EXAMINATION PAPER

SUBJECT:	EXAMINER:
CERTIFICATE IN ROCK MECHANICS PAPER 3.4 : OPEN PIT	GLEN MC GAVIGAN
SUBJECT CODE:	**MODERATOR:**
COMRME	PETER TERBRUGGE
EXAMINATION DATE:	**TOTAL MARKS:** [100]
20 OCTOBER 2011	**PASS MARK:** 60%
TIME: 9:00 – 12:00	

NUMBER OF PAGES: 18

SPECIAL REQUIREMENTS:

1. **Answer *__ALL FIVE__* questions**
2. References other than those provided are not permitted.
3. Hand-held electronic calculators may be used.
4. Put your examination number on the outside cover of each book used and on any graph paper or other loose sheets handed in.

NB: your name must not appear on any answer book or loose sheets.

5. **__Write in ink on the RIGHT HAND SIDE of the paper only (only the right hand pages will be marked).__**
6. **__Include the stereonet with you answer book__**
7. Show all calculations on which your answers are based.
8. Illustrate your answers by sketches of diagrams wherever possible.
9. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
10. Answers must be given to an accuracy that is typical of practical conditions.

QUESTION 1

Limit equilibrium and numerical (continuum, discontinuum and hybrid) modelling techniques are widely used in the analysis of slopes. Compare the two techniques as applied to slopes focusing amongst other aspects on the following: **[20]**

- Input parameters, failure criterion and strength models used in the methods
- Advantages
- Limitations
- Outputs and results of the analysis
- Typical software packages used

	Limit equilibrium	Numerical techniques
Input parameters, failure criterion and strength models: **4**	Slope geometry Slip limits, slip surface type e.g circular, path. For structural failure analysis (Joint orientation) Unit weight. Hoek Brown, Generalized HB, Anisotropic, Mohr Coulomb, Barton Bandis Water surface, both pheratic and piezometric Surface loads, line loads, reinforcement	Slope Geometry (2D and 3D) Boundary conditions As with LE but including elastic and plastic properties as well as stress states. User defined models can also be used Post failure propoerties Water surface, both pheratic and piezometric Surface loads, line loads, reinforcement
Advantages **4**	Fast and easy to use. Probabilistic analysis easily accommodated.	Can account for stress (in-situ and induced) Can mode elastic and plastic behavior. Can mode non linear stress - strain behavior and

		anisotropy. Can account for deformation and displacement in the failure rock mass. Can model continuum and discontinum materials. Can model actual failure surfaces and helb describe failure progression. Satisfy translational and rotational equilibrium. Can model in 3D. Allows for user defined strength models
Limitations **4**	Cannot account for stress Underlying assumption is that failure is of a rigid body (only sliding) Out of slices forces are ignored Cannot be used to model toppling, block flow failures and crushing of the toe failures	Difficult to set up and long running times. Although new versions are very user friendly. Probabilistic analysis (Monte Carlo) simulations not included and many iterations required is PoF is desired. Requires in-depth knowledge of continuum and discontinuim mechanics. Models in general must be scaled down due to hardware limitations (especially in discontinuim models)

		Can model actual failure surfaces and helb describe failure progression. Satisfy translational and rotational equilibrium.
Outputs and results of analysis **4**	Approximated failure surface, FoS and PoF	FoS (derived however by the shear strength reduction method). Stress and strain, deformation and displacement plots. Failure surface
Typical packages used **4 (half marks for each)**	Slide, Slope W, Swedge, Rocplane	Flac (finite difference), UDEC (Discontinuim), Elfen (Hybrid), Phase 2 (Finite Element) etc

[20 MARKS]

