Question 1

Multiple Choice

Wrong answers are **NOT** negatively marked. Showing calculations can result in partial marks

1.1. **A** (2)

1.2. **D** (2)

1.3. **B** (1)

1.4. **B** (3)

ESS = stress - strength = 10MPa - [0.5MPa+(15MPa*Tan25°)] = - 6.8 MPa

1.5. **D** (3)

NOTE - spacing is SKIN to SKIN, therefore Area = 2.2m * 1.7m (not 2m*1.5m)

You were instructed to use g=9.81m/s2.

SR = (20 * 9.81)/(2.2*1.7) = 52.46 kN/m2

1.6. **A** (3)

EA = Area under graph. **NB.** Load in kN and subtract the initial yield!

You were instructed to use g=10m/s2.

EA = Rectangle + triangle

EA = (20*10)*(200mm-75mm) + 0.5*(20*10)*(250-200) = 30 kJ.

1.7. **A** (3)

y intercept = log(70) = 1.845

Slope (is negative!) = (0 - 1.845) / (2.65 - 0) = - 0.7

1.8. **B** (3)

Energy index, simply put is a ratio that allows the energy of a given event to be compared to that of a given grouping of events. There exists some dispute as to how EI is calculated and for this reason this question was later scrapped from the exam for students who got it wrong.

Method 1 (using the logarithm of Energy)

logE(event A) = 12.6, logE(fit) = 10.6. EI = 12.6 / 10.6 = 1.18 > 1.0 thus burst type

logE(event B) = 8.6, logE(fit) = 10.2. EI = 8.6 / 10.2 = 0.84 < 1.0 thus slip type

Answer is B. If students studied this method and applied it, they were given full marks.

Method 2 (perhaps more correct and using actual Energy value in Joules)

E(event A) = 10^12.6 J, E(fit) = 10^10.6 J. EI = [10^12.6] / [10^10.6] = 100 > 1.0 thus burst type

E(event B) = 10^8.6 J, E(fit) = 10^10.2 J. EI = [10^8.6] / [10^10.2] = 0.025 < 1.0 thus slip type

Answer is not there! Students were thus given the benefit of the doubt here if they got it wrong and the question was marked out of 17 ignoring Q1.8.

TOTAL : 20

Question 2

2.1.

Required support resistance

$= 0.8m \times 2.25m^2 \times 3000kg/m^3 \times 9.81m/s^2 / 2.25m^2$

$= 23.54\ kN/m^2$ (1) (2)

OR if 0.6m used for height instead of 0.8m then only 1 mark awarded.

Required support resistance

$= 0.6m \times 2.25m^2 \times 3000kg/m^3 \times 9.81m/s^2 / 2.25m^2$

$= 17.66\ kN/m^2$ (1 mark only)

Support capability

$= 8000kg/unit \times 9.81m/s^2$

$= 78.48$ kN / unit (1)

Note: Safety Factor is assumed to have been applied to the support performance (8tons is down rated). Students who applied an additional safety factor were NOT penalised.

Maximum spacing of units

$= 78.48kN/unit / 23.54kN/m^2$

$= 3.33m^2/unit$ (1)

Optimal spacing of units:

Strike spacing – ideally 1 row of tendons per blast (i.e. 1.0m)

Dip spacing – based on above, maximum dip spacing 3.3m (1)

But, based on fall dimensions, it may be better to reduce the dip spacing to < 1.5m (blocks are 1.5m x 1.5), to pin individual blocks. **Units having a slightly lower load bearing capacity could be considered to optimise the design.** **<u>Note – mark deducted if students don't realize that the block size is smaller than the calculated value and that a reduced spacing should be suggested.</u>** (1)

Length and installation angles of tendons

Minimum tendon length = 0.6m fall height + bond length + additional length if angle of installation < 90 degrees. (1)

Ideal would approx 1.0m in-the-hole tendon, installed at between 70 and 90 degrees. (Marks deducted if 1.2m (or longer) solid tendon specified at 90 degrees installation angle, due to difficulty of installation)

2.2.

Possible answers:

- Mechanical tensioned end anchors, with or without grout
- Hydraulically-prestressed tendons (Hydrabolts)
- Marks also given for TENSIONED resin-grouted units (3)

Units must be active, so no marks given for cement-grouted only or non-tensioned tendons (rebar / Sheppard crooks / Split sets). Candidates must motivate their choice.

