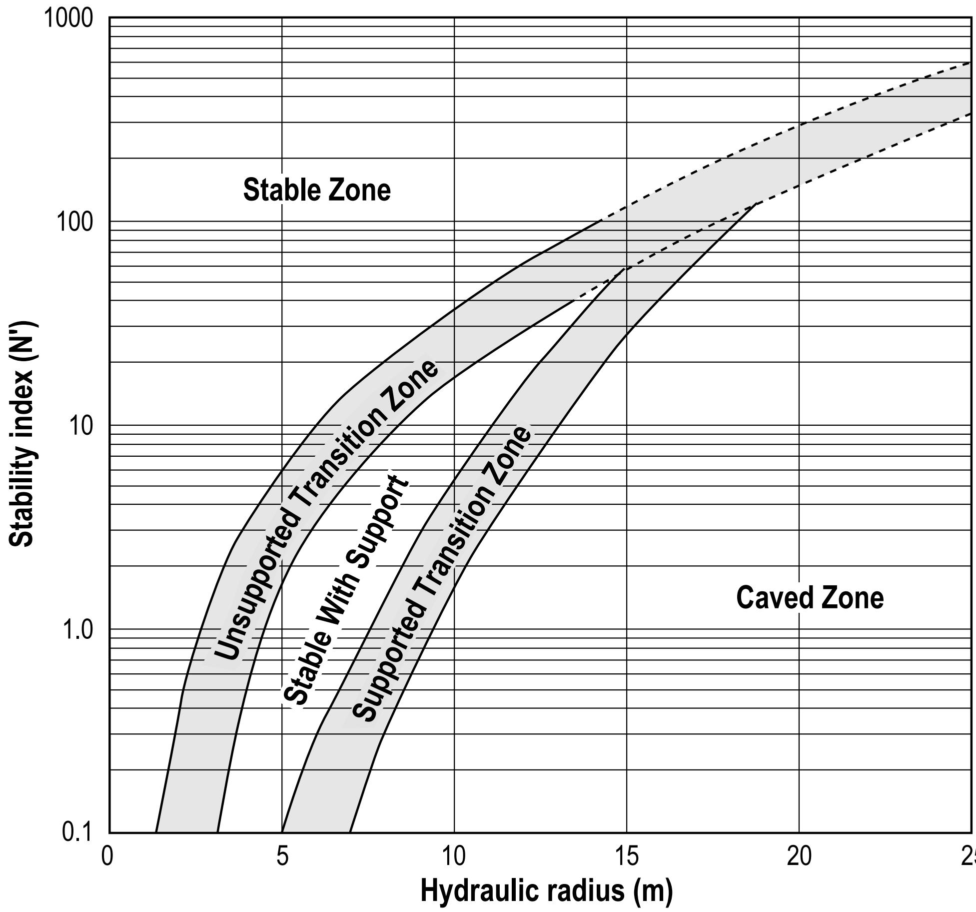

Figure 3. Stability graph, after Nickson (1992).

The method is summarised in Potvin and Hadjigeorgiou (2001). Determination of adequate stope dimensions is one of the most critical decisions to be made at the feasibility study stage of a mine. The profitability of an operation is directly linked to productivity, which in turn, is influenced by stope dimensions. The potential for dilution can be determined from a design charts proposed by Clark and Pakalnis (1997) Figure 4 or Capes (2009), Figure 5. This approach employs an index defined as:

$$\text{ELOS} = \frac{\text{equivalent linear overbreak}}{\text{slough}} = \frac{\text{volume of slough from stope surface}}{\text{stope height} \times \text{wall strike length}}$$

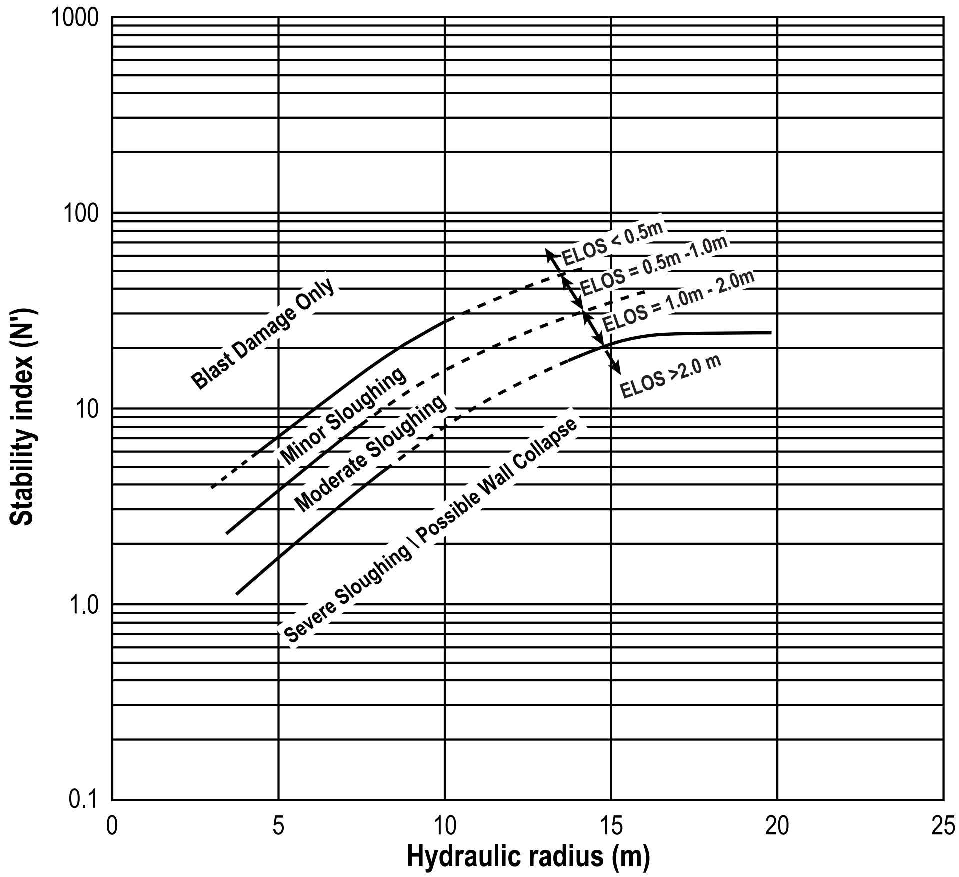

Figure 4. Estimation of overbreak/slough for non supported hanging walls and foot walls, after Clark and Pakalnis (1997).

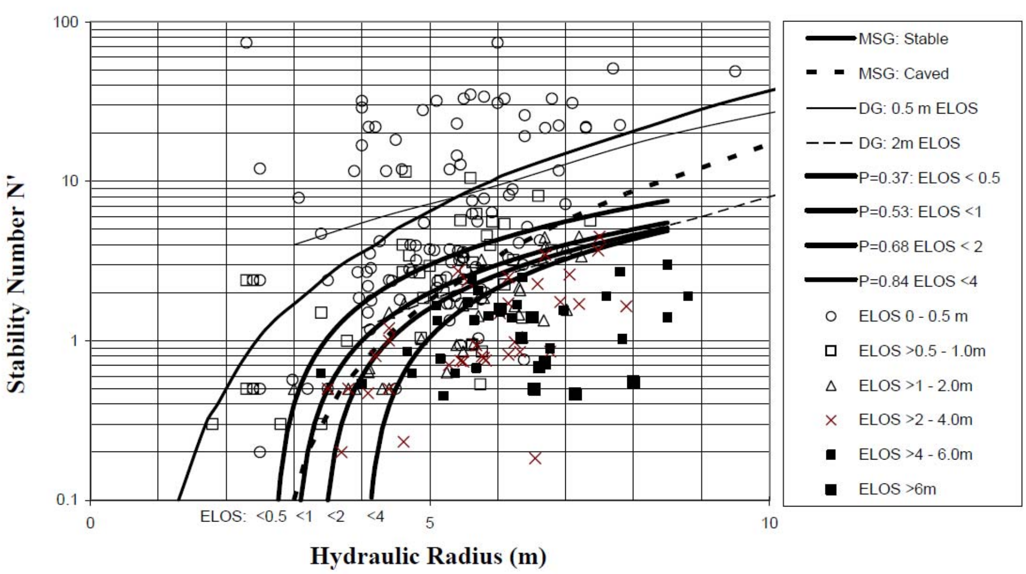

Figure 5. Dilution Graph based on highest percentage correct classification, after Capes (2009).

4.1 Evaluation of Q'

Although it would appear that the Q ratings were recorded, during logging, the provided report (Golder 2010) lists the geomechanical data in summary form as part of the RMR_{76} system Bieniawski (1976). The Stability Graph method, however, relies on the Q system. As a preliminary assessment and in the absence of access to the raw geotechnical data the average RMR_{76} value was used from the Golder report (2010).

The variation in RMR_{76} values was only available for the geomechanical data of Lodes 1000 and 1100. It was assumed that similar variations were applicable to the other lodes. Consequently, a similar range was used for the others lodes with a minimal RMR equal to the mean RMR-10 and the maximal RMR equal to mean RMR +5. For the purposes of the stability graph analysis the Q' ratings were determined by the site specific relationship developed by Golder (2010).

$$Q' = e^{(RMR-52)/8}$$

It is strongly reccomended that once the raw data become availble the analysis be revised based on the resulting Q' ratings and not the site specific data.

The adjustment factors, A, B and C of the stability graph were determined, as described in Potvin and Hadjigeorgiou (2001), and based on the data compiled by Golder (2010). The range in UCS values used in the analyses for factor A is reported in Table 3. The stresses were based on hydrostatic stress with σ_v = 0.027(depth) (kPa/m^3) and σ_h was determined based on k ranging between 1.0 and 1.5. This has resulted in a range of A adjustments (max, min). The A adjustments should, however, be revised to account for the induced stresses. The adjustment Factors B and C were calculated based on the joint set orientation data in Table 5. These data were plotted on stereonets and the critical joint was defined for every surface.

4.2 Evaluation of the Stability Graph Ratings

The results of the completed stability graph analyses are presented in appendix A. Table 6 summarizes the input parameters for the stability index for Lode 1000 and the range of stope dimensions provided by Agnico Eagle Mines.

Table 6. Stope dimensions and calculated stability index values.

	Stope Dimensions				Q'		A		B	C	N'	
	min	max		Stope	min	max	min	max			min	max
Height (m)	20	20		Back	3.4	25.7	0.37	1.00	0.20	2.0	0.5	10.2
Span (m)	5	10		HW	9.4	25.7	0.87	1.00	0.25	4.5	9.2	28.9
Length (m)	15	25		FW	9.4	25.7	0.87	1.00	0.25	6.5	13.2	41.7
Dip (^{0})	62			Ends	3.4	25.7	0.2	1.00	0.25	8.0	1.3	51.4
Depth (m)	200			PHW	0.7	5.0	0.2	0.87	0.25	4.5	0.1	4.8
				PFW	0.5	3.4	0.2	0.87	0.25	6.5	0.1	4.8

Note: HW hanging wall; FW foot wall; PHW proximal hanging wall; PFW proximal foot wall.

Figure 6 provides a sample printout indicating the stability range for the range of hydraulic radiuses and rock mass quality. It can be seen that hanging and foot walls as well as the stope ends are expected to be stable for all the projected range of rock mass quality. The back walls are expected to be stable but if the backs are in the worst extreme of expected rock mass they will fall in the transition zone.

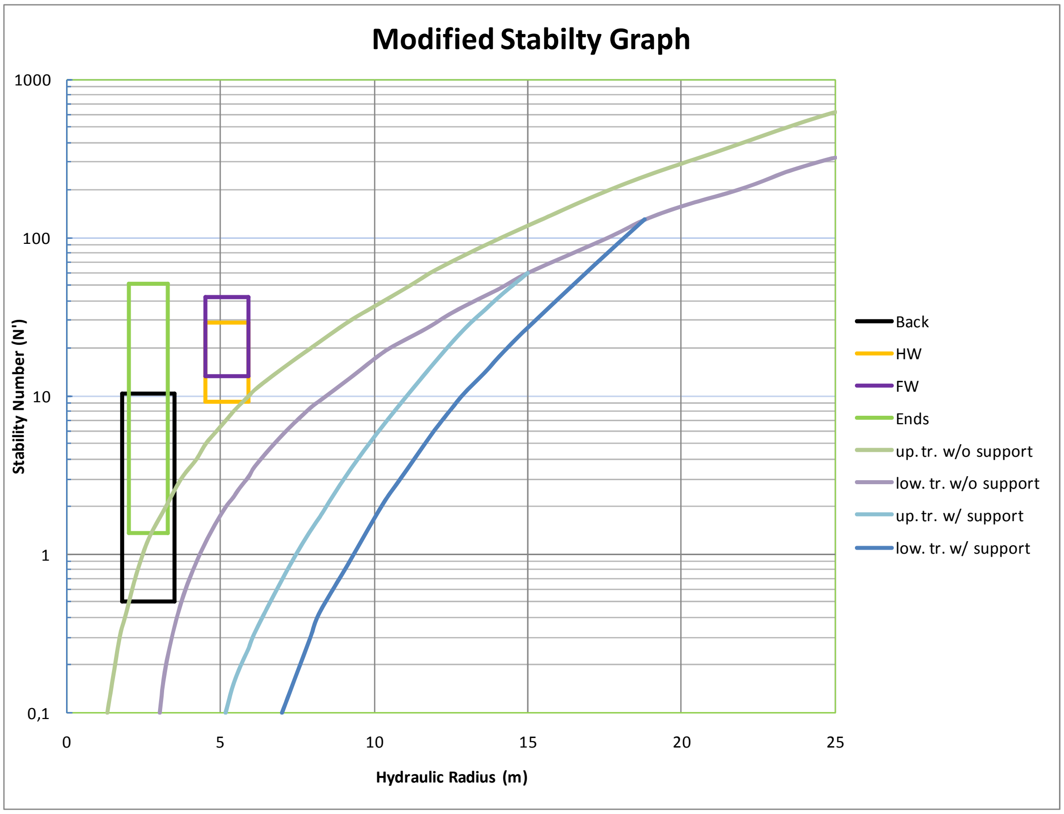

Figure 6. Stability Graph analysis for stopes in 1000 Lode.

ELOS has been integrated in the stability graph, providing a series of design zones, Clark and Pakalnis (1997). Although this data presentation does not account for the influence of support, it provides a useful tool for hanging walls and footwalls in a low or relaxed-stress state, and with parallel geological structure being present. For design purposes the more recent version of the guidelines, Capes (2009). was used Referring to Figure 7 it is noted that the expected overbreak slough is limited to less than 0.5 m.

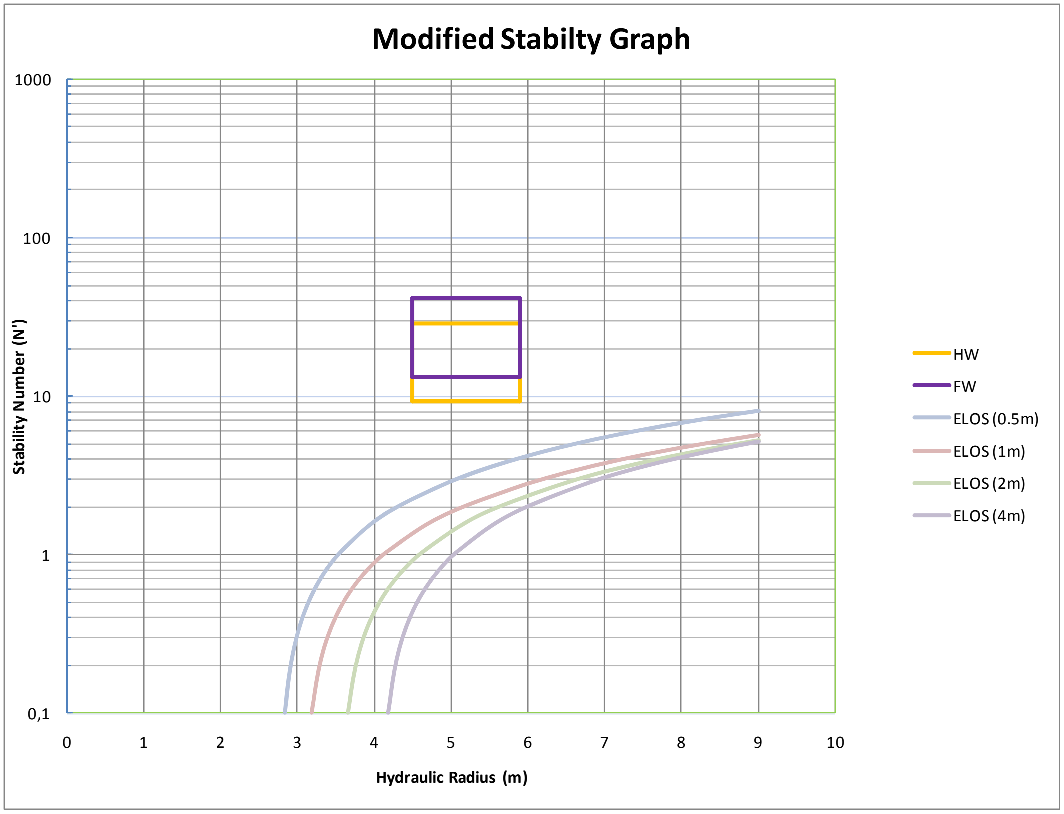

Figure 7. Estimation of overbreak/slough for non supported hanging walls and foot walls for 1000 Lode.