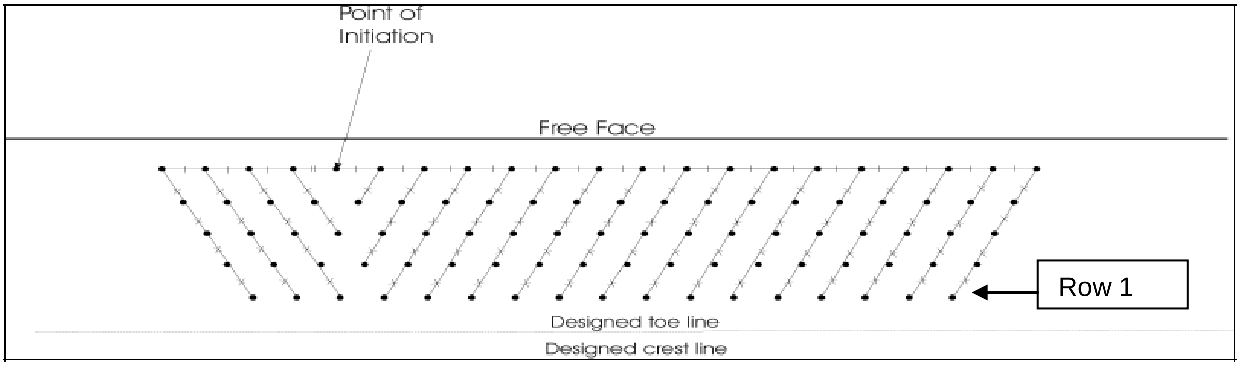
QUESTION 2

You are the legally appointed geotechnical engineer on Newrock mine. The mine has been experiencing an ever increasing number of shallow seated inter-ramp scale failures. The slopes in question are designed with a FoS of 1.2 at 62 degrees (toe to crest) and a height of 50m. Based on your analysis you attribute the failure primarily to poor blasting methods against the final pit boundaries.

The rock in question is a well bedded sandstone with an unadjusted MRMR of 45. The bedding daylights in the pit slope at approximately 38 degrees.

The mines production blasts are optimised for fragmentation and the production blasts are modified against the final pit walls to currently modified in an attempt to limit the damage. The following design is used:

	Normal production blast	Final wall blast
Hole Diameter	310	310
Hole length (excluding sub-drill)	11m	11m
Sub-drill	3.5m	2.5m
Drilled rows	8	5
Explosives	• ANFO • 700kg/hole	• ANFO • 700kg / hole • Row 1 – 610kg / hole
Initiation	Shock tube	Shock Tube
Burden and Spacing	8.4 x 9.2	8.4 x 9.2
Stemming	Yes	Yes, but not in last row against final wall
Row 1 stand off	N/A	3m



Due to the poor availability of excavators an increased incidence of blasting against the previous muck pile is occurring (no free face).

The general manager does not share your opinion that blasting is the main contributor and attributes the failures to a poor slope design and he has asked you to justify your findings:

1. Discuss the blast damage mechanism likely to occur in the sandstone and how blasting is likely to contribute to failure. **[5]**

Sandstone can be regarded as having an anisotropic strength (strength in varying directions) due to the highly jointed and bedded nature of the rock mass. Sandstone is in general relatively brittle with a low Youngs modulus. The blast damage mechanisim in this rock type is likely to be 2 fold (linked to the high gas and shock energy of ANFO):

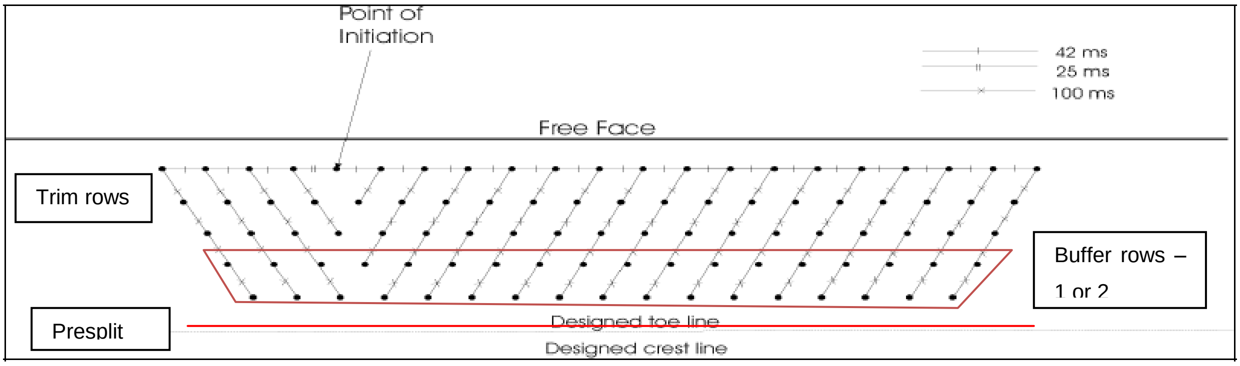
- Damage from intrusive gasses – joints and bedding planes in particular could be “opened” up by penetrating gasses resulting in a loss of cohesion. Because the rock mass is anisotropic this would result in a reduction in shear strength in the direction of bedding.
- Damage from blast shock energy – as a result of the low E and relatively brittle nature of the rock mass, the sandstone could be susceptible to brittle fracturing as a result of the progression of P and S waves through the rock mass.