2.3.

Required support resistance

= (3.0m x 8.0m2 x 3000kg/m3 x 9.81m/s2) / 8.0m2

= 88.29 kN/m2 (1)

Maximum spacing of units

= 350.0kN/unit / 88.29kN/m2

= 3.96m2/unit – rounded to 4 m2/unit (1)

Note at least 2 elongates per 8m^2 block are required.

Recommended dip and strike spacing of units

Given the requirement for scraper cleaning, units should be spaced a minimum of 1.5m apart on strike, with a more usual spacing being 2.0m. This results in a dip spacing of 2.0m. (2)

Given the rectangular shape of falls, closer strike spacing can be investigated, with increasing dip spacing, to achieve an optimal balance. i.e strike spacing of 1.8m with 2.2m dip spacings will work well Alternately 1.6m strike x 2.5m dip. **Note that 2.2m (or more) on strike is too large as this is larger than the average failed block size.** (1)

Maximum distance from the face for installing elongates

Two possible methodologies:

- Keep elongates close to the face (6m max) to prevent layer separation and possible ground movement. As this lies within the blast damage area, it implies that pre-stressing units will be required for elongates, with a cost implication.
- Based on the FOG database info, and given that the tendons are supporting the face area, remove elongates to beyond the range of possible blast damage (8 – 10 m), eliminating the need for pre-stressing units. (2)

Note:- The first methodology is preferred as it will prevent bed separation which is leading to the large back area falls. MArks awarded as long as the student motivates his strategy.

2.4.

No, it cannot. (1)

The tendons fall within the 3.0 m height supported by elongates, and therefore do not contribute additional support capability (in fact, they only add to the mass of the beam!). Note that this does not mean that they are totally ineffective and don't assist at all in the back area at all. It just means that given the method used to calculate support resistance, their contribution cannot be added to the calculation (easily). (2)

TOTAL : 20

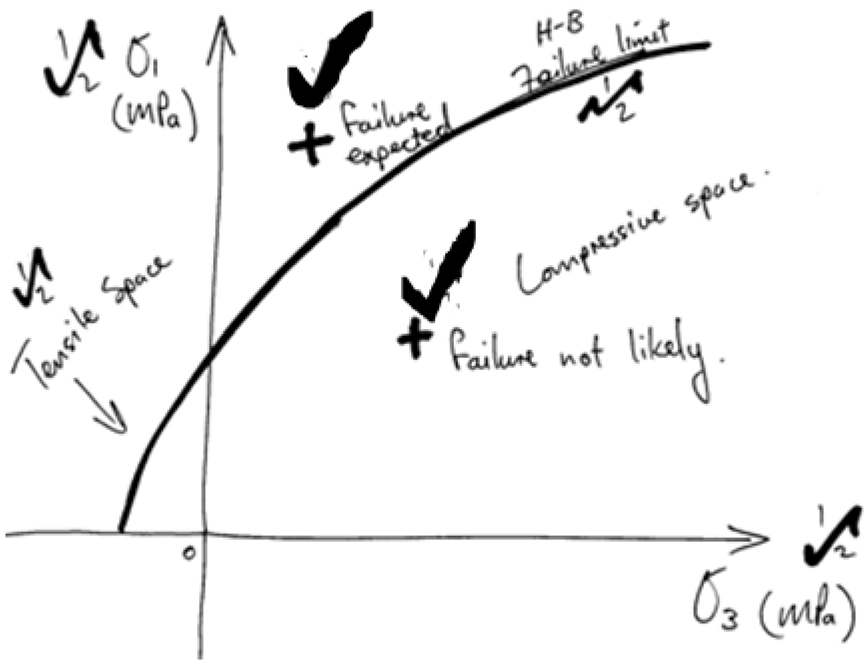
Question 3

3.1. **(2)**

Stress levels in Pillars A and B are higher than stress levels in the central pillar B. This is due to the large 200m spans adjacent to these pillars. Marks also given if students are simply able to read off the APS values and contrast them correctly.

NOTE: Most students were unable to read off the APS properly. APS applies to the AVERAGE level of stress **<u>inside</u>** the pillar and NOT the stress contours 10 m above or below the pillars.