5.0 Preliminary Assessment

The stability graph analysis suggests that there are no major anticipated problems for the design stopes. If the analysis is based on the average or most probable N' values for the stopes using mean N' values all surfaces are stable except some backs for larger HR in lode 1155, Table 7.

Table 8 presents the stability analysis results based on average N' values for the proximal hanging and foot walls. It is recognised that stability problems are expected in the proximal hanging wall and foot wall zones. This will invariably result in expanded spans, (including failed PHW (0.5m) and PFW (0.5m), and can potentially have an impact on back stability for large HR for lodes 1050 and 1100. The analysis is restricted by the available PHW and PFW data for only 5 lodes, Table 8. As more data becomes available for other lodes this may influence the stability of stope backs.

Table 7. Stope Stability analysis based on average rock quality values.

	Stability Graph				Elos (m)				
Lode	Back	HW	FW	Ends	Back	HW	FW	Ends	Comments
1000	S	S	S						Less than 0.5 m
1015	S	S	S						Less than 0.5 m
1025	S	S	S						Less than 0.5 m
1050	S	S	S						Less than 0.5 m
1100	S	S	S						Less than 0.5 m
1152	S	S	S						Less than 0.5 m
1153	S	S	S						Less than 0.5 m
1154	S	S	S						Less than 0.5 m
1155	UTZ	S	S						Backs in UTZ for larger HR
1252	S	S	S						Less than 0.5 m
1255	S	S	S						Less than 0.5 m

Legend: Stable (S); Unsupported Transition Zone (UTZ); Stable with Support (SWS); Supported Transition Zone (STZ).

Table 8. Stability Analysis based on average N' values for the Proximal Hanging Wall and Foot Wall.

	Stability Graph				Elos (m)				
Lode	Back	HW	FW	Ends	Back	HW	FW	Ends	Comments
1000	S	CZ	CZ						HW and FW in "caved zone"
1025	S	CZ	CZ						HW and FW in "caved zone"
1050	S	CZ	CZ						HW and FW in "caved zone"
1025	S	CZ	CZ						HW and FW in "caved zone"
1100	S	CZ	CZ						HW and FW in "caved zone"

Legend: Stable (S); Unsupported Transition Zone (UTZ); Stable with Support (SWS); Supported Transition Zone (STZ); Caved Zone (CZ).

The results of the stability analysis based on lower limit N' are summarised in Table 9. If the minimum N' values are used, i.e. conservative analysis, the stability index will place the HW, FW and back in the unsupported transition zones. Provided good blasting practices are implemented this is not of major concern. Assuming that the lowest N' values are encountered in the HW, FW the maximum expected ELOS will be 2 m. if the lowest N' values are used for the PHW and PFW then instability is expected. This can potentially result in expanded spans (including failed PHW (0.5m) and PFW (0.5m)) and can also have an impact on the stability of the back.

Table 9. Stability Analysis based on lower limit N’.

	Stability Graph				ELOS (m)				Comments
Lode	Back	HW	FW	Ends	Back	HW	FW	Ends	
1000	UTZ								Concern at the Back for lowest N' values
1015	UTZ	SWS	SWS			2	1		Concern at the FW and HW for lowest N' values
1025	UTZ	SWS	SWS			2	2		Concern for HW and FW for lowest N'
1050		UTZ	UTZ			1			Concern for HW and FW and ends for lowest N'
1100	UTZ	UTZ							Concern for ends and backs
1152		UTZ	UTZ				0.5		Concern at HW for lowest N'
1153		UTZ							OK
1154	SWS	SWS	UTZ	SWS		2			Concern for largest HR
1155	SWS	UTZ	UTZ	SWS					Concern for largest HR
1252	SWS	UTZ	UTZ	SWS					Concern for largest HR
1255	UTZ	SWS	UTZ			1	0.5		Concern for smallest values of N'

Legend: Stable (S); Unsupported Transition Zone (UTZ); Stable with Support (SWS); Supported Transition Zone (STZ).

5.1 Limitations of the Analysis

All analysis was undertaken based on the compiled data and not the raw data. As the Q” values were not available, they were determined using the site specific conversion, RMR_{76} = 8 lnQ' + 52 between Q’ and RMR_{76} proposed by Golder (2010). In this preliminary analysis the stress results were based on empirically determined estimates of the in situ stress. These should be revised using numerical stress analysis models. Mapping results were limited and the assumption was made that there is only one structural domain. As more data become available this will probably have to be reviewed further.

5.2 Path Forward

The report by Golder (2010) has some information on the raw field data. The Excel, MSAccess, aQuire geomechanical database should be acquired and reviewed further. This will allow a revision of the Q’ ratings based on the field data and not resort to the use of empirical conversions. Access to the full data can allow further refining of the observed variability in rock quality. Currently this is restricted to the data from Lodes 1000 and 1100.

As identified by Golder (2010) it is necessary to expand the geotechnical data collection database by drilling and logging more holes. Golder (2010) suggest that boreholes should traverse all mineralised areas including 4 boreholes within the rectangle defined by 539850 E and elevation 9650 m to 9800 m and one borehole near 539850 E near elevation 9850.

In the absence of further mapping data it is necessary to consider directional drilling to acquire more information on the orientation of fractures. The geological and structural data should be further analysed and grouped into the appropriate structural regimes. The use of further laboratory testing can provide more insight and allow the necessary data for input to numerical stress models.

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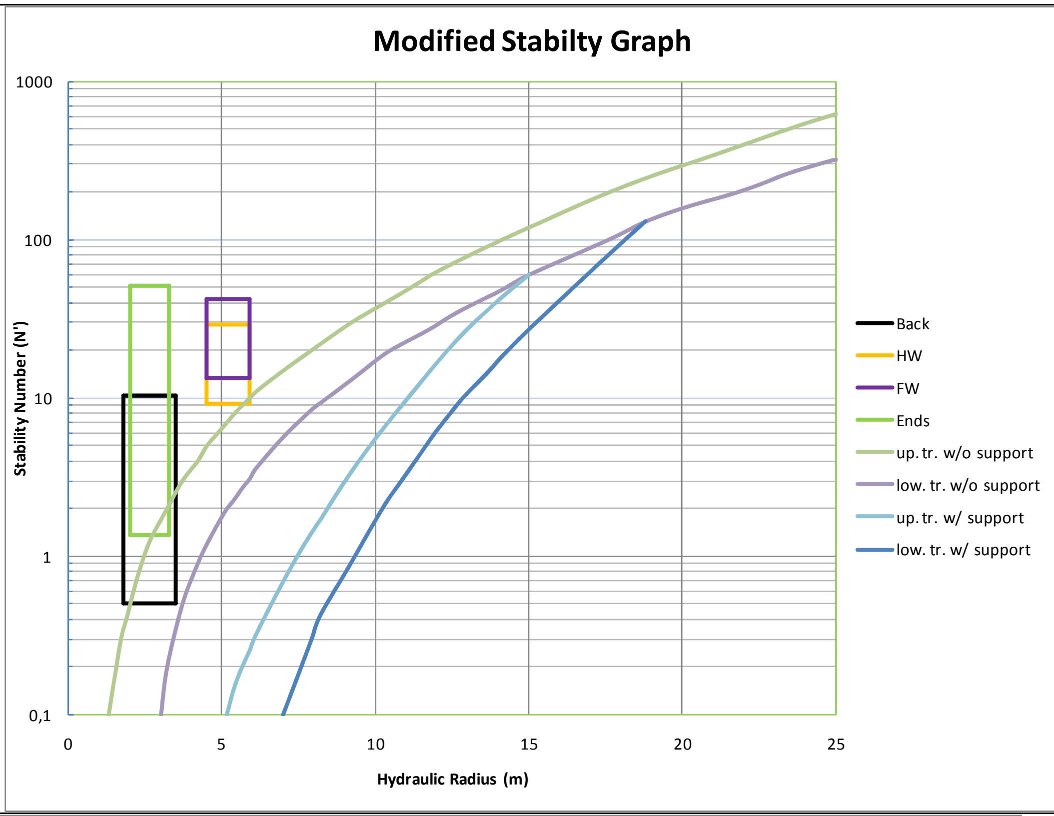
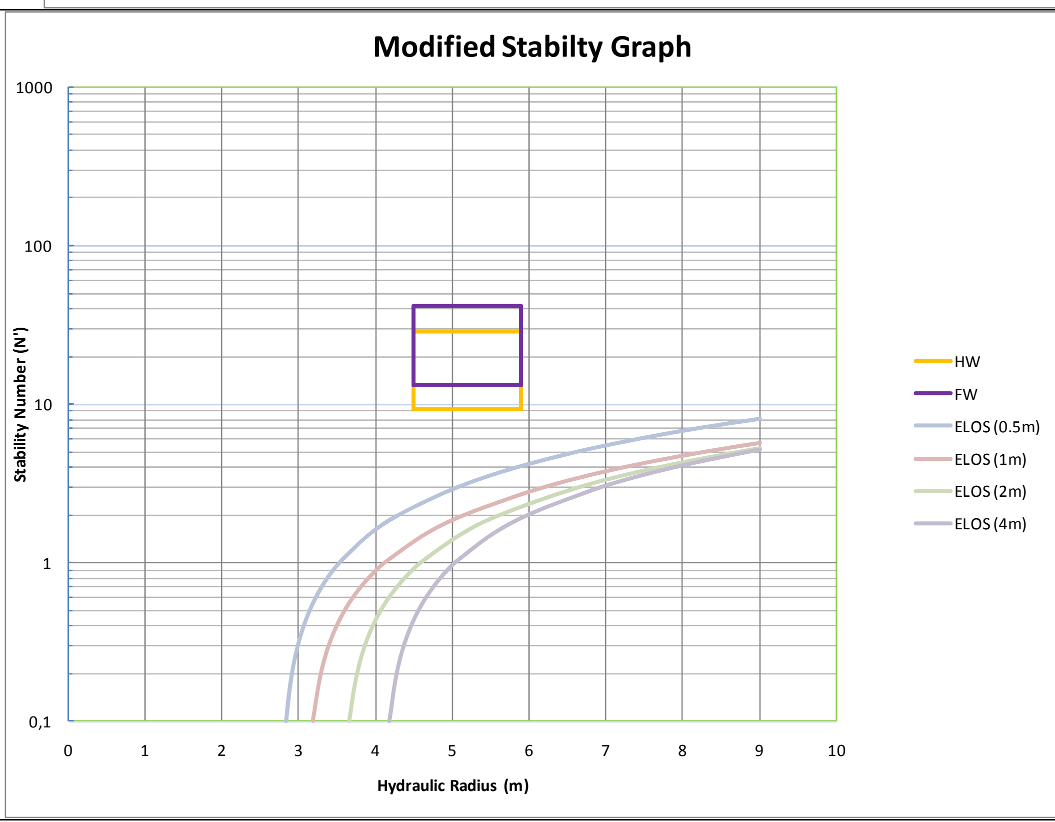
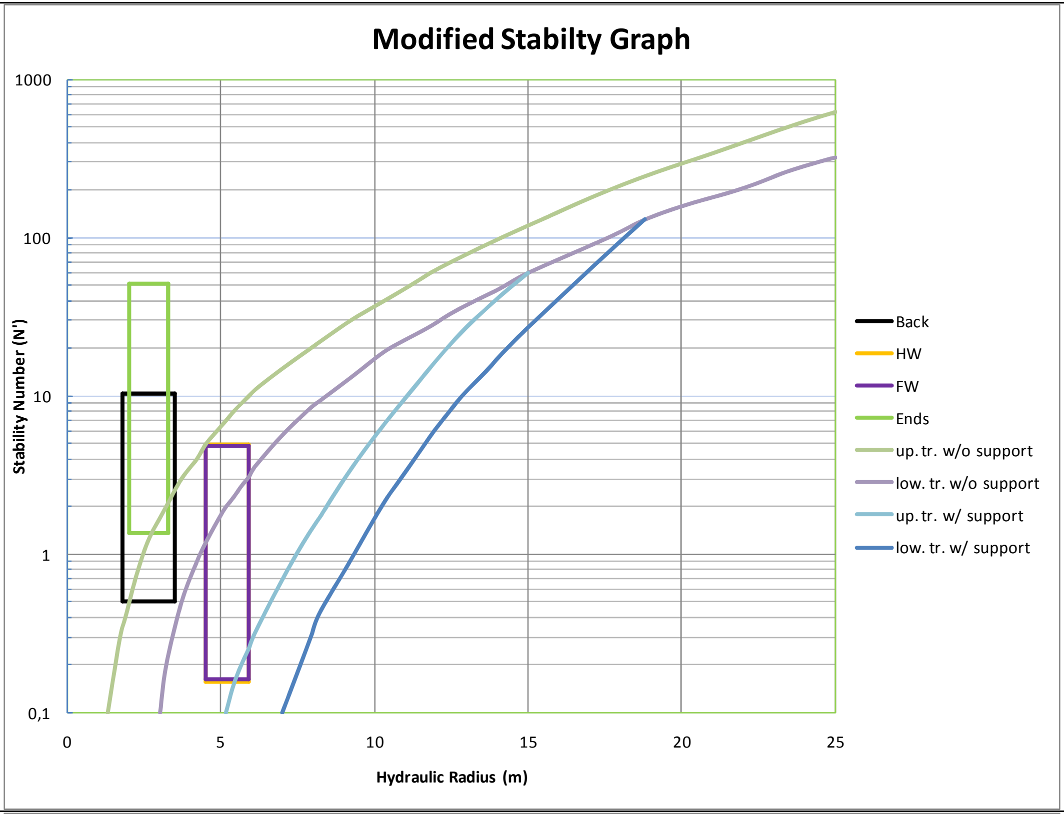
Appendix A