2. Critically evaluate the modified production blasts and propose and justify a new blasting strategy to reduce the incidence of slope failure. **[10]**

	Final wall blast	**Comment**
Hole Diameter	310	Too large – results in too much explosives per hole
Hole length (excluding sub-drill)	11m	N/A
Sub-drill	2.5m	Should not be sudbrill over the underlying bench crest
Drilled rows	5	OK
Explosives	• ANFO • Row 1 and or 2 20 % reduction in charge	ANFO is fine as a trim/buffer block explosive, but it does generate a significant amount of gas and shock. The reduction of row 1 charge is good practice
Initiation	Shock Tube	Fine – but to insure hole by hole detonation (electronic detonation) should be considered
Burden and Spacing	8.4 x 9.2	Fine for the hole diameter
Stemming	Yes, but not in last row	OK

	against final wall	
Row 1 stand off	3m	Toes may form be formed due to excessive toe burden

New design



Presplit (discuss the aim)		
Hole Diameter	165mm or smaller	
Spacing	1.5 – 2m	
Explosives	Splitex , Explogel or the like	
Initiation	Instantaneously/0 Delay To be blasted before trim/buffer block is drilled	
Subdrill	0	
Stemming	None, unless there are restrictions on noise and vibration	
Stand off	2m	
Buffer rows (discuss the aim)		
Hole Diameter	165mm	Too large – results in too much explosives per hole
Hole length (excluding sub-drill)	11m	N/A
Sub-drill	0m	Should not be sudbrill over the underlying bench in order to protect the crest.
Drilled rows	1 - 2	OK – will result in a

Explosives	• ANFO • In buffers reduce charge by 20% vs buffer rows	ANFO is fine as a trim/buffer block explosive, but it does generate a significant amount of gas. The reduction of row 1 charge is good practice
Initiation	Shock Tube or more ideally electronic detonation, increase timing towards the buffer	Fine – but to insure hole by hole detonation aelectronic detonation should be considered
Burden and Spacing	Reduce burden to approx 0.65 x that of the trim	Burden - 25 to 35 x hole diameter Spacing – 1- 1.5 x Burden
Stemming	Not in buffer rows	0.7 to 1 x burden
	Trim rows	
Hole Diameter	165mm	Too large – results in too much explosives per hole
Hole length (excluding sub-drill)	11m	N/A
Sub-drill	0m over the underlying bench crests.	Should not be suddrill over the underlying bench in order to protect the crest.
Drilled rows	3 – 4	OK – ensures the explosive energy is limited and that there is not a build up of energy towards the presplit
Explosives	• NB to maintain energy factors in trim blocks in order to maintain fragmentation. • ANFO • Normal production blast for 165mm diameter hole.	ANFO is fine as a trim/buffer block explosive, but it does generate a significant amount of gas. The reduction of row 1 charge is good practice
Initiation	Shock Tube or more ideally electronic detonation	Fine – but to insure hole by hole detonation electronic detonation should be considered
Burden and Spacing	4.9 (30 x hole d) x 6.1 (1.25 x	Burden - 25 to 35 x hole

	B)	diameter Spacing – 1- 1.5 x Burden
Stemming	Yes but not in buffer rows Trim rows – 3.4 (0.7x)	0.7 to 1 x burden
Free face	The buffer and trim bust be blasted towards at least one free face	

3. Using Laubschers Mining Rock Mass Rating System quantify the impact/benefit of your proposed design using the Haines and Terbrugge Design Chart. **[5]**

   MRMR Blasting adjustment factors:

Technique	**Adjustment (%)**
Boring	100
Smooth wall blasting	88
Good conventional blasting	82
Poor blasting	70

Current slope angle 62 deg FoS 1.2

Plotting this slope on the Haines and Terbrugge chart it is clear that the slope angle is too steep for the current blasting conditions and it could reasonably be assumed that blasting was not accounted for in the design. The current blasting practices given the increased number of failures can be regarded as "poor" and hence have a blasting modifier of 0.7. Therefore:

MRMR of 45 x 0.7 = 31.5

The resultant slope angle considering the current blasting conditions (assuming a constant 1.2 FoS) is 54 deg. The slopes in question should therefore be flattened to 54 deg to ensure stability.

Should the blasting practices be improved to "Smooth wall blasting" and the blasting modifier of 0.88 applied:

MRMR of 45 x 0.88 = 39.6

Slope angle at 50m with a FoS of 1.2 = 58 degrees.

Your recommendation to the manager should be that the current slope design is very aggressive and given the current blasting practices the design is not feasible. It is likely that blasting damage was not taken into account during the initial design. Your recommendation would be to implement the smooth wall blasting practices in order to reduce the impact of flattening the slope from 8 degrees to 4 degrees.