3.2. **(4)**



3.3. **(12)**

<u>Pillar foundation failure</u> **(4)**

Pillar foundation failure can be tested using a simple empirically determined rule of thumb that suggests that a pillar's foundation will fail when the average pillar stress inside the pillar (APS) exceeds 2.5 times the UCS of the foundation material.

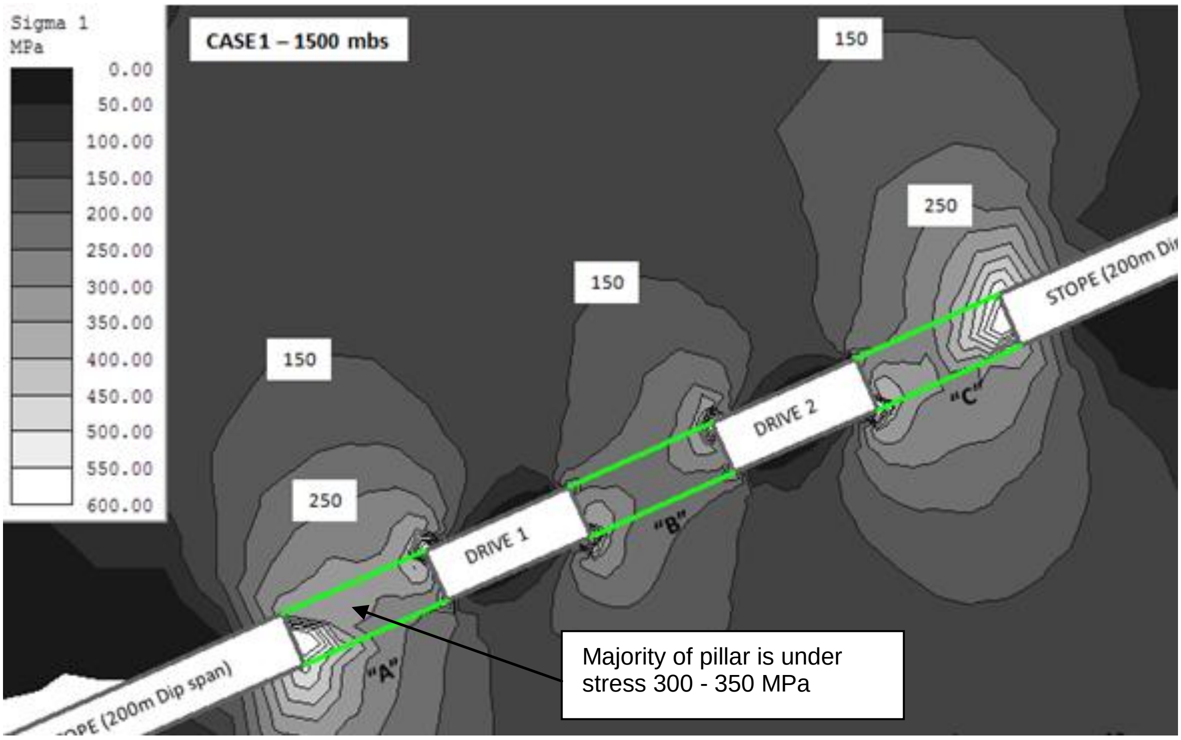
APS < 2.5 UCS (1)

Reading from the plots provided the following can be noted : - (1)

APS (CASE 1 Pillar A) ~ 300 MPa or more (300MPa < APS < 350 MPa). Look at the figure below. Most of the area inside pillar A lies between the 300MPAa and the 350 MPa contours. The 150MPa and 250MPa labels are ONLY given to you to know the scale of the contours!

APS (CASE 1 Pillar B) ~ 200 MPa or more (200MPa < APS < 250 MPa). (Lowest)

APS (CASE 1 Pillar C) ~ 300 MPa or more (250MPa < APS < 350 MPa). (Higher than A)



APS (CASE 2 Pillar A) ~ 550 MPa or more (500MPa < APS < 650 MPa).

APS (CASE 2 Pillar B) ~ 450 MPa or more (400MPa < APS < 500 MPa). (Lowest)

APS (CASE 2 Pillar C) ~ 300 MPa or more (550MPa < APS < 650 MPa). (Higher than A)

(note that you have to look at the stress contours that are INSIDE the pillar and select a reasonable average) :-

Conclusion (2)

In case 1 ALL APS values are less than 2.5 x 200 MPa = 500 MPa. Pillar foundation failure is not expected.