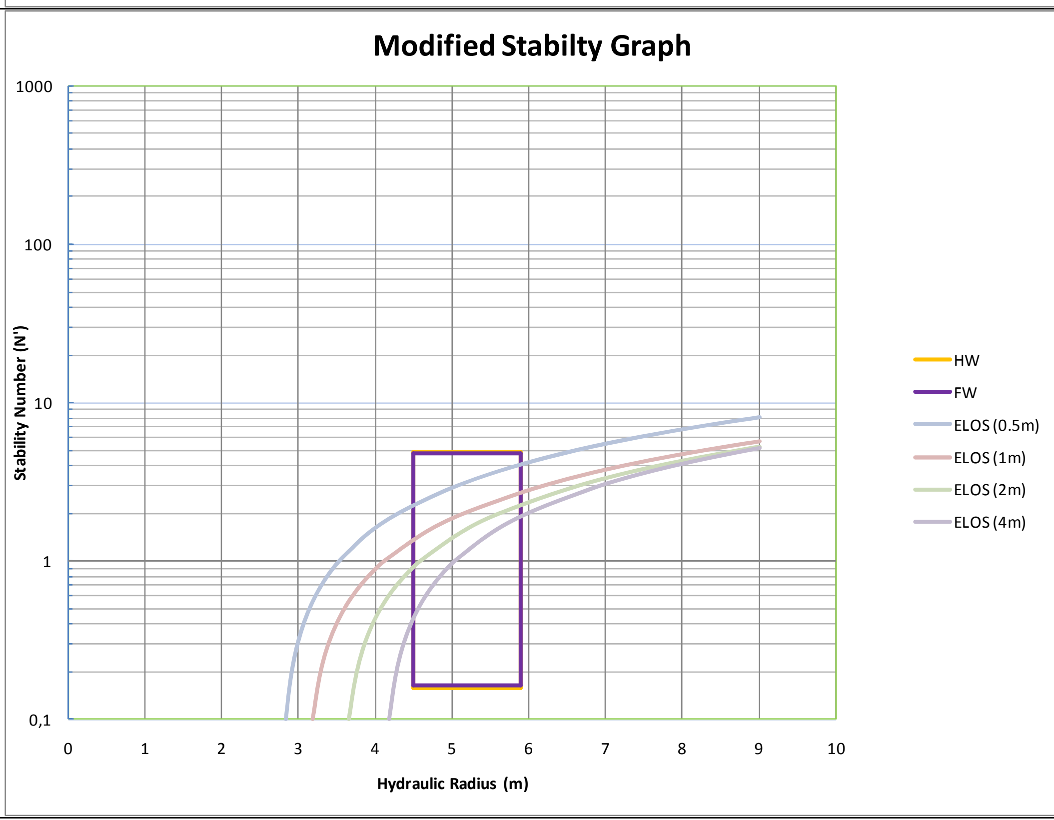
Stability Graph and ELOS Analysis Plots



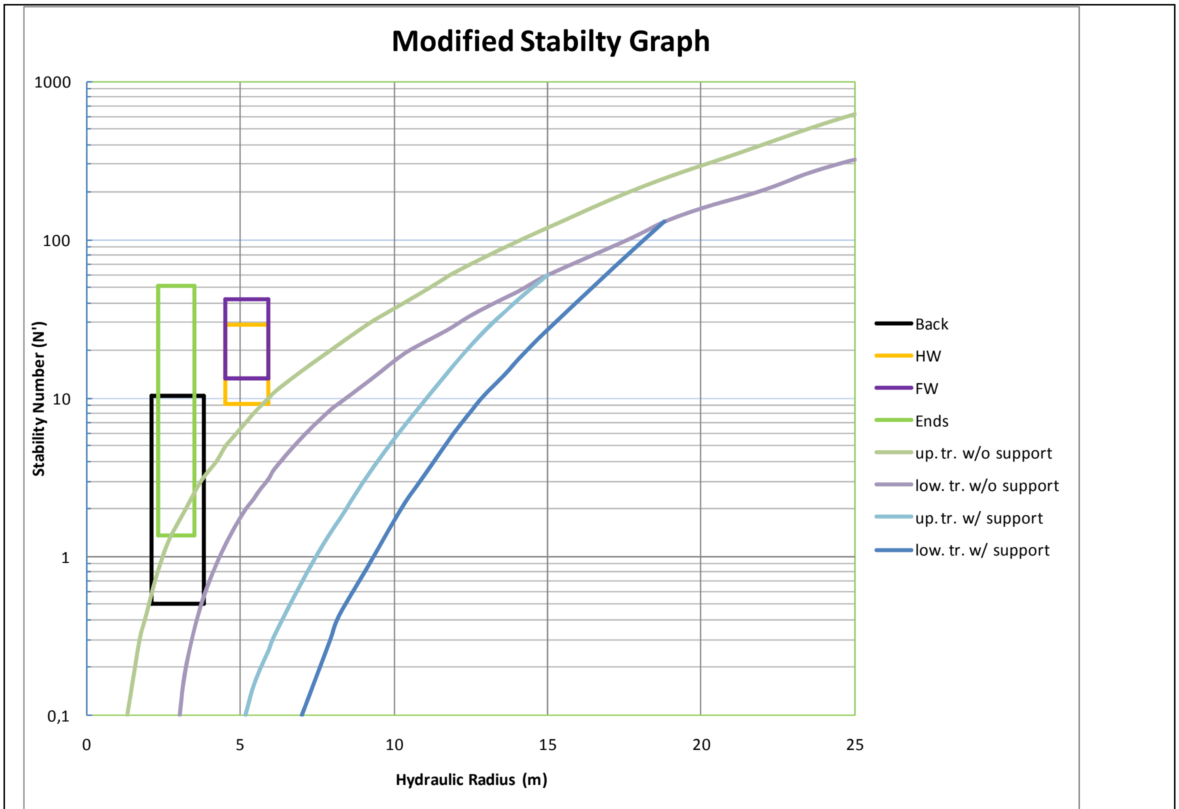


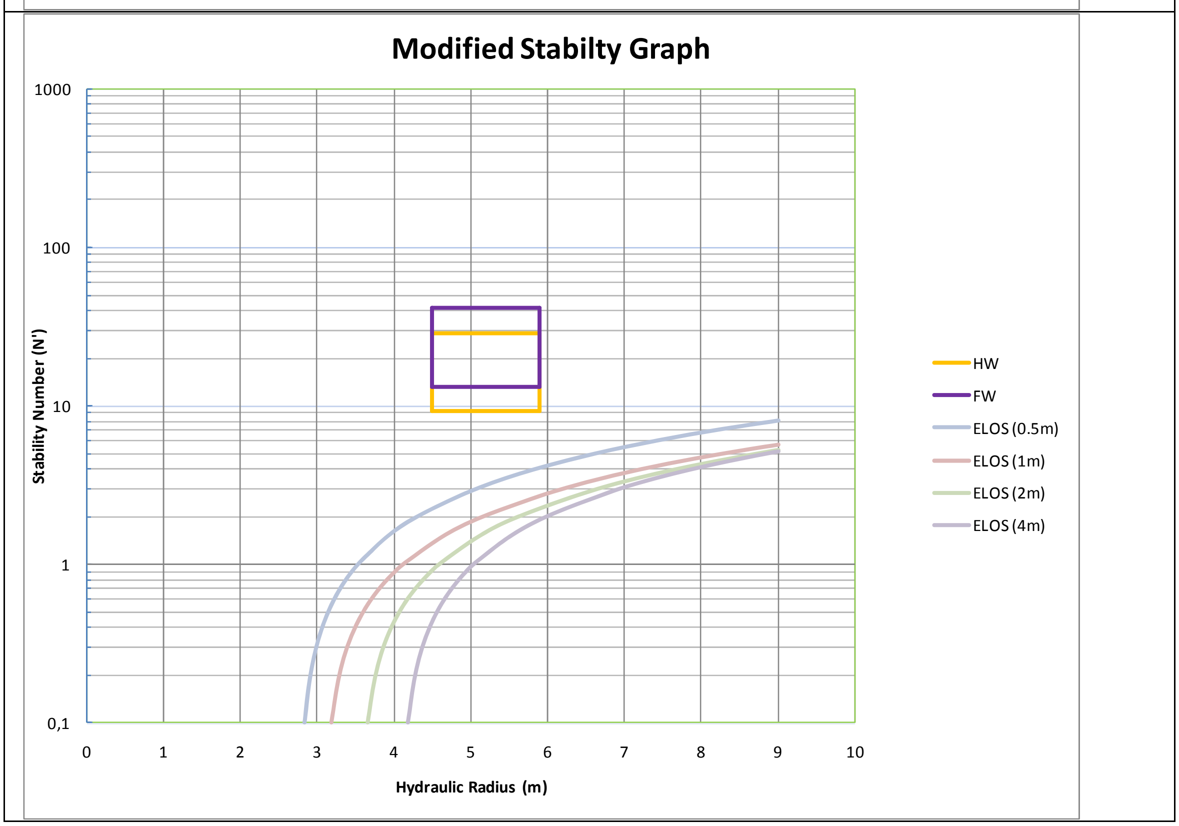
Stability Graph and ELOS analysis for Lode 1000 at a depth of 200m.



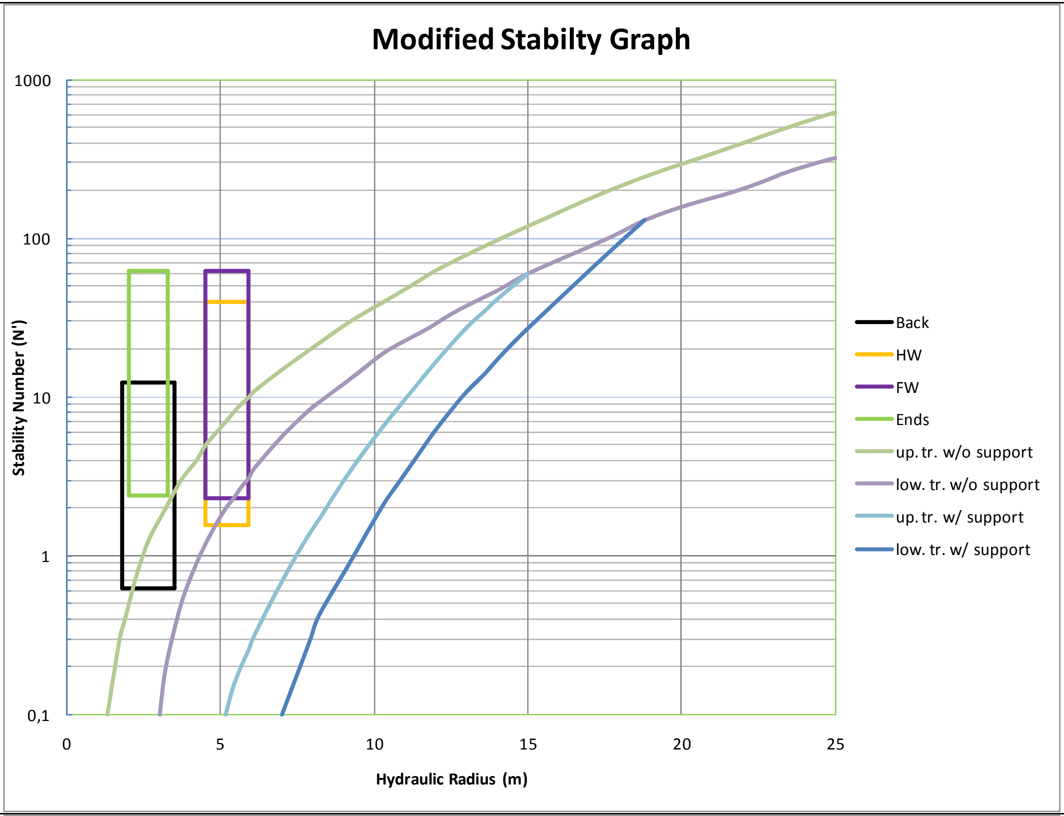


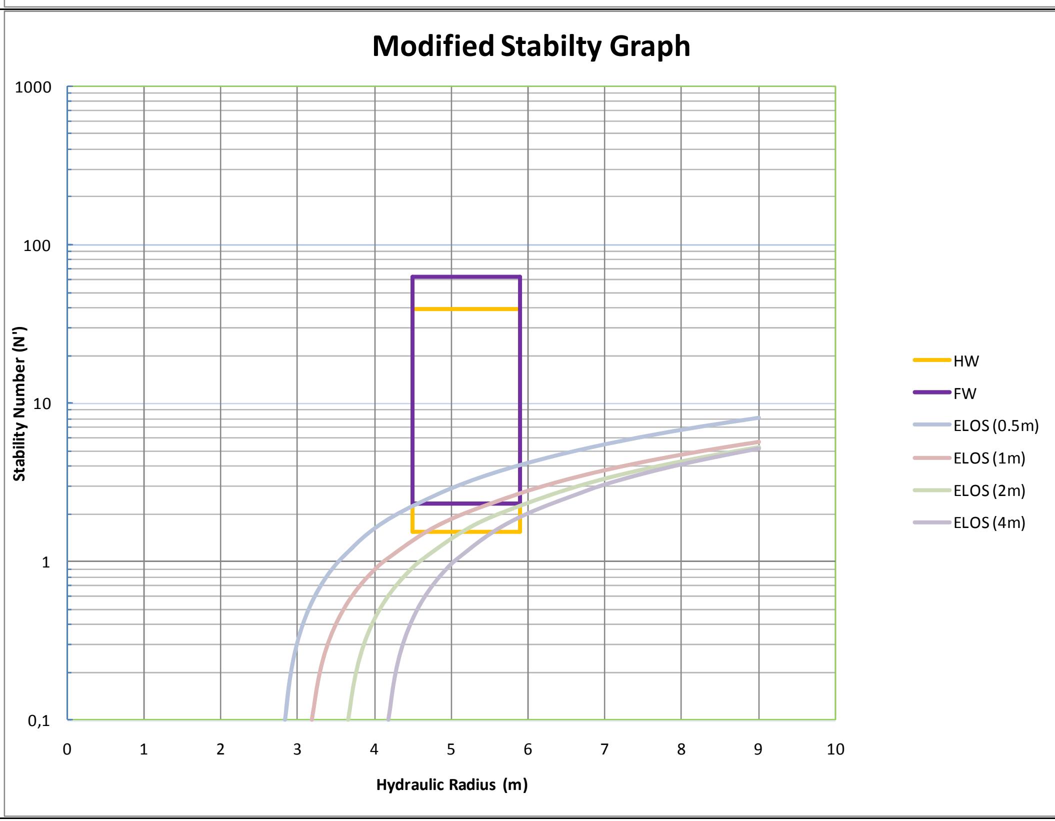
Stability Graph and ELOS analysis for Lode 1000 at a depth of 200m using proximal HW and FW Q'.