[20 MARKS]

QUESTION 3

You are the lead geotechnical consultant on a bankable feasibility study into a new mine diamond mine. The pit is characterised by the following:

- The pit is elongated (trending N-S) in nature and is 5.5km long and 450m deep.
- Main access is via a haulage ramp constructed on the eastern slope
- The primary crusher is planned to be built 100m from the crest of the Northern Slope and cannot be moved.
- The main waste dump is situated on surface 50m from the pit crest (Southern Slope)
- No permanent infrastructure is planned for the Western slopes.
- There is a general lack of intact rock material and rock mass data due to difficult rotary core drilling conditions. Core recoveries are on average 54%.
- No groundwater information is available although the owner assures you this will not be a problem.
- The owner is willing to install extensive real time slope monitoring systems.

The owner has no experience in slope stability and has asked you to define the levels of acceptable risk in terms of Factor of Safety (FoS) and Probability of Failure (PoF) for bench, inter ramp and overall slopes.

Given the characteristics of the pit **define** and **justify** your selection of **FoS** and **PoF.** What additional recommendations would you make regarding the pit layout in general as well as the positioning of infrastructure? **[20]**

Discuss the FoS and PoF linked to the consequence of failure (Use any of the acceptability criteria e.g. Priest and Brown (1983)., Kirsten (1983), SRK Consulting (2006), Swan and Sepulveda (2000)

Primary crusher – N Slope should me more conservative considering the consequence of failure of the slope on mine production. (NB the crusher cannot be moved)

Primary access on the East – should be more conservative as this is the only access to the pit.

Western wall – could be steeper/more aggressive does not carry any major infrastructure.

Other factors to consider:

Waste dump is too close to the pit crest (50m) considering the depth of the pit (450m) and will influence the stability of the slope. Three options could be considered:

- Flatten the slope to account for the impact of the dump on the stability of the slope and the consequence of failure should a slope failure lead to the spill of the waste dump into the pit. A cost benefit analysis would assist in determining the benefit of flattening the slope vs shorter travelling distances.
- Move the waste dump as to ensure that it does not impact on the stability.
- Consider a numerical modelling exercise to determine the optimal distance of the dump from the pit crest which is likely not to impact on stability.

Single access to the pit is a risk as a failure could cut off all access to the pit which could impact production and rescue efforts in the event of a failure. A second access permanent access could be considered which would reduce the risk associated with failure on the east. Alternatively a second emergence access (narrow, single ramp) could be considered to be used in the event of a failure.

The data available for the slope design is likely to be lacking due to the poor core recovery. This should be accounted for in the design and the angles appropriately adjusted for poor data.

Groundwater conditions should not be assumed to be dry. A sensitivity analysis to determine the impact of water on the slope should be considered and a network of piezometers installed. If this is not possible the slope angles adjusted accordingly.

As the owner is willing to install real time slope monitoring methods, the exposure of personnel is likely to be managed to acceptable levels. Slope monitoring has a limited impact in managing the economic impacts of failure (clean up, production delays etc). A fault and event tree and risk consequence analysis could be conducted to determine whether the economic or safety consequence of failure drives the slope design. If it is safey driven, steeper slopes could be considered as the exposure of personnel to the slope hazard can be managed.

QUESTION 4

The upper 37.5m of your operation is to be developed in medium silt. The geohydrologist has indicated that the natural ground water table rests 12m below surface and that you can expect seepage from the face at approximately 25m. No strength tests have been performed but you have found typical values for soil parameters after an intensive literature review and desktop study:

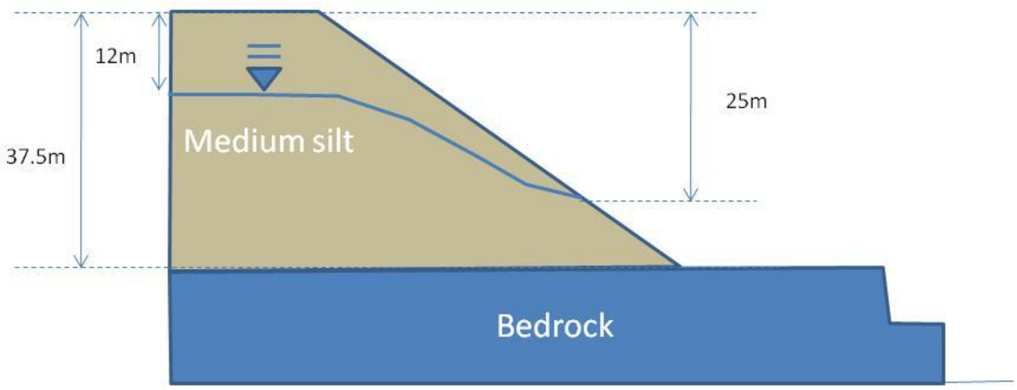
Description	Density (kN/m3)	Cohesion (kPa)	Friction angle
Loose silt	16	2	29
Medium silt	17	5	30
Dense silt	18	10	31
Soft clay	16	5	23
Moderately stiff clay	17	10	24
Stiff clay	18	25	25

The manager has asked you to design a slope in this material at a FoS of 1.5.