In case 2 APS for Pillars A and C are definitely more than 500 MPa and foundation failure is thus possible.

<u>Depth of stress fracturing</u> **(4)**

In the question students were told that

b) The "Hoek-Brown strength factor" expresses the level of modelled stress relative to the limit defined by the H-B failure criterion. Values > 1.0 suggest stress levels below the H-B limit whereas Values < 1.0 suggest modelled stress levels above the H-B limit.

If the modelled stress is higher than the H-B limit, then failure of the rockmass is possible. Looking at Figure 3 failure is possible in the lighter "white" areas where the H-B factor is < 1.0.

In CASE 1 this zone is limited to the immediate sidewalls of drives 1 and 2. The scale on the figure can be used to estimate failure to about 2m into the sidewall. The installed 2.4m long tendons should support this damage quite adequately.

In CASE 2 this zone increases in size significantly. Pillars A and C are expected to fail throughout their entire widths. The result is that higher sidewall deformations can be expected and it will be difficult to control these movements (even given better support) in the longer term.

Conclusions (4)

1. This geometry will not work for case 2 - the pillar stresses are too high and foundation failure is possible. Either increase the width of the pillars or reduce the span (back length) between levels to reduce the APS and to prevent violent foundation failures. Another acceptable option is to both increase pillar size a bit and then introduce stope backfilling to reduce volumetric closure. (2)

2. The problem is that sidewall extension fracturing will be significantly worse and will result in very large deformations and possible uncontrollable closing up of the drives. The only sensible solution is not to site PERMANENT access ways on the reef horizon. Change the layout to use off reef development that is located either deep enough in the footwall or the hangingwall to not be affected by the mining induces stresses.
Students suggesting very intensive support strategies were however awarded marks as long as the description of the problem and the suggested additional support was sensible. (2)

3.4. (2)

Phase2 is 2 dimensional and the geometry in and out of the page is modelled as if it were infinitely continuous - i.e. a long continuous excavation or a long continuous pillar. The strike pillars extend continuously for hundreds of metres along strike. They can thus be correctly assessed as being of "infinite" length. The problem can be simplified to that of a plane strain problem and can thus be assessed in 2 dimensions.

Cases where pillars have a clear 3 dimensional geometry i.e. bord and pillar layouts would not be well suited to Phase2 analyses.

TOTAL : 20

Question 4

4.1. See handbook pgs 74, 163 **(6)**

As regional support backfill

- effectively reduces volumetric closure. In so-doing it effectively
- reduces the energy release rate (ERR) on the face as well as
- reducing the size of excess shear stress (ESS) lobes that could affect the stability of nearby geology. (3)

As Local support backfill

- Stabilises the hanginwall by providing areal coverage on a large scale - Stops the dislocation of back area key blocks
- Absorbs energy (thus reducing damage in the stope) from nearby seismic events.
- Reduces closure - thus allowing elongates to work more effectively (also confines them making them stronger and able to provide active load longer)
- Prevent unwanted access into the back areas (forces early sweepings) (3)

4.2. **(2)**

"b" represents the strain asymptote - maximum strain. "a" represents the stress generated at half of the maximum strain "b".

4.3. **(2)**

At least 2 of the following

- Increased closure in stopes.
- Closing up of strike gullies / centre raises
- More damage to support
- Deteriorating ground conditions at the face
- Increases levels of seismicity (activity rate or magnitude of events)

4.4. **(3)**

To answer this question you have to first notice that the current fill is much softer than the original one. To determine the stress generated within the fill at 20m behind the face the following process is followed.

- SW at time of placement 5m behind the face = 1.5m - (5*20mm) = 1.4m (bonus mark)
- Closure between 5m and 20m behind the face = 15m * 20 mm/m = 300mm (1)
- Strain in fill = 300mm / 1.4m = 214 mm/m or 0.214 mm/mm or % (1)

- Reading 0.214% strain off from the graph one notes that the original fill should have given approximately 30MPa stress generation at 20m behind the face whereas the actual fill provides less than 1 MPa. (1)

4.5. (2)

At least 2 of the following

- **The loading rate is different. Slower underground than it is in the lab.**
- Change in mix design brought on during the transportation of the pumped fill. Separation of backfill constituents or the effects of excessive pipe wear
- Incorrect placement in the stope - backfill not pumped to the hangingwall
- Poor curing / consolidation of fill (poor weeping)
- Excessive shrinkage of fill (draining of water)