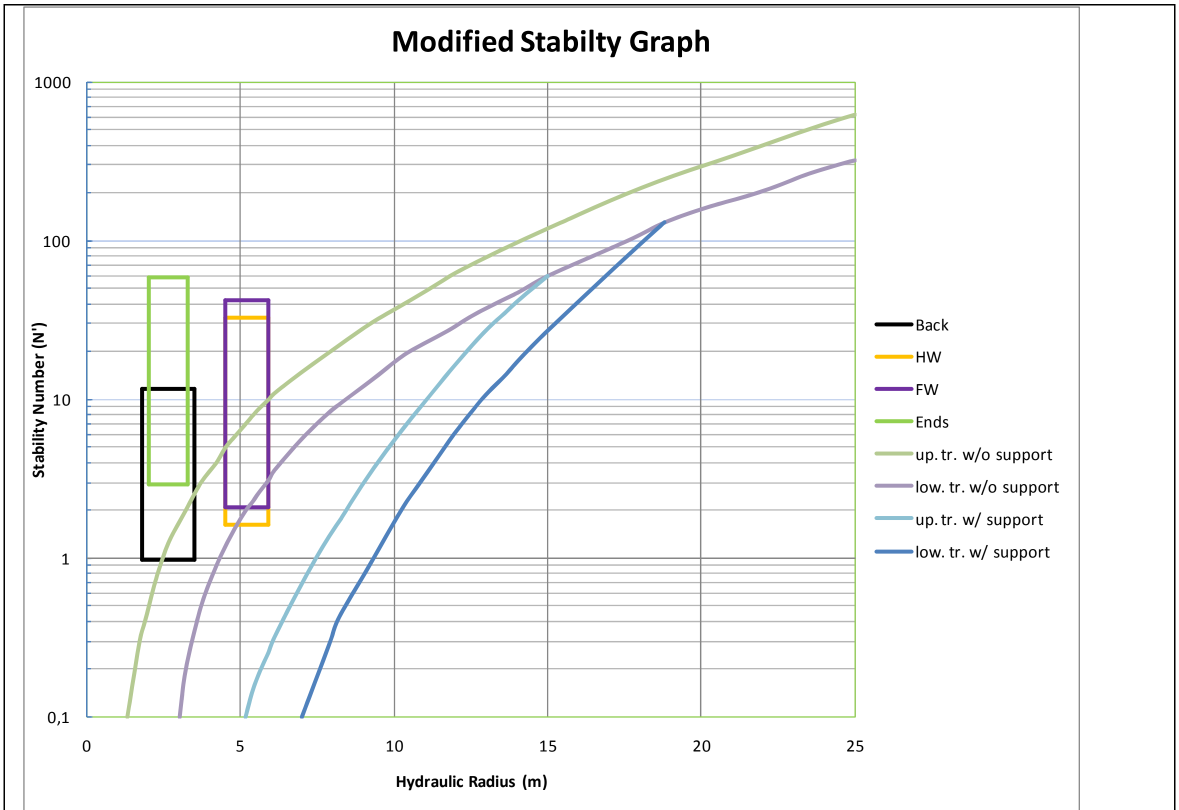


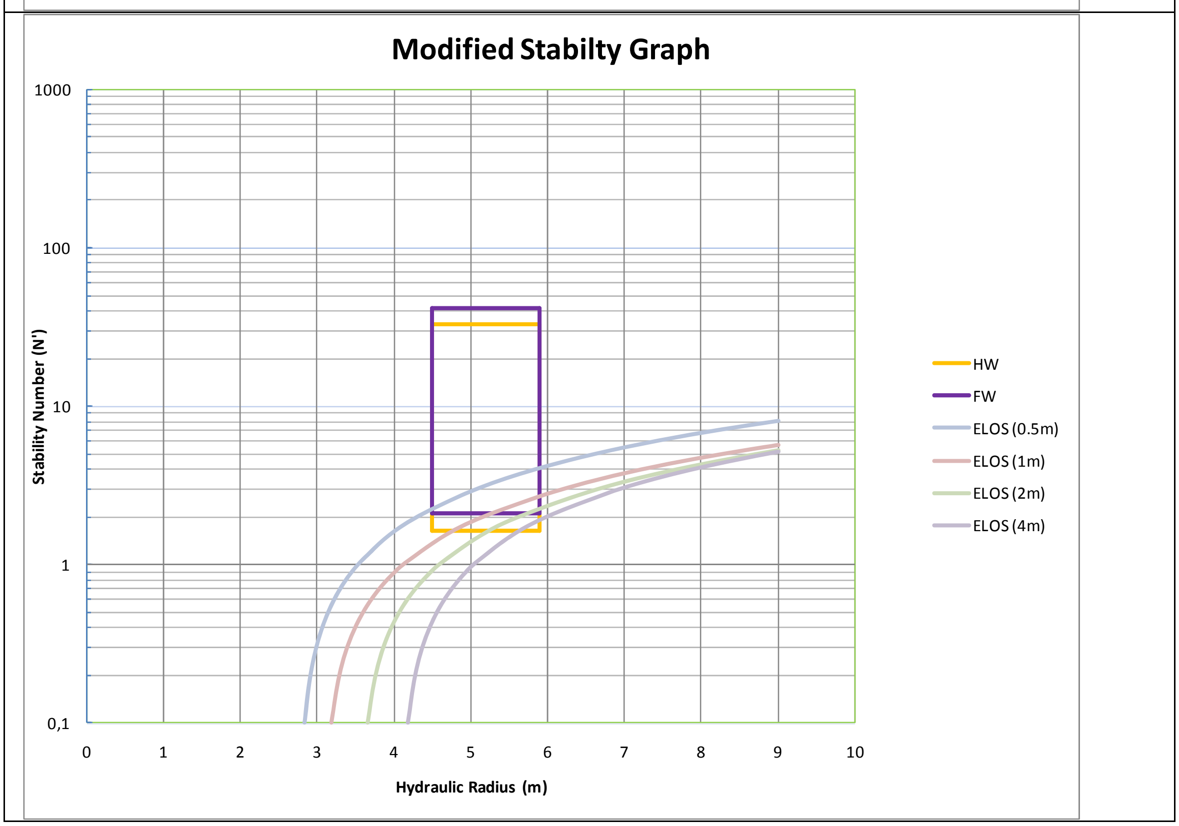
Stability Graph and ELOS analysis for Lode 1000 at a depth of 200m with span increase by 1m.



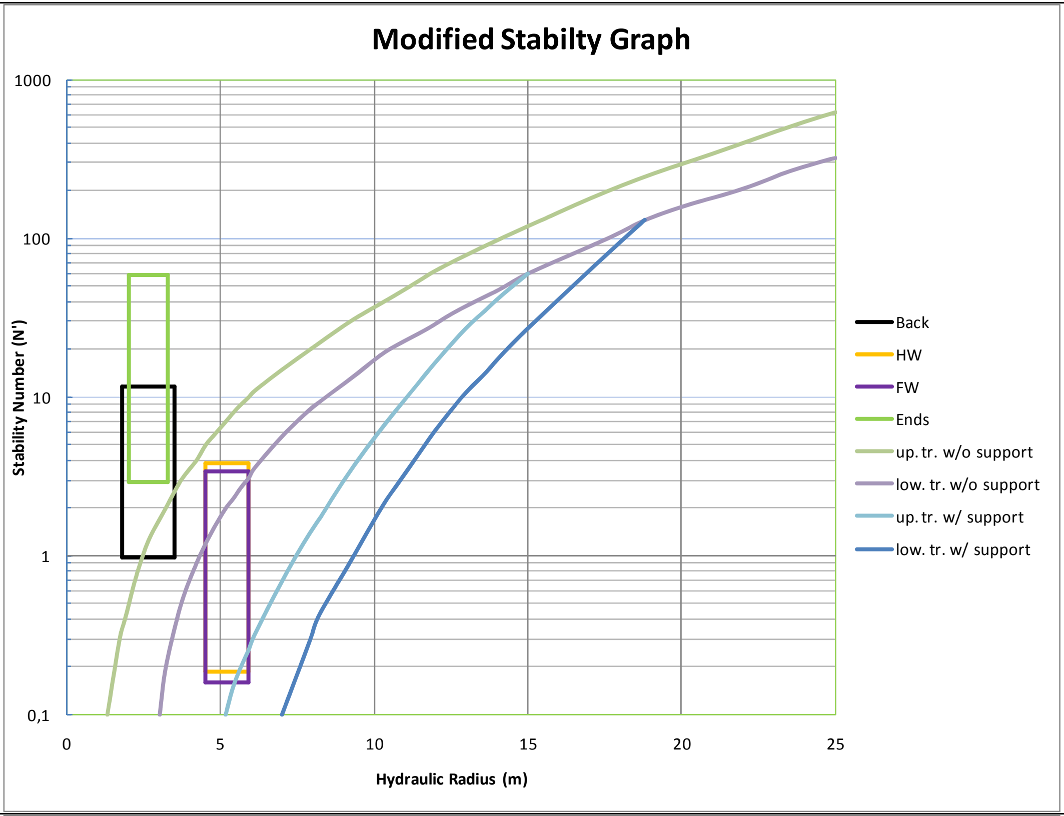


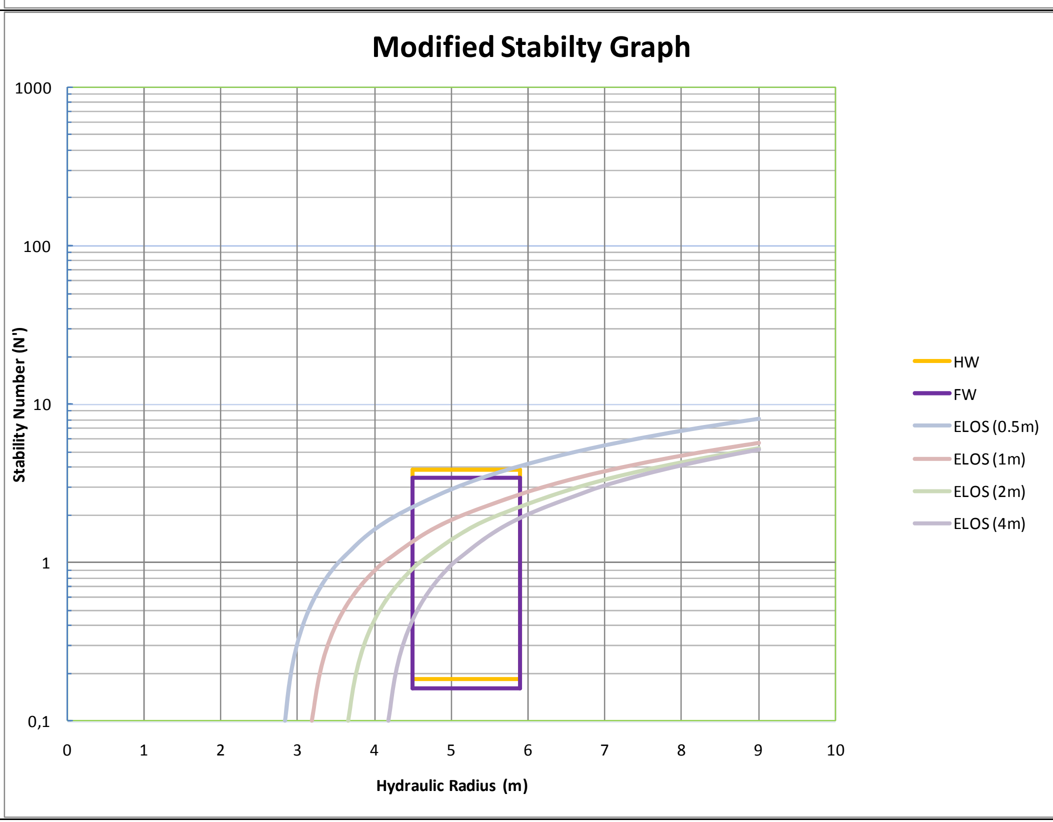
Stability Graph and ELOS analysis for Lode 1015 at a depth of 400m.



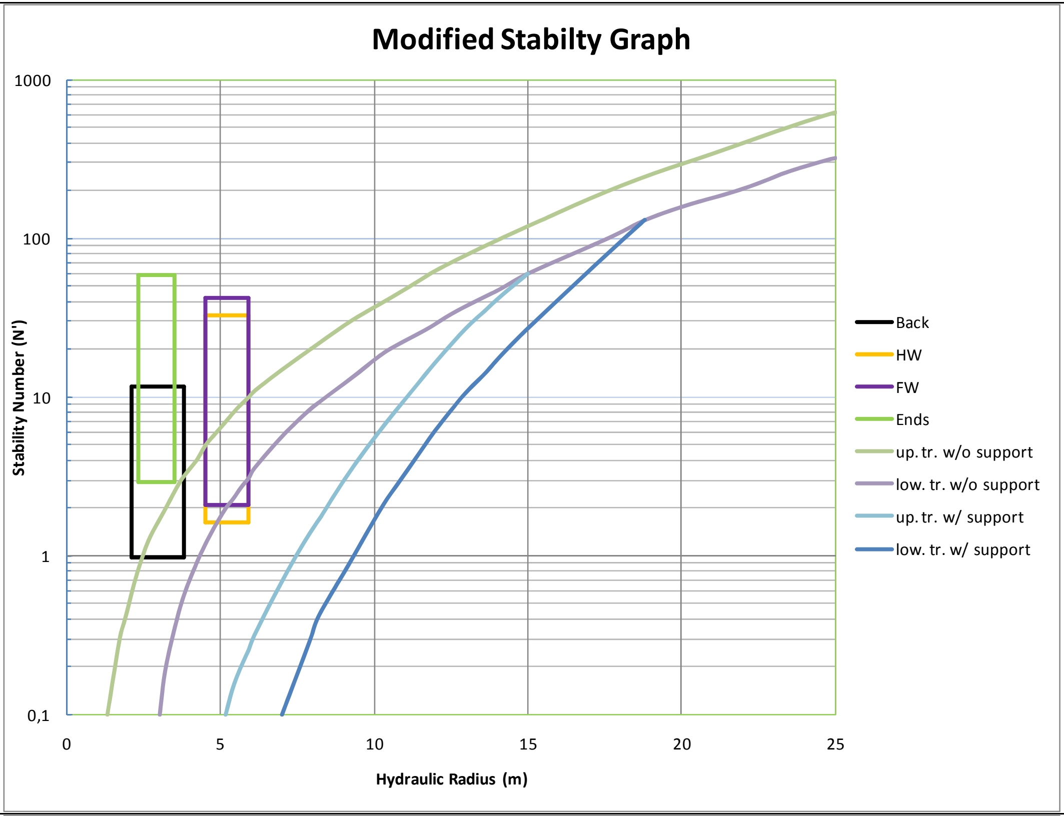


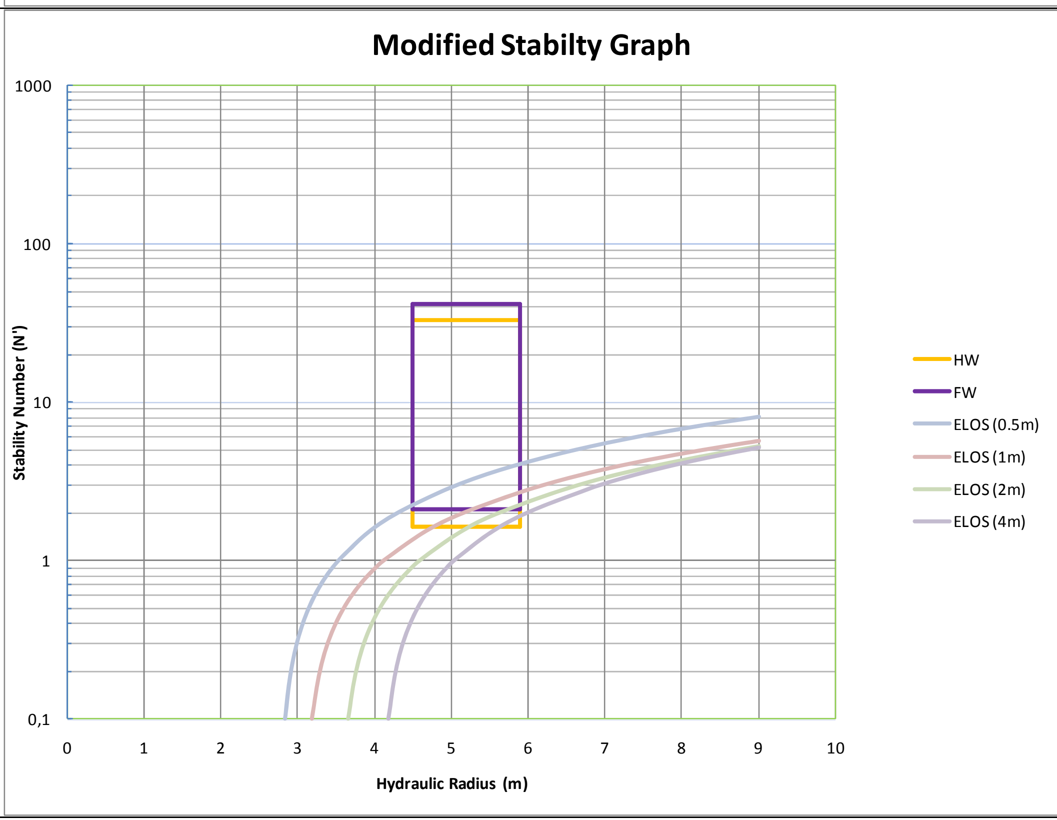
Stability Graph and ELOS analysis for Lode 1025 at a depth of 150m.