Using the stability charts provided:

1. Determine the maximum slope angle given the information provided. **[10]**
2. The manager is not happy with your recommendation and has deemed the slope to be too flat which has a negative impact on the economics of the operation. He has requested that you increase the slope angle by 10 degrees. Determine under what conditions this would be feasible, if at all, and make a recommendation to the manager? **[10]**

1. Use stability chart no 3.



c = cohesion = 5kPa

Φ = friction angle = 30

Y = unit weight = 17kN/m^3

F = Factor of Safety = 1.5

H = Slope height = 37.5

a. Calculate c/Y.H.tan Φ

= 5 / 17(37.5) tan 30

= 0.014

b. Calculate either tan Φ / F or c / YHF

tan Φ / F = 0.38

c / YHF = 5 / 17(37.5)1.5 = 0.005

Determine the slope angle from the chart provided:

Given the information provided the stability chart in question does not provide sufficient resolution on order to accurately define the slope angle as the intersection of c/Y.H.tan Φ and tan Φ / F or c / YHF, is extremely close to the origin and no slope angles are provided. The only indication that you can give the manager is that the slope angle should be less than 20 deg **.** At 20 degrees the FoS of the slope in question will be:

tan Φ/ / F = 0.58, therefore

F = tan Φ / 0.58

F ≈ 1

It is therefore obvious that for a FoS of 1.5, a considerably flatter slope angle than 20 degrees will be required.

The recommendation to the manager should be that given the information provided and the prevailing conditions, you, as competent rock engineer cannot provide a reliable slope angle to any degree of confidence. The only indication you can provide is that the slope a slope angle of less than 20 degrees will provide a FoS of one or greater.

2. The manager has indicated that his is not acceptable and would like a steeper (10 degree slope angle) as the angle of less than 20 has a negative impact on the economics of the operation.

   The following options can be considered in order to steepen the slope:

   a. Dewater: If the slope in question could be fully dewatered the following slope angle could be attained:

      i. Use stability chart no 1.
      ii. FoS = 1.5
      iii. Calculate c/Y.H.tan Φ
           = 5 / 17(37.5) tan 30
           = 0.014
      iv. Calculate either tan Φ / F or c / YHF
           tan Φ / F = 0.38
           c / YHF = 5 / 17(37.5)1.5 = 0.005
      v. Slope angle @ FoS 1.5 fully drained slope is approximately 22 degrees.

   b. Reduce the required FoS from 1.5 to 1.3 **and** fully drain the slope
      i. Use stability chart no 1
      ii. FoS = 1.5
      iii. Calculate c/Y.H.tan Φ
           = 5 / 17(37.5) tan 30
           = 0.014
      iv. Calculate either tan Φ / F or c / YHF
           tan Φ / F = 0.44
           c / YHF = 5 / 17(37.5)1.3 = 0.006
      v. Slope angle @ FoS 1.3 fully drained slope is approximately 28 degrees.

The recommendation to the manager should be to ensure that the slope in question is completely drained at all times, irrespective of the chosen FoS. This could be done through vertical dewatering wells or sub horizontal drainage wells. It could be further recommended that if the FoS could be reduced to 1.3, which is not unreasonable for a 37.5 m high slope in soft material considering that any instability could be managed (due to the ductile nature of the failure) through monitoring and clean up a maximum angle of approx 28 degrees is possible.

Other alternatives:

Artificial support
Reduce slope height – effectively flatten the slope

[20 MARKS]

QUESTION 5

You have recently completed a mapping exercise in the open pit where you have identified 2 faults, with dip and dip directions of F1 = 45 ^{o} /105 ^{o} and F2 = 70 ^{o} /235 ^{o}, respectively. Two very prominent sub-vertical joint sets exist with a dip and dip direction of J1 =50^o/195^o and J2 = 60 ^{o} /005 ^{o}. Bedding dips (BP) at 40^o degrees into and strikes parallel to the pit. The bench angle is 78 ^{o} degrees and the overall slope angle is 45 ^{o} degrees, the dip direction of the slope and bench is 185 degrees. The friction angles for the faults are estimated at 26 degrees and 31 degrees for the joints. The slope is dry.