4.6. (4)

The **sample size distribution** describes the spread of particle sizes of the solids from which the backfill is made. **Porosity** is a measure of the non-solid volume (voids and water) within the fill material expressed as a percentage of the total volume. (1)

As a general rule backfill stiffness and strength increases with reduced porosity. (1)

The sample size distribution directly affects the porosity of the material. The lowest porosity (and thus the strongest best performing backfill) is achieved when there is an optimum mix of both larger and smaller particles within the backfill medium. Small particles can fill the space between larger particles thus reducing the overall porosity. (2)

Note that only having larger particles or only having smaller particles does not on its own affect the porosity % much - there must be an optimum balance and blend of both smaller and larger solid particles.

4.7. (2)

At least 2 of the following

- Water content
- Slurry relative density
- Flowability (Rheology)
- Percolation rate

TOTAL : 20

Question 5

5.1 Chapter 5 = General Information **(4)**

5.1 Locality

A brief description and locality map to indicate the location of the mine in relation to towns, existing infrastructure and any other relevant features such as mines sharing a common boundary, dams, rivers and any other topographical features which could influence the strategies adopted.

5.2 Geological Setting

Geological structures, such as faults and dykes and stratigraphy, around individual orebodies or seams must be described and any hazardous conditions highlighted. A typical geological section of the mine must also be included. A detailed geological assessment may not be necessary but a map showing major geological features in relation to mining outlines and shafts must be included.

5.3 Mining environment

The mining environment describes major subdivisions of an orebody, which dictates specific fundamental extraction strategies and occurs on a regional scale thus crossing mine boundaries.

5.4 Ground Control Districts

The location and extent of ground control districts must clearly be described in the COP. The nature of the virgin stress field in which mining is to take place, as well as the occurrence of significant pore water and any other local geological features, must be included here. All ground control districts must be indicated on a Ground Control District Plan

5.5 Mine Rock Fall and Rock Burst Incident Analysis

The COP must contain a tabulation of the mine's five year history of rock-related casualties (fatals, reportables and disabling incidents) and non-casualty incidents (where available), categorised according to rock bursts and rock falls per 1000 employees at work for both surface and underground operations. From this information the risk associated with each hazard can be established. These statistics should be normalised with respect to production tonnage in the different ground control districts.

Students to correctly name and briefly discuss at least 4 of the above. Marks deducted if no discussion (Read the question)

5.2.1)a) **(1)**

The terms ***hazard*** and ***risk*** are defined in section 102 of the Mine Health and Safety Act as

Hazard - Means a source of or exposure to danger.

*(Alternatively, a **HAZARD is something that has the potential to cause HARM.** This includes substances, machines, methods of work or other aspects of work Organisation; (The term danger is not defined in the Act))*

Risk - Means the likelihood that occupational injury or harm to persons will occur.

*(Alternatively, RISK **is the LIKELIHOOD that the harm from a particular hazard will occur**; The extent of the risk depends on not only the severity of the harm to a person but also the number of people who will be harmed. Risk therefore reflects both the likelihood that the harm will occur and its severity in terms of the degree of harm and the number of people harmed).*

5.2.1)b) **(1)**

Existing controls - Means those controls (physical, managerial or procedural etc) that are currently in place specifically to reduce the likelihood of harm due to a given hazard.

Additional controls - Means those controls (physical, managerial or procedural etc) deemed to be necessary (following the conducted hazard identification and risk assess (HIRA) process) and being in addition to those controls that are already in place, aimed at further reducing the risk to a more acceptable level.

5.2.2)a) **(2)**

Mine management to involve representatives from all applicable departments. Most important is :-

- Safety rep (of U/G crews) and representatives of the general work force NB!.
    - NB! This is essential to ensure chosen controls are practical, acceptable and achievable. **(Mark deducted if workforce not mentioned)**
- Mine management (Mine manager and upper level management)
    - NB! This is essential to ensure chosen controls are practical, acceptable and achievable.
- Rock Engineer
- Safety Manager / Officer and other relevant persons

5.2.2.)b) **(2)**

The team is to identify and assess all rock related hazards. This is often best done by classing hazards according to the various mining operations (drilling, blasting etc.)