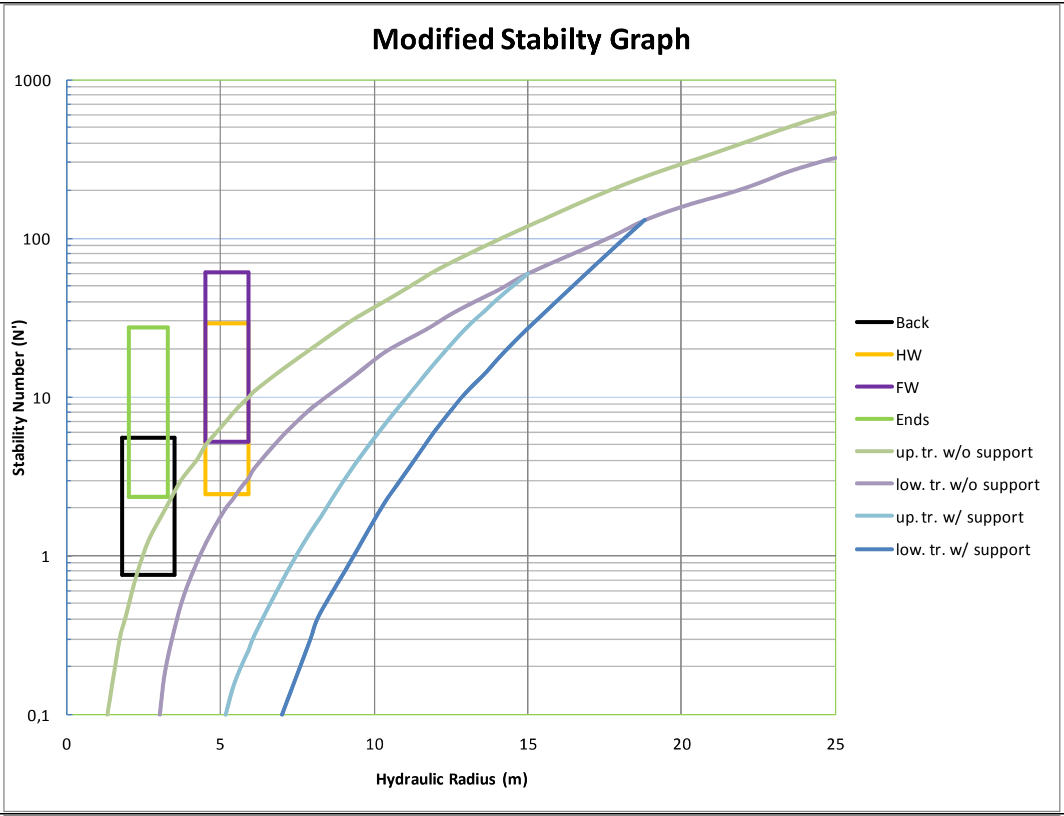


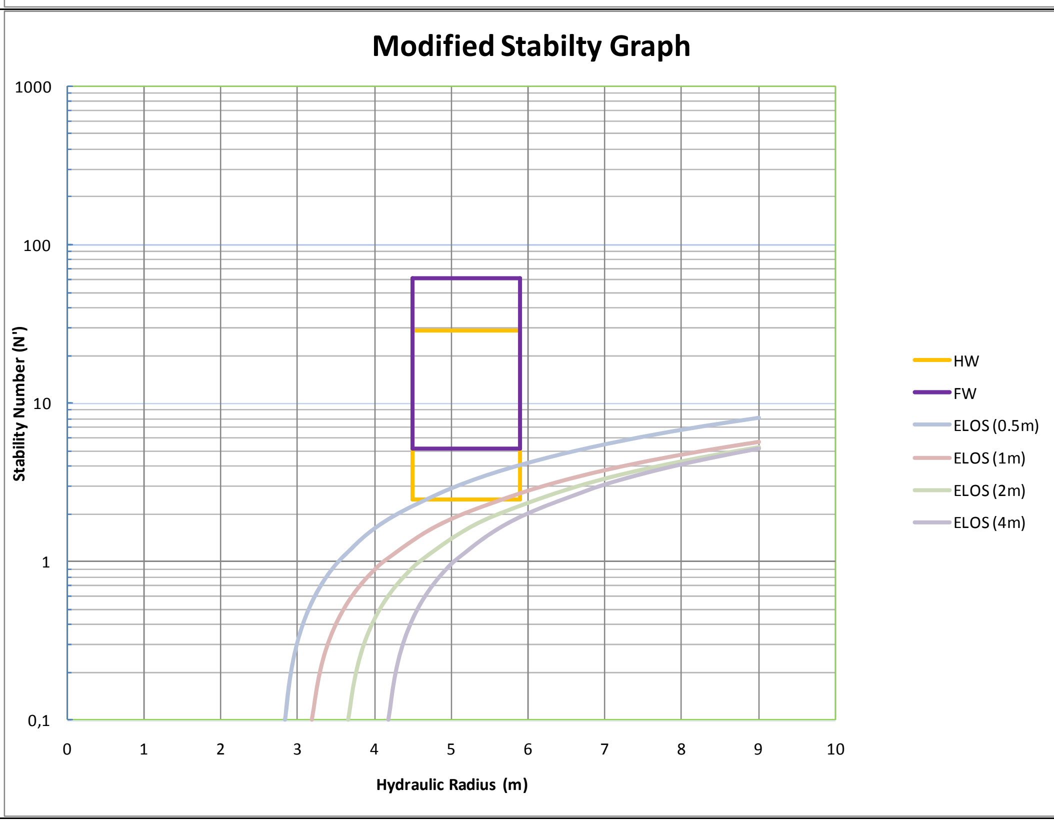
Stability Graph and ELOS analysis for Lode 1025 at a depth of 150m using proximal HW and FW Q'.



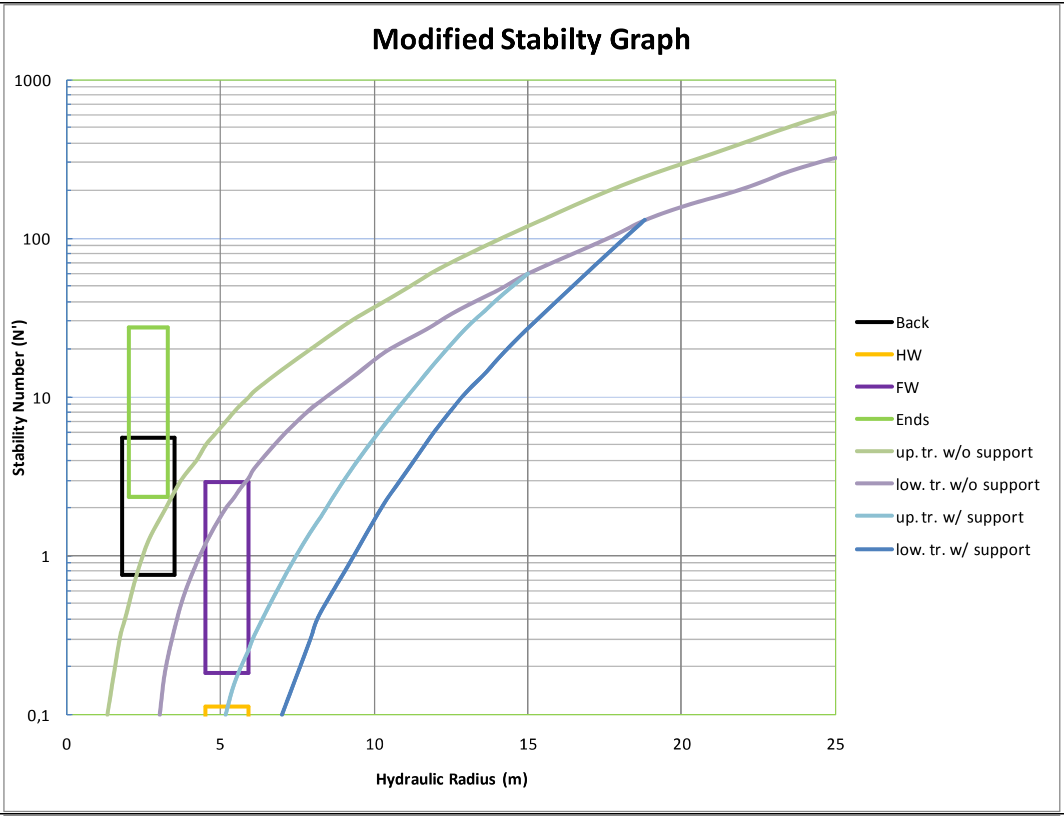


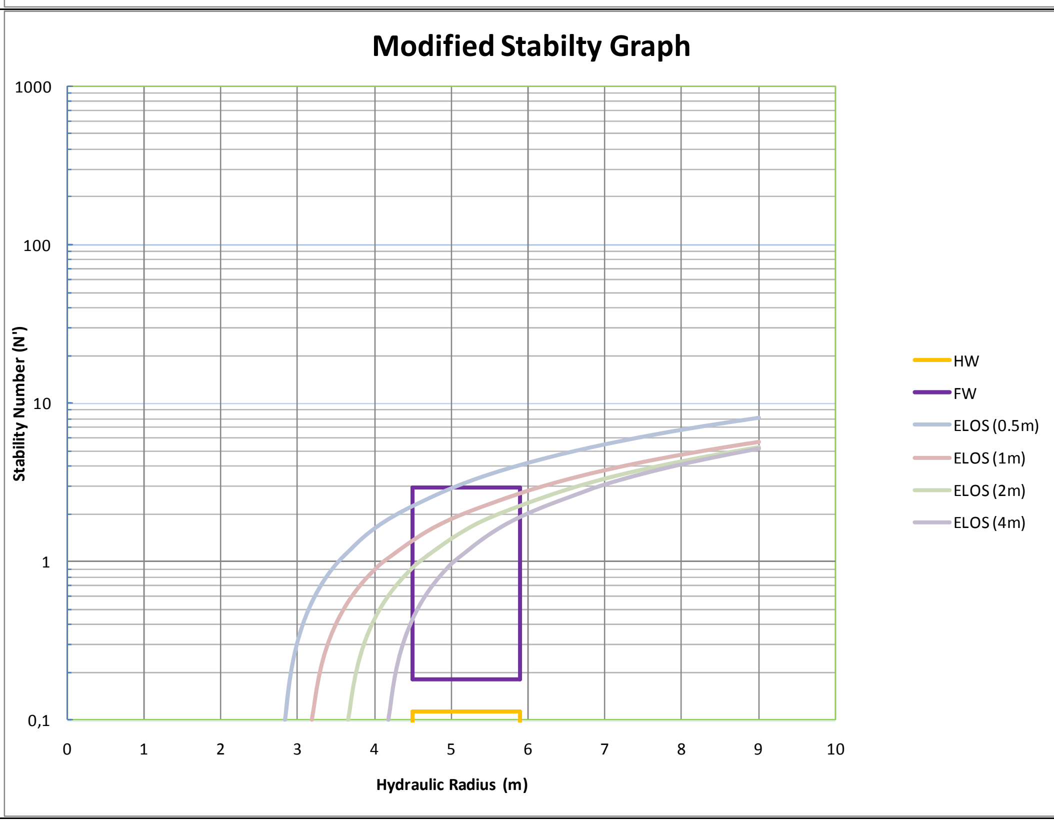
Stability Graph and ELOS analysis for Lode 1025 at a depth of 150m with span increase by 1m.



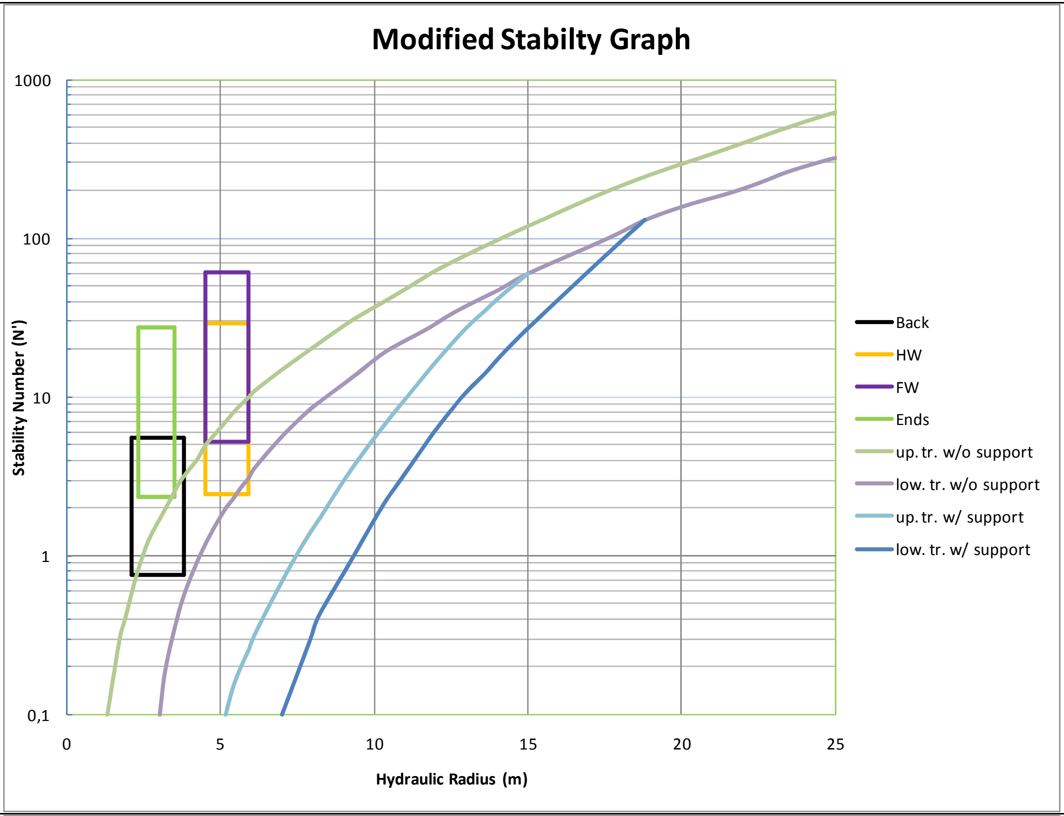


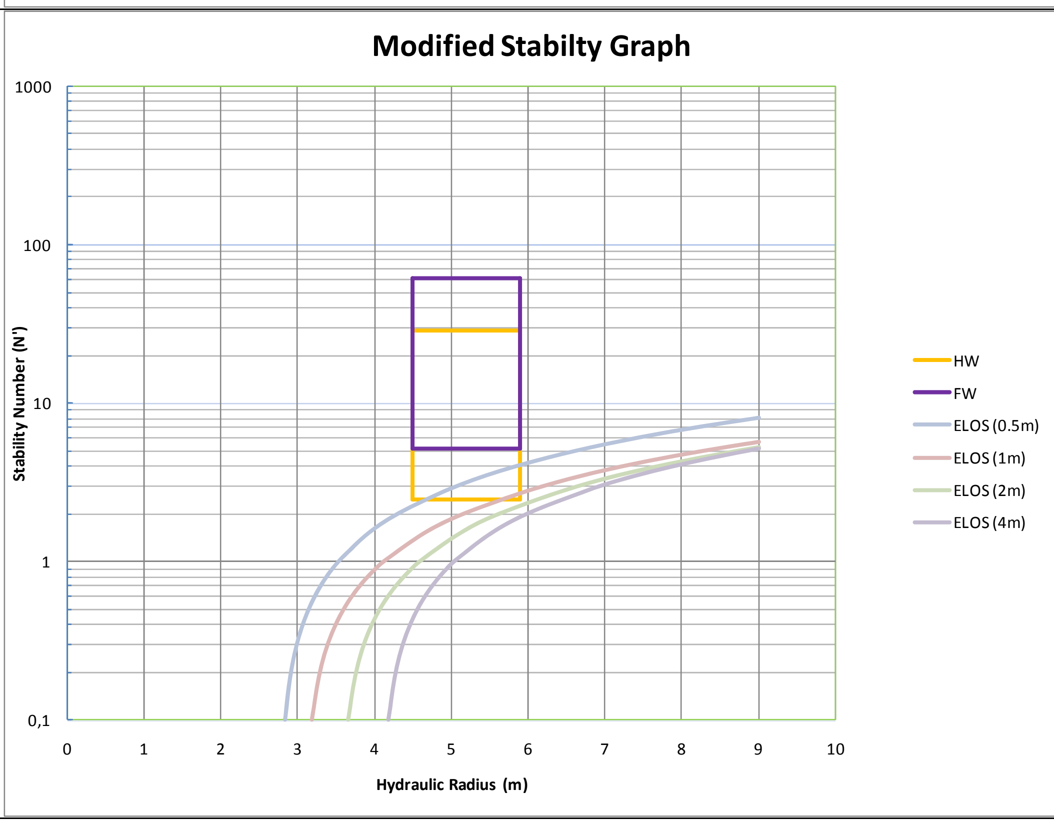
Stability Graph and ELOS analysis for Lode 1050 at a depth of 100m.