1. By means of a stereonets identify the **most probable failure mechanism/mechanisms** on a **bench** and **overall** slope scale and motivate your answer by discussing the **kinematic criteria** for each failure (no factor of safety calculations required, please hand in your stereonet with your answer booklet.) **[15]**

2. With the use of the stability charts determine the **Factor of Safety,** if kinematically possible of the intersecting faults. **[5]**

   Where: FoS = A tan θ_a + B tan θ_b

1. Please see attached stereonet for all of the possible failures (included after the answer):
   a. For planar (bench and overall – BP, bench only J1)
      i. Dip of joint must exceed the angle of friction
      ii. Discontinuity must daylight
      iii. Dip of the discontinuity must be less than the dip of the slope face:

         $\Psi > \beta > \Phi$

         Where:

         Ψ : dip of the slope face

         B : dip of the discontinuity

         Φ : angle of friction

      iv. Strike or dip direction of the discontinuity must be within approx 20 degrees of the strike or sip direction of the slope face
      v. Release planes provide negligible resistance

   b. Wedges (bench failure – F2/J1, F1/J1, bench and overall – F2/BP, F1/BP, F1/F2)
      i. Dip of intersection must exceed the angle of friction
      ii. Intersection must daylight
      iii. Dip of the intersection must be less than the dip of the slope face:

         $\Psi > \beta > \Phi$

         Where:

         Ψ : dip of the slope face

         B : dip of the line of intersectuin

         Φ : angle of friction

iv. Release planes provide negligible resistance

c. For toppling – (bench failure on J2)

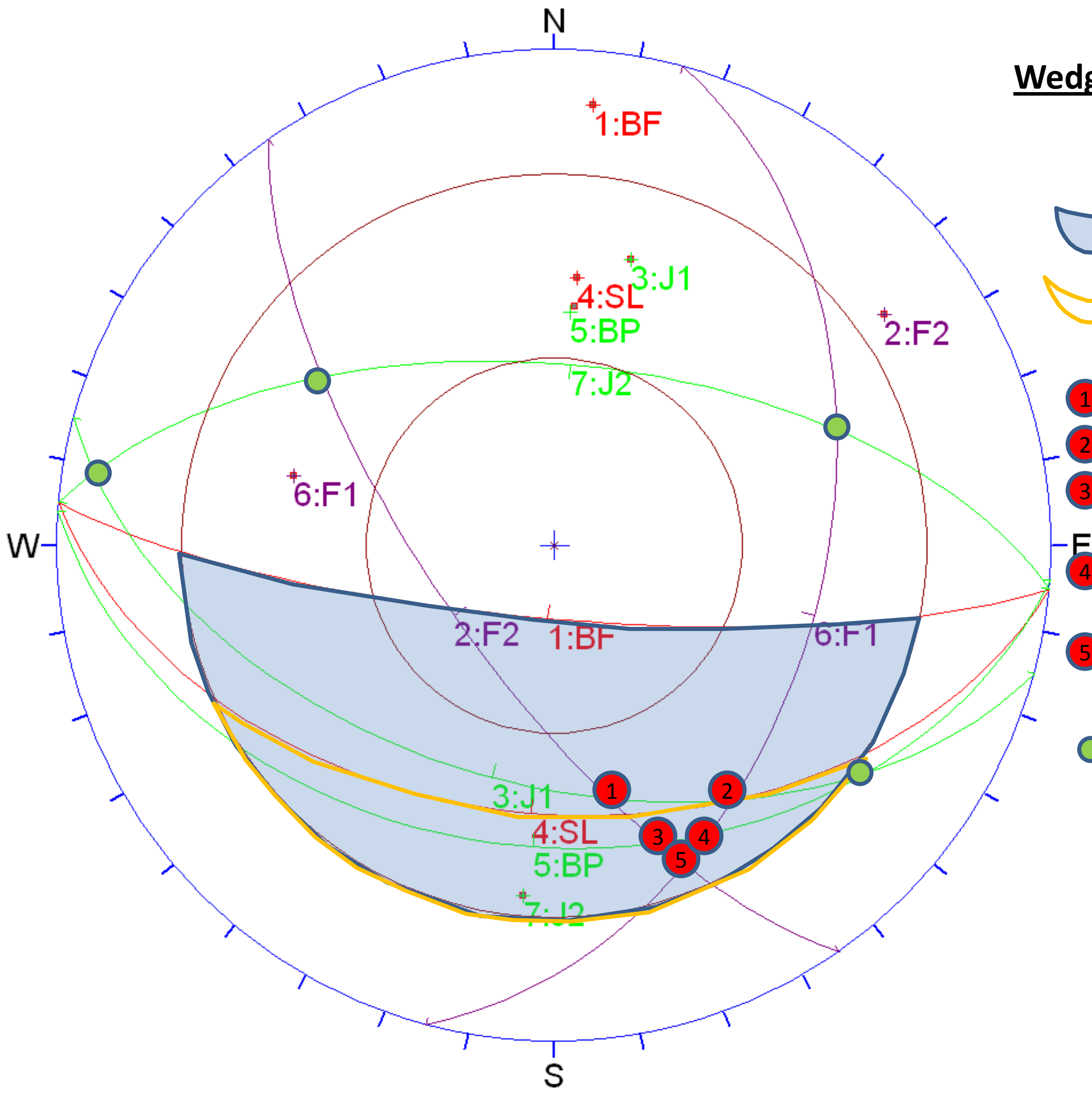
Identification of the conditions for failure (Wedge, Toppling, and Planar, either on the stereonet or written. (2 wedge, 2 toppling, 2 planar)