A Risk Matrix type approach is often used whereby those who are carrying out the risk assessment categorise the **consequence**s of the hazard, and its **likelihood** separately and then combine them on a matrix to produce a priority based on a Risk Rating.

Each hazard is assigned a Risk Rating (RR) where

$$RR = \underbrace{\text{Probability (P) x Exposure (E)}}_{\boxed{\text{Frequency / Likelihood}}} \text{ x } \underbrace{\text{Consequence (C)}}_{\boxed{\text{Consequence}}}$$

Probability = Can/will the hazardous situation occur?

Exposure = Will people / machinery be exposed?

Consequence = Assuming a hazard causes harm to men or machinery, how severe will this harm be?

5.2.2.)c) **(2)**

The objective is to **classify and rank rock related hazards in terms of risk** i.e. to identify those hazards that currently pose the highest risk to the operation. **RANKING** of the risk is a key objective. Furthermore the purpose is to :-

Determine all necessary control measures necessary to either **eliminate, control at the source or minimise** the risk; and insofar as the risk remains, provide for personal protective equipment; and institute a programme to monitor the risk to which employees may be exposed.

5.3)a) **(4)**

As per the DME guidelines (2002), A COP must set out a description of the design methodology to avoid uncontrolled collapses of the mine or portion/s thereof, and the effects of the mining methods employed on surface structures and topography. This is typically achieved through different pillar types as detailed below.

Type	Role	Design guidelines
Barrier or boundary pillars	Legal requirement. Separates different mines. Provides mine compartmentalisation (fire/ flooding).	Legal Width > 18m W:H > 15:1
Stabilising pillars	Provide regional stability. Support overburden weight to surface.	Spaced 1/4 to 1/2 of the depth below surface W:H > 5:1 Use squat pillar formula. FOS ~ 1.5 or 1.6 or 2.0 in some cases Check foundation failure with APS criteria (APS < 2.5 UCS)
Instope pillars	Support the tensile zone between stabilising pillars (if stabilising pillars are used) ELSE must support overburden weight to surface. Crush pillars may also be used purely to stabilise poor ground (re-establishing)	W:H<4.5 but is typically not less than 1.5 to 2.0 Use Hedley-Grant pillar formulation. FOS can either be ~0.7 (crush pillars) ~1.0 (yield pillars) or >1.6 (Non yield pillars).

To get 4 marks students to at least show that they understand that

- the entire weight to surface must be supported (either through regional pillars or through non yield instope pillars)
- The mine needs to be compartmentalised against fire/floods
- Students must make some sensible reference to pillar formulation, FOS and W:H ratios.

5.3)b) **(4)**

Typical Sequential grid mining layout / geometry. (main points) **(2 marks)**

- Top down (underhand configuration) – over hand or “c” shape acceptable in some situations (as long as it promotes other rules)
- Reduce spans (20-30m wide dip pillars spaced 180-200m apart between sequential grids)
- Mine towards solid
- Approach angle to structures > 35°
- Mine away from structures
- Keep good and straight Face shapes
- Limit leadlags to less than 10m and develop sidings 3 - 4m in depth
- Use of pre-conditioning
- Etc.

Reference to at least 2 of the above (or other applicable discussions) for 2 marks

Instope support requirements **(2 marks)**

Type	Role	Pros	Cons
Packs	Long term – back area support. Provide high load bearing capacity	Provide high load bearing capacity Durable / resilient Energy absorption (cement based packs)	Less stiff (not active) Can't be installed close to the face. Time consuming construct
Elongates	Immediate and active support in the short term	Active /immediate support. Pre-stressed	Limited life / limited deformation Blast damage
Tendons	Immediate support (closer to the face than elongates)	Can be installed close to the face Don't hamper scraping operations	Limited in terms of length / zone of influence. Lack of durability (if not grouted)
Backfill	Reduces volumetric closure / controls seismicity / reduces face stress	Very effective at controlling seismicity. Reduces ERR / ESS Prevents back area falls and exposure of people here	Expensive plant Piping and handling Less effective in Sequential grid layouts unless used in high amounts (70% coverage)

For 2 marks ,

- Reference to at least 2 of the above (in terms of pro's and cons)
- Reference to the terms "Support Resistance" and "Energy Absorption" in support design

OR

- Reference to "active but short term" vs "passive but durable" in terms of elongates v.s packs

TOTAL : 20