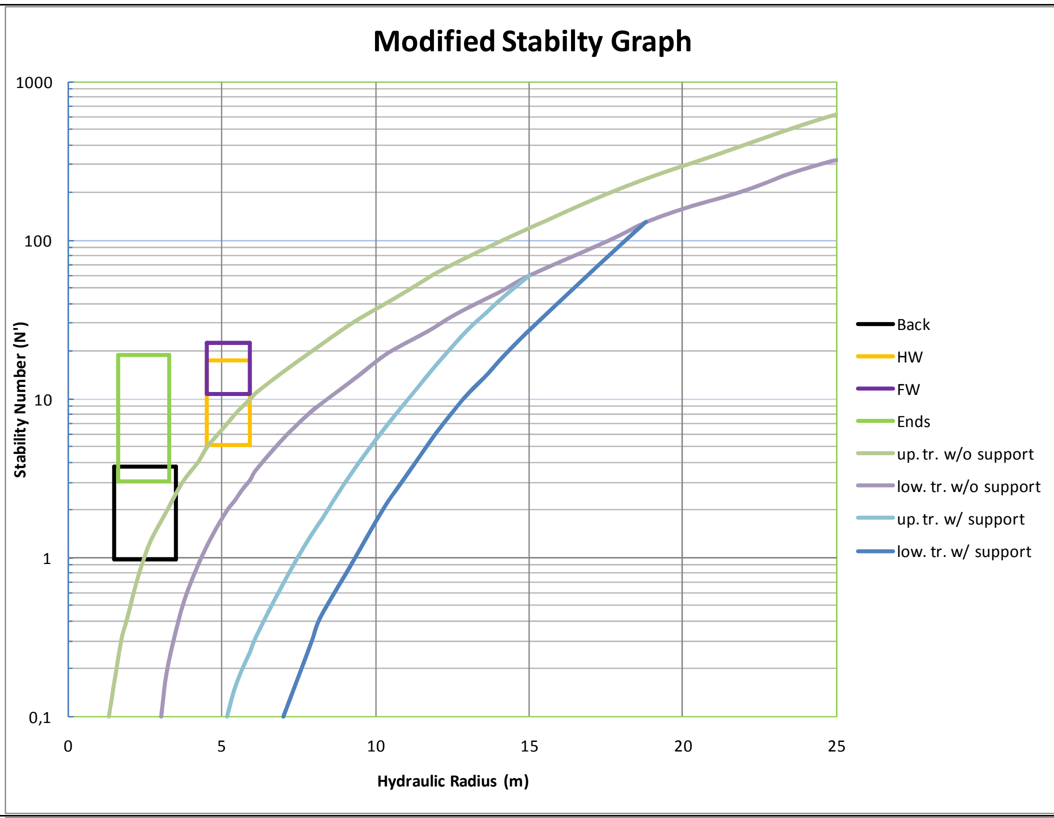


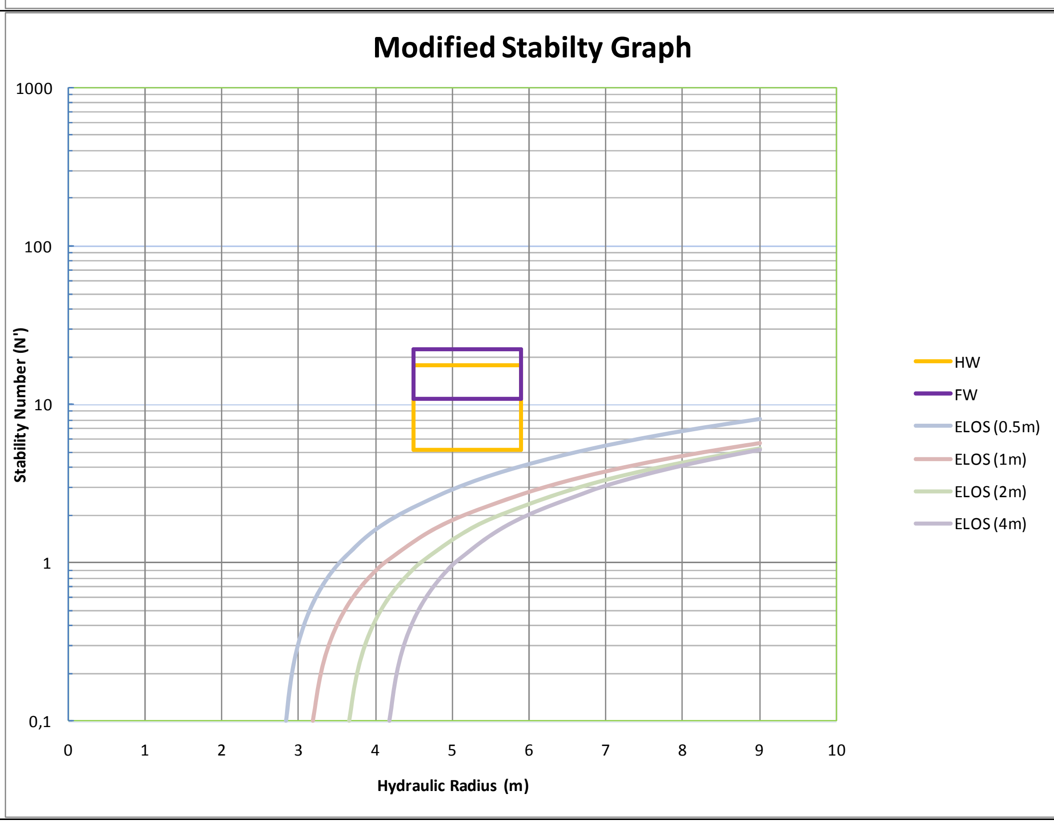
Stability Graph and ELOS analysis for Lode 1050 at a depth of 100m using proximal HW and FW Q'.



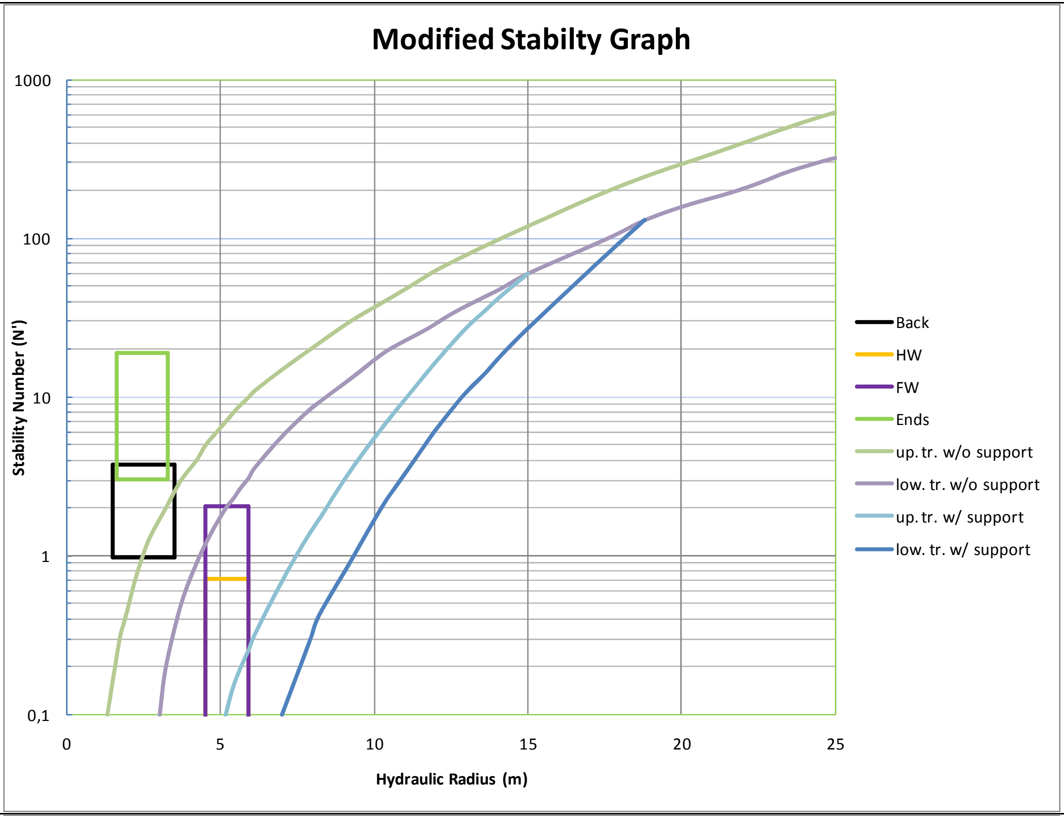


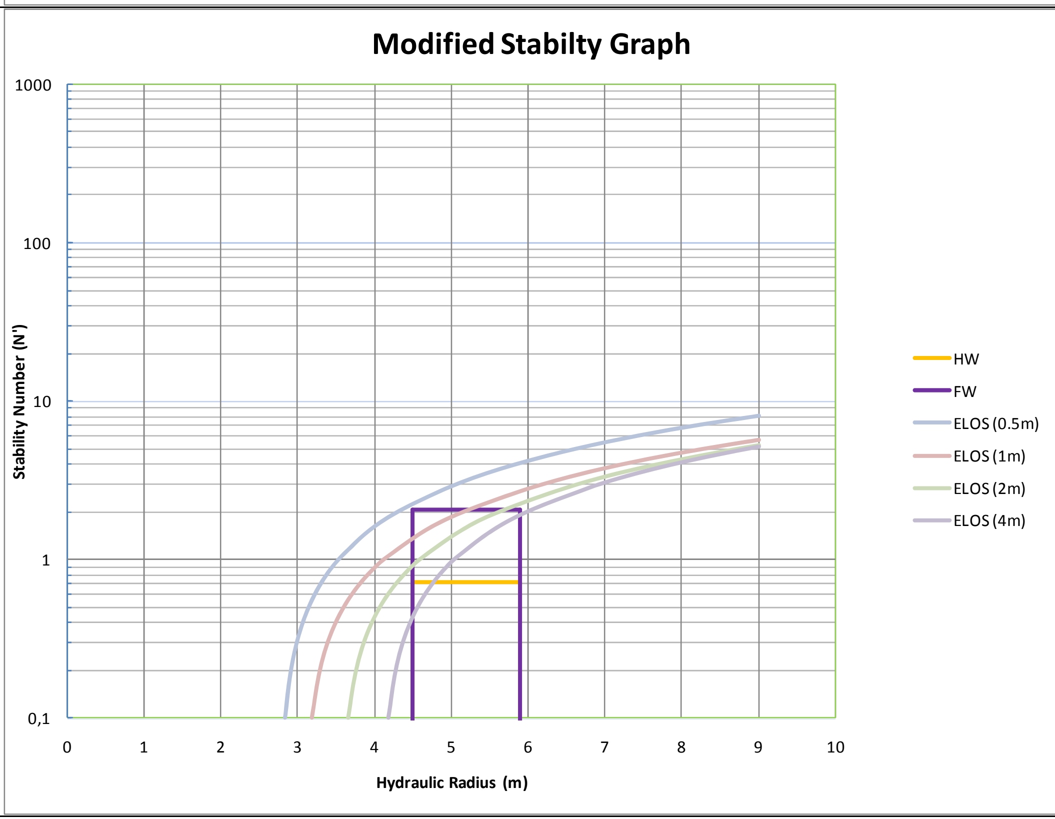
Stability Graph and ELOS analysis for Lode 1050 at a depth of 100m with span increase by 1m.



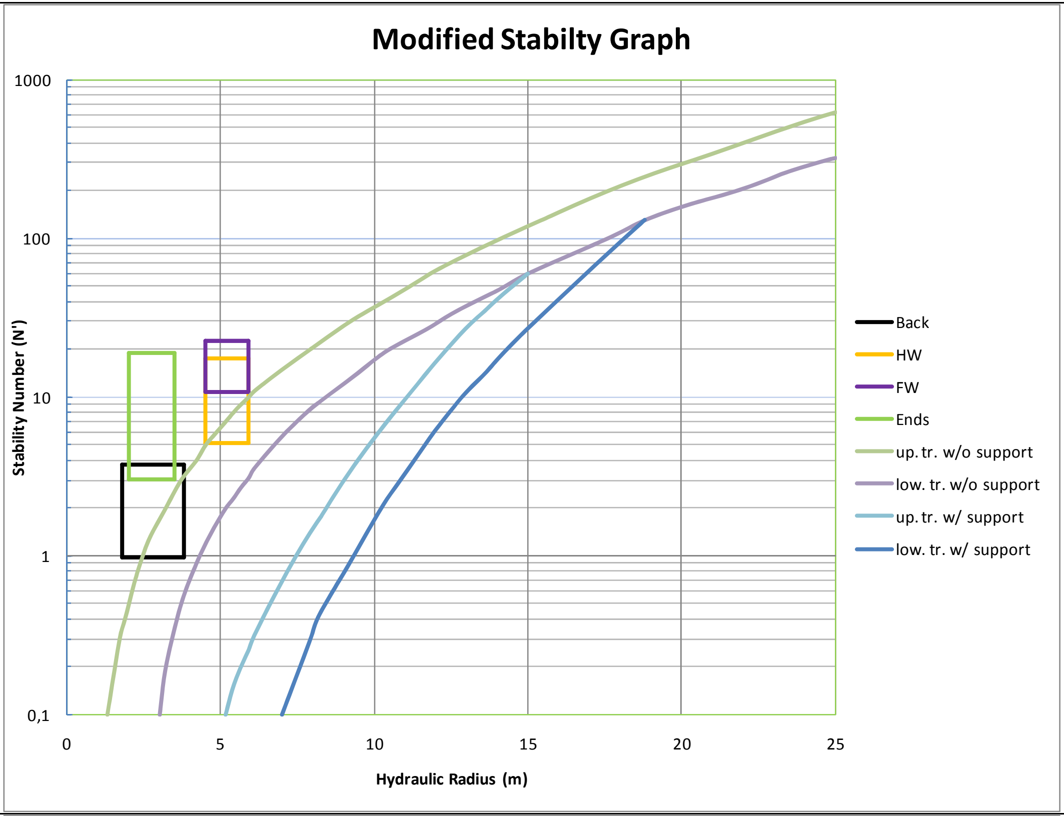


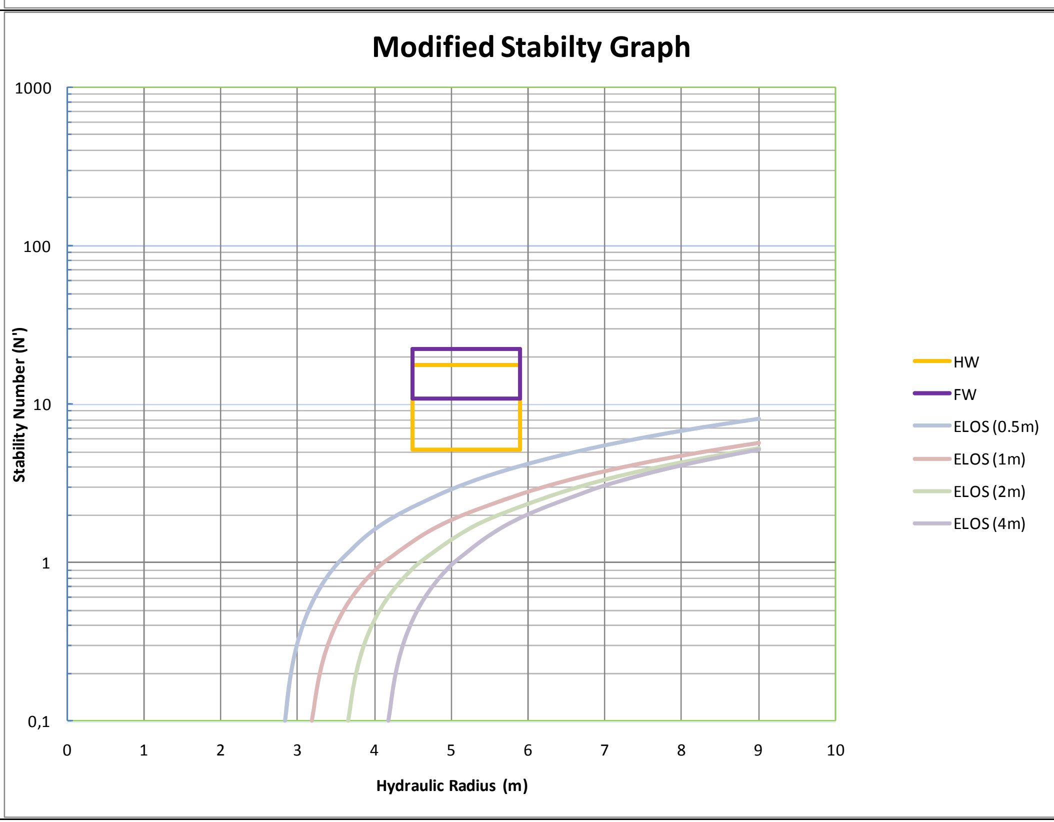
Stability Graph and ELOS analysis for Lode 1100 at a depth of 200m.