2. Factor of safety calculation:

a. Trend and plunge of intersection – 158^{O} and 31^{O}

- Calculation:
    - Flatter of the 2 planes is A, therefore A is F1
    - Dip Difference = 25 deg
    - Dip Dir Difference = 130 deg
    - Therefore: either dip dif chart of 20 deg or 30 deg:
        - FoS (30 deg chart) = 1.6 tan 26 + 1 tan 26
          = 1.12
        - Fos (20 deg chart) = 1.55 tan 26 = 1.05 tan 26
          = 1.26

[20 MARKS]



Wedge failure analysis

Wedge failure zone – bench

Wedge failure zone – overall

1 Bench scale wedge failure F2/J1

2 Bench scale wedge failure F1/J1

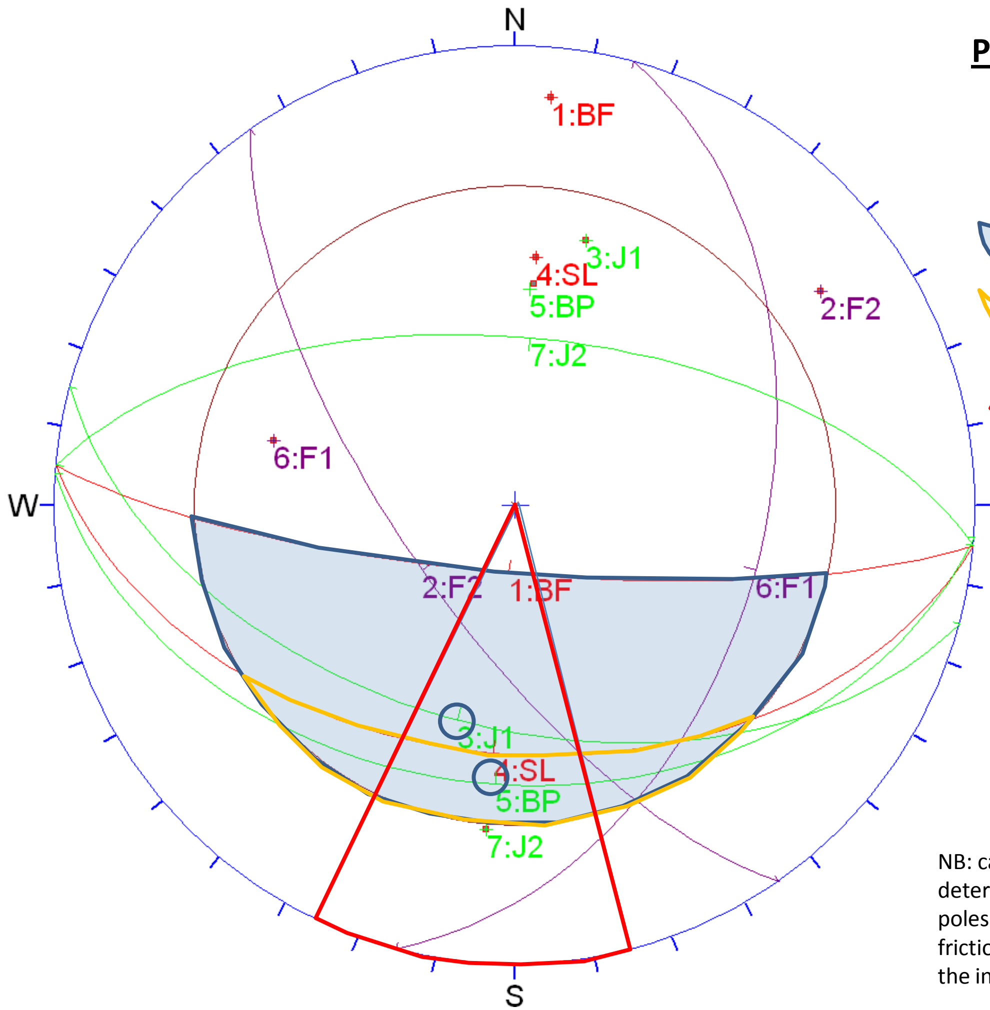
3 Bench and overall scale wedge failure F2/BP

4 Bench and overall scale wedge failure F1/BP

5 Bench and overall scale wedge failure F1/F2

Other wedges formed but not kinematically feasible at the proposed slope orientations

Planar failure analysis



Planar failure zone – bench

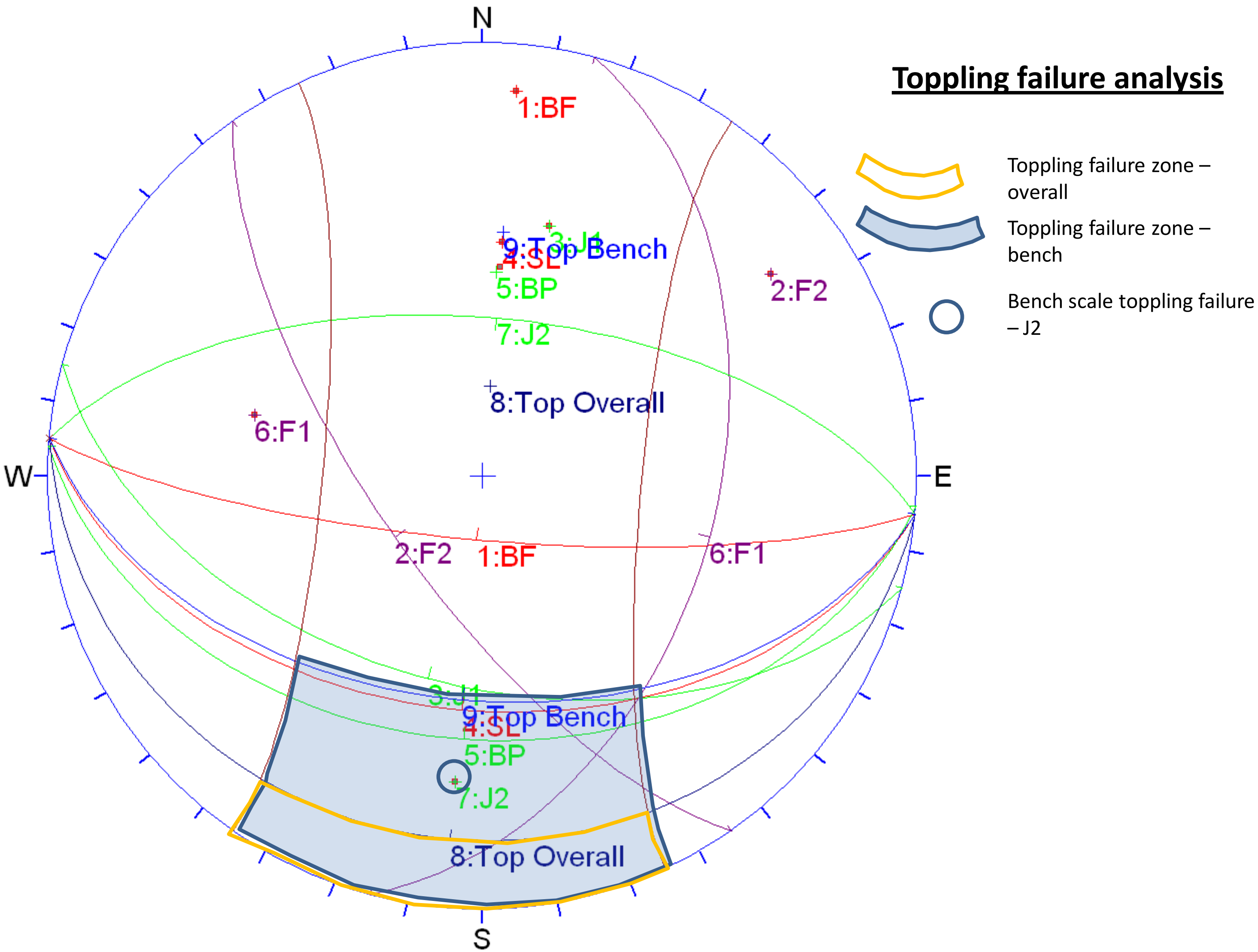
Planar failure zone – Overall

20 degree dip direction window for planar failure

Bench and overall scale Planar failure - J1

Overall scale Planar failure - BP

NB: can also use the pole plot and determine kinematic failure from the poles of BP and J1 – in this case the friction circle would be measured from the inside/origin of the stereonet


N
W
E
S
1:BF
3:J1
9:Top Bench
4:SL
5:BP
2:F2
7:J2
8:Top Overall
6:F1
2:F2
1:BF
6:F1
3:J1
9:Top Bench
4:SL
5:BP
7:J2
8:Top Overall
Toppling failure analysis
Toppling failure zone – overall
Toppling failure zone – bench
Bench scale toppling failure – J2