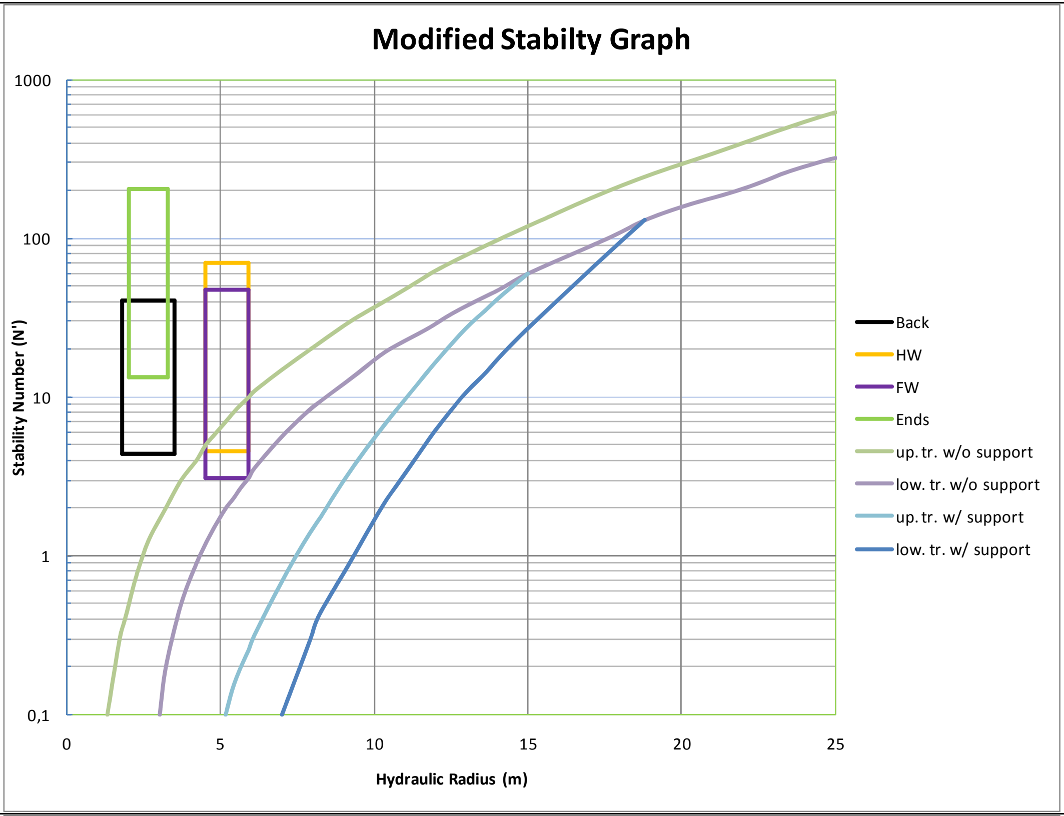


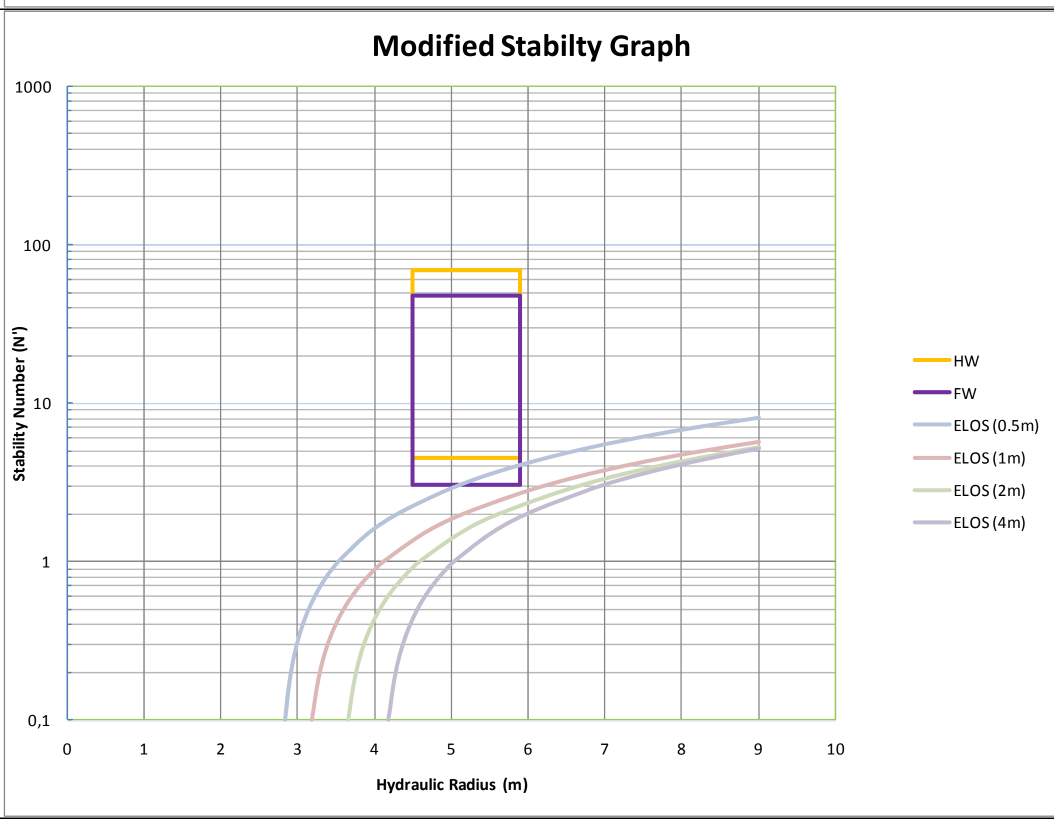
Stability Graph and ELOS analysis for Lode 1100 at a depth of 200m using proximal HW and FW Q'.



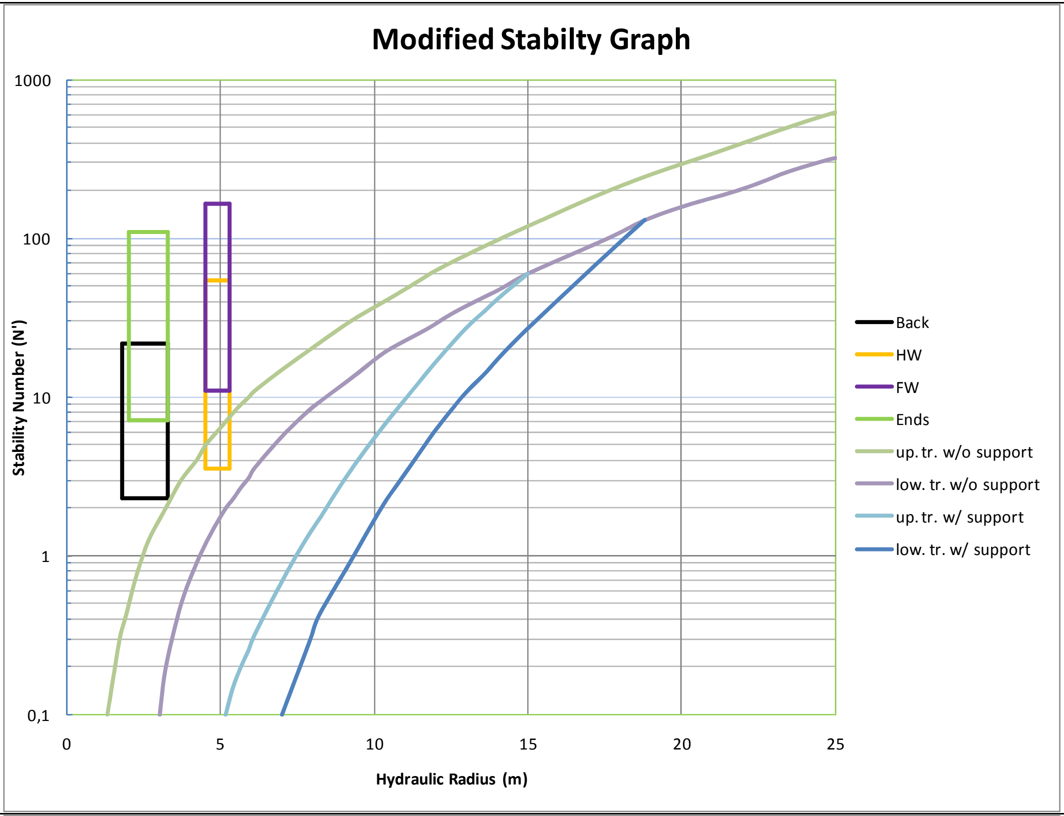


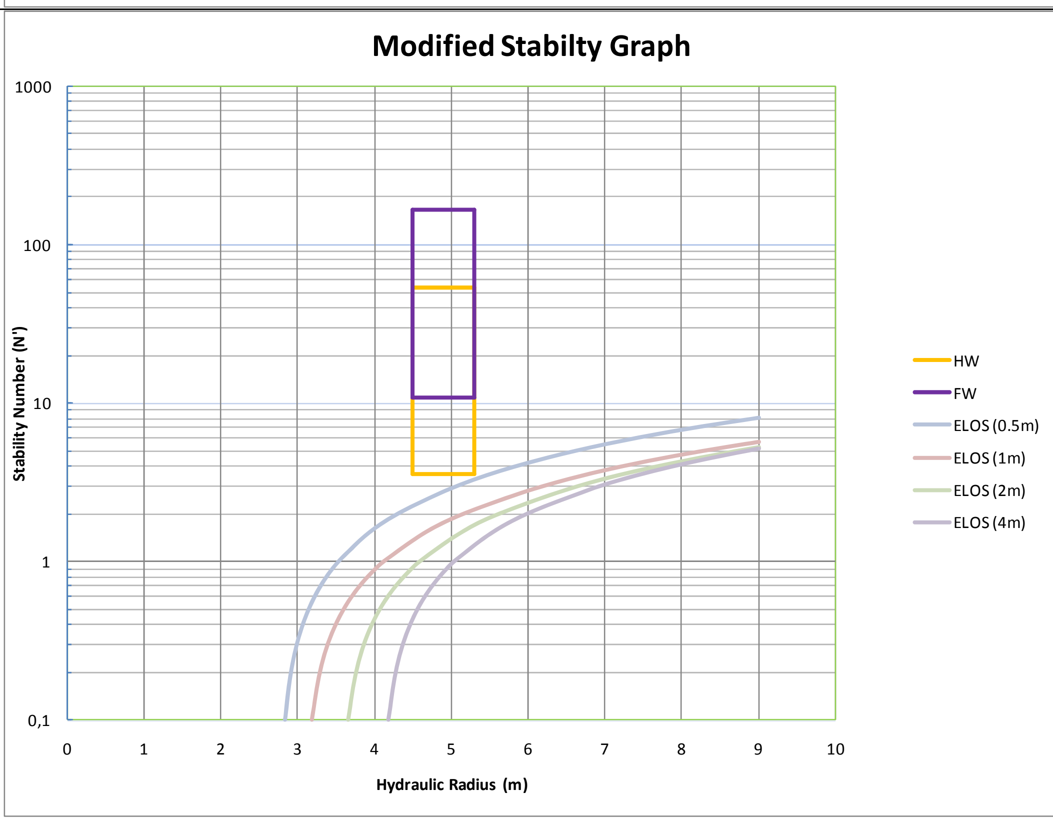
Stability Graph and ELOS analysis for Lode 1100 at a depth of 200m with span increase by 1m.



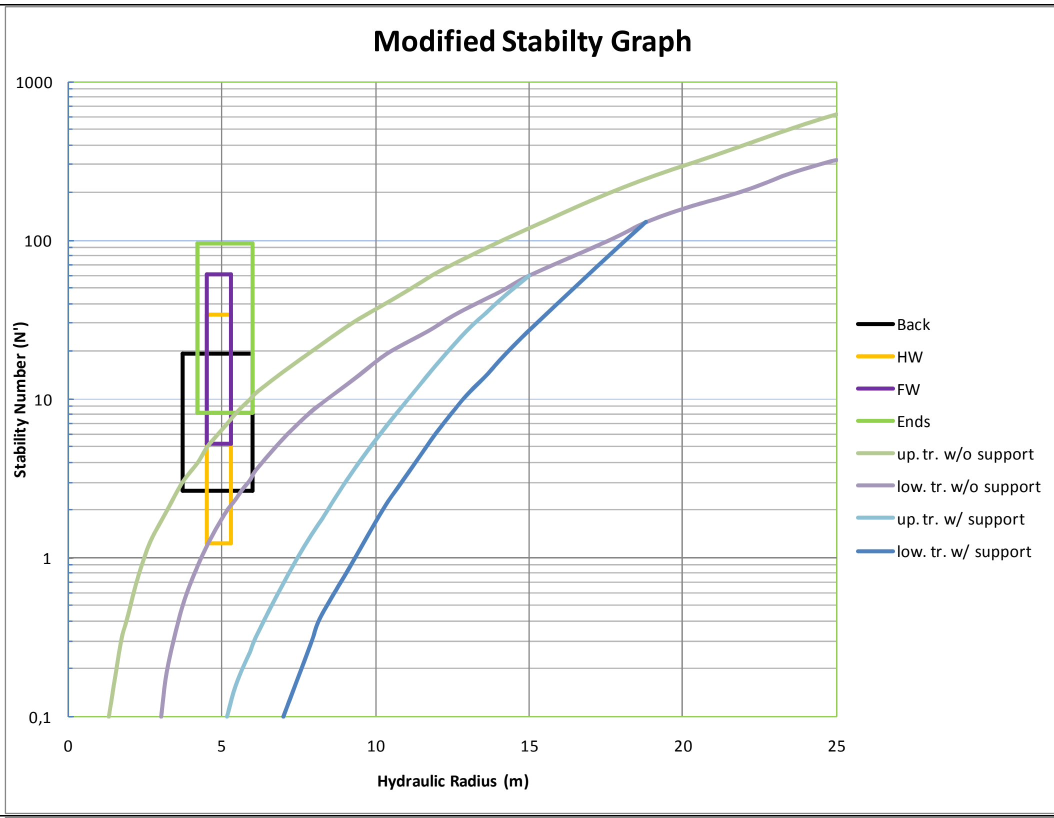


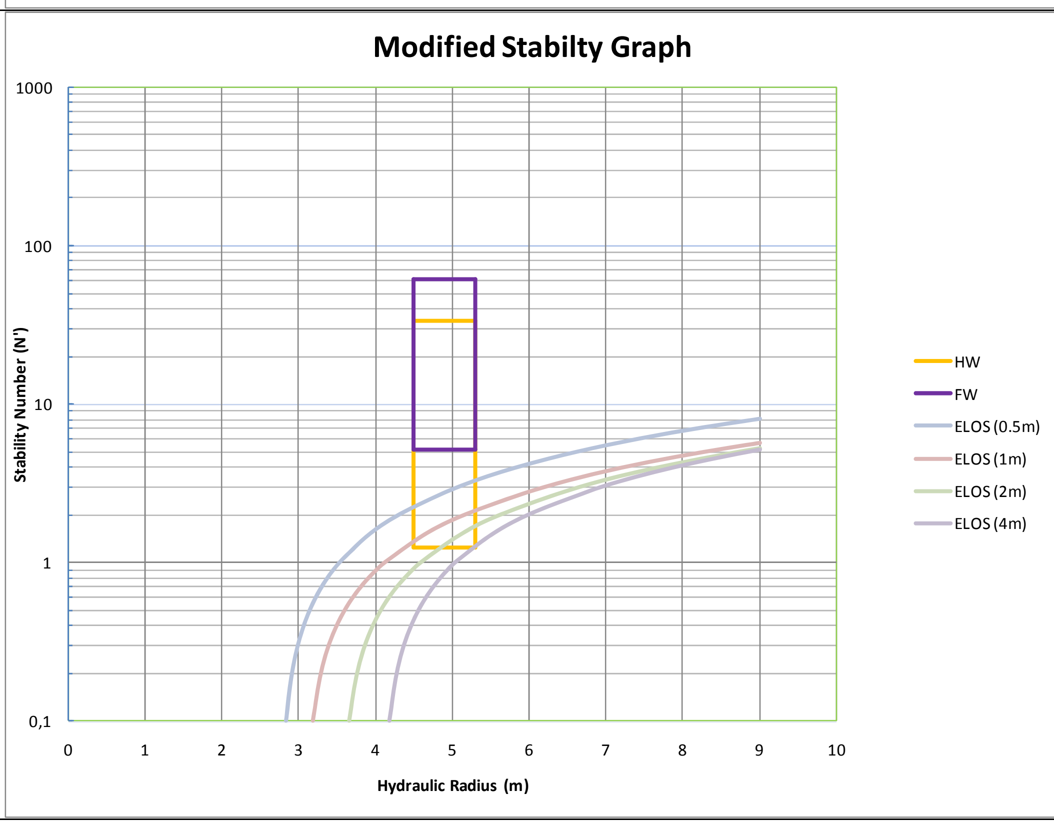
Stability Graph and ELOS analysis for Lode 1152 at a depth of 250m.



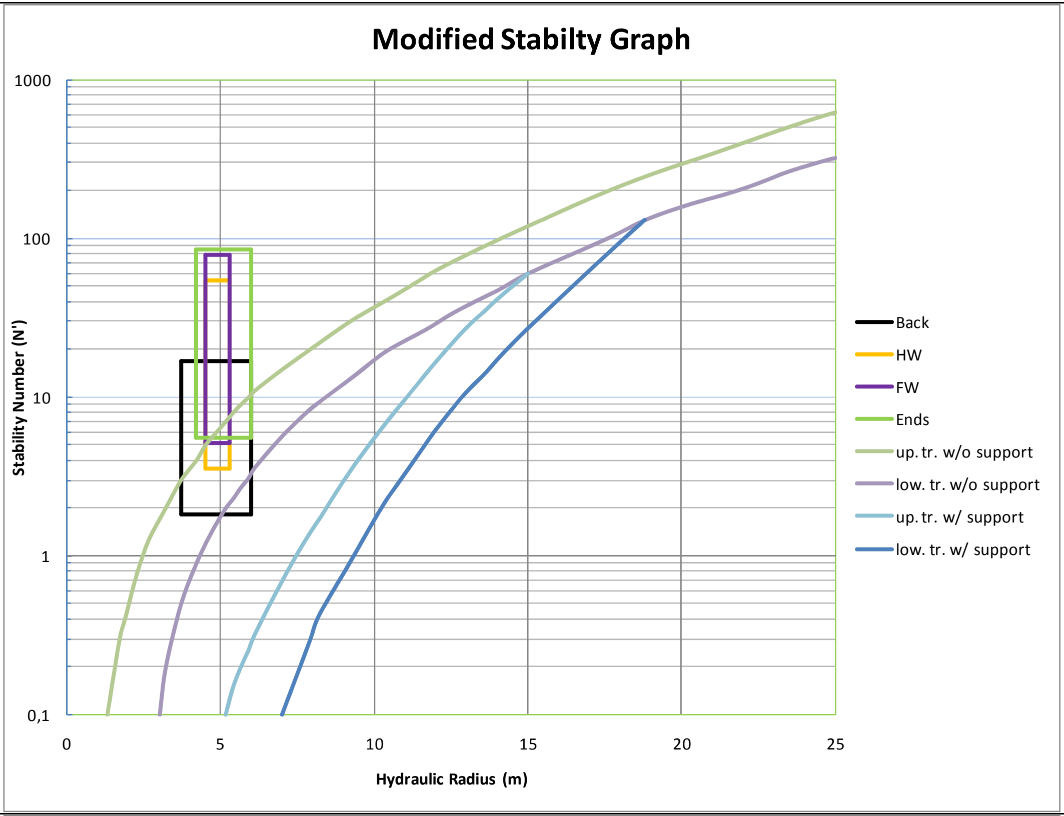


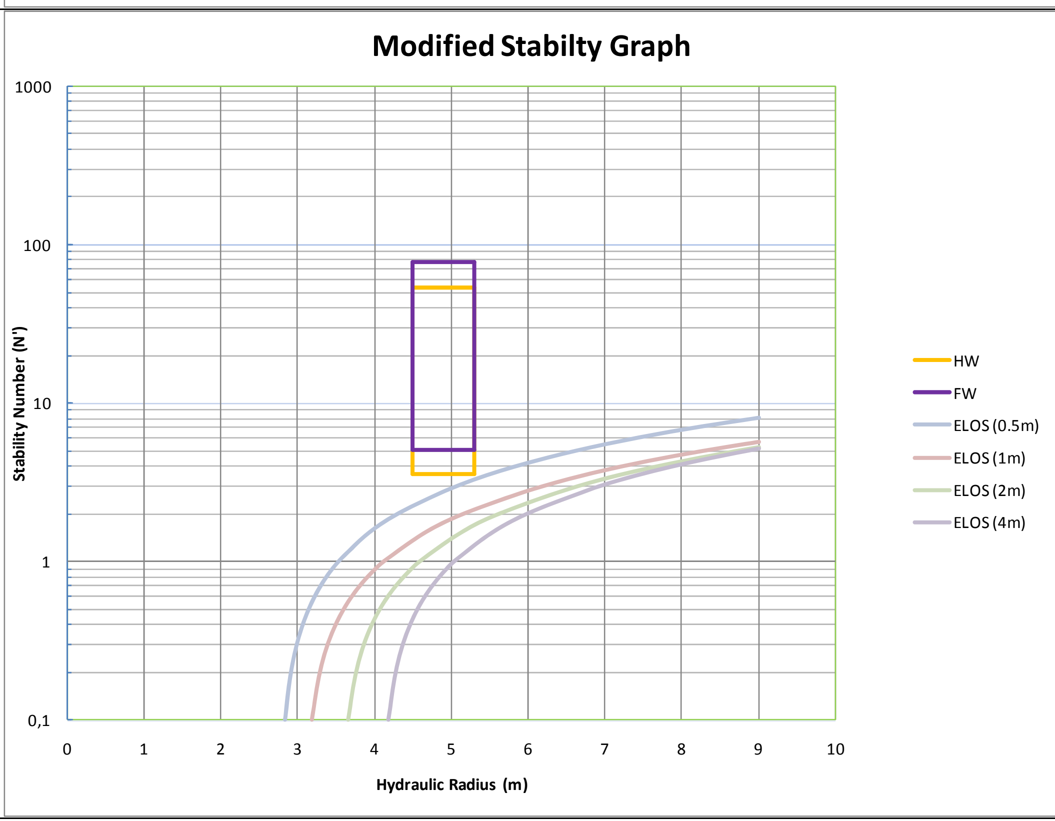
Stability Graph and ELOS analysis for Lode 1153 at a depth of 250m.



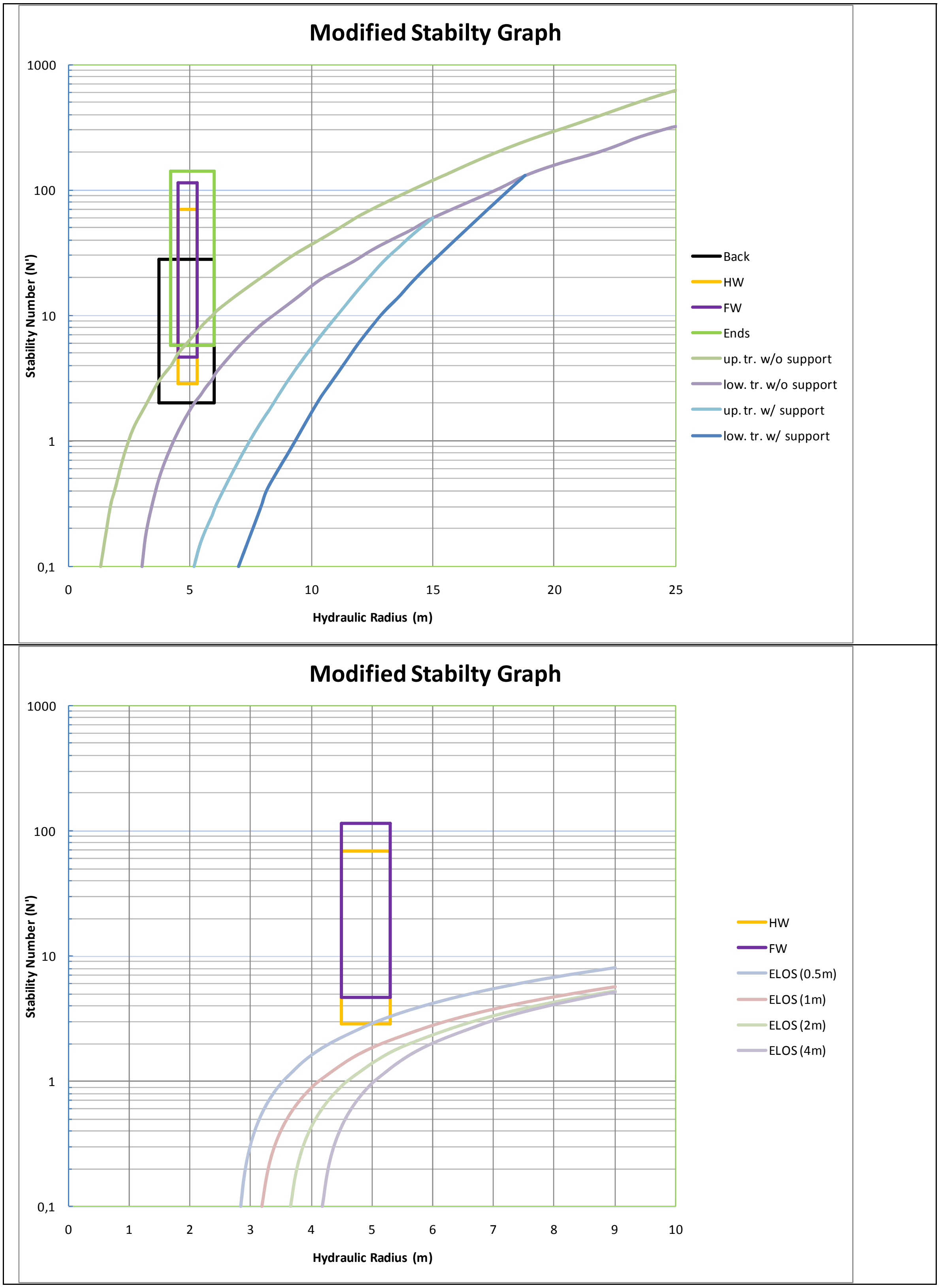


Stability Graph and ELOS analysis for Lode 1154 at a depth of 200m.

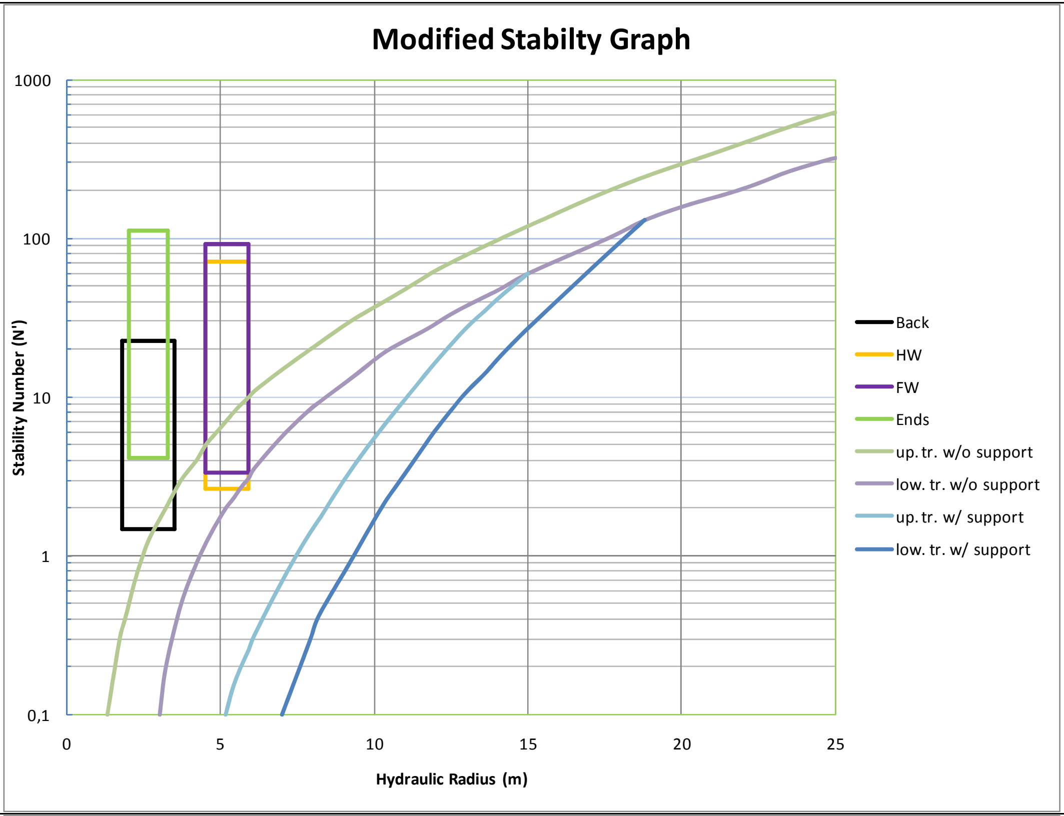


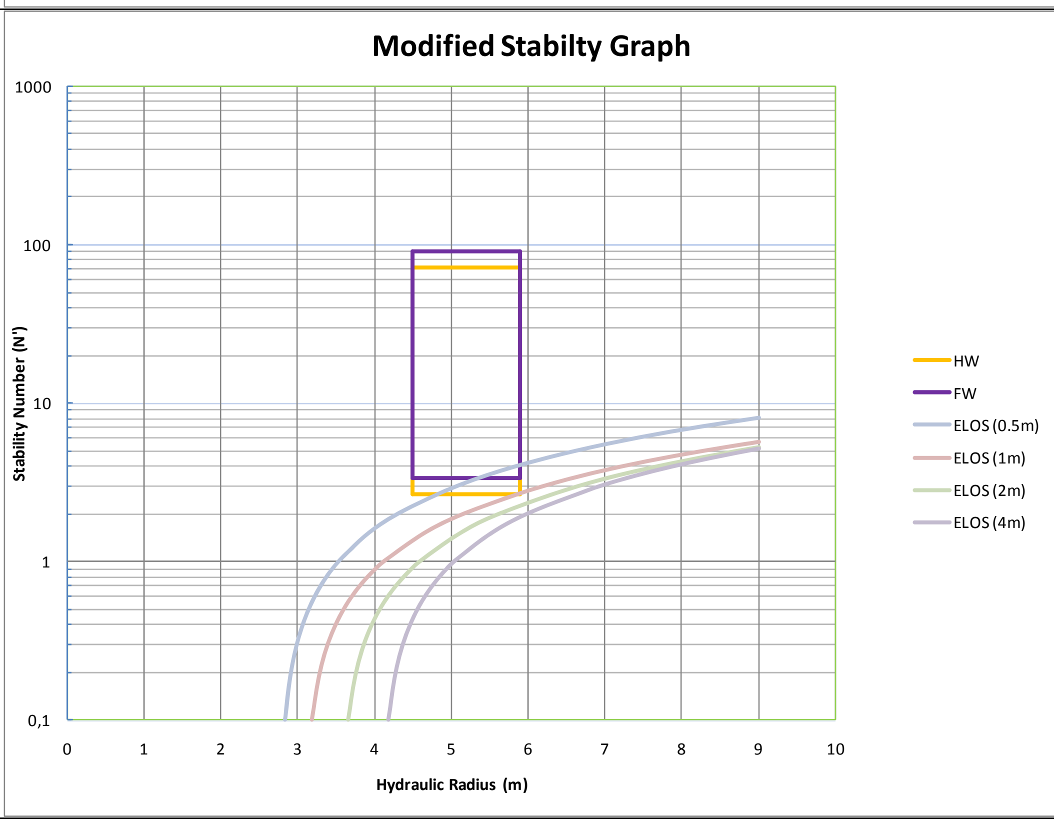


Stability Graph and ELOS analysis for Lode 1155 at a depth of 250m.



Stability Graph and ELOS analysis for Lode 1252 at a depth of 350m.





Stability Graph and ELOS analysis for Lode 1255 at a depth of 400m.