<table>
<tr><th colspan="2"><u>EXAMINATION PAPER</u></th></tr>
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CHAMBER OF MINES OF SOUTH AFRICA EXAMINATION FOR CERTIFICATE IN ROCK MACHANICS PAPER 3.2 (COAL OPTION)

SUBJECT CODE

EXAMINATION DATE:

TIME:09H00 – 12H00</td><td>Examiner:

G Makusha

Moderator:

B Madden</td></tr>
<tr><td colspan="2">Number of pages 12 (including formula sheet)</td></tr>
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SPECIAL REQUIREMENTS:

1. **Answer all questions.**
2. References, other than those specified below, are not permitted
3. Put your examination number on the outside cover of each book used, and on any graph paper or other loose sheets handed in.

N.B Your name must not appear on any answer book or loose sheets

4. Show all calculations on which your answers are based.
5. Hand-held electronic calculators may be used.
6. Write on the right hand page only.
7. Illustrate your answers by sketches or diagrams wherever possible.
8. Answers must be given to an accuracy which is typical of practical conditions.
9. In answering the questions, state any assumptions made.
10. A list of formula and any other essential charts and tables will be issued at the time of the examination.
11. Contacting of examiners and moderators is forbidden.

Question 1

Given that $S = 288\frac{w^{2.46}}{Hh^{0.66}(w+B)^2}$ and $\Delta w_i = w_i\frac{(S/S_i)-1}{2.46-2W_i/(W_i+B)}$

1) Compute the safety factor for coal mine workings given that the the depth of workings is 175m to seam floor, the bord width pillar width and height are 6.0m, 3.5m and 17.0m, respectively. (3) Ans $S = 288\frac{(17)^{2.46}}{175\,(3.5)^{0.66}(17+6)^2} = 1.45$
2) A thick coal seam occurs at a depth of 65m to the floor. It has been decided, for practical reasons, that it will be convenient to mine the seam with bords at 17.0m wide centres. Both the seam and roof are competent so that practical experience suggests that it is permissible to employ a bord width of 7.0m. Compute a safe working height, assuming that the safety factor of 1.6 is required. Ans $h = \left[\frac{288w^{2.46}}{HS(w+B)^2}\right]1/0.66 = \left[\frac{288(10)^{2.46}}{65*1.6(17)^2}\right]1.5152 = 4.6$ (5)

3) The coal seam at a new project will be mined at a depth of 125m. It has been decided that the bord width and the select mining height should be 6.5m and 5.0m, respectively. Compute the safe pillar width, assuming that the safety factor should be 1.6.

   Ans use formula below in an iterative process to get to answer $\Delta w_i = w_i\frac{(s/s_i)-1}{2.46-(2w_i/(w_i+B))}$, where w_i= pillar width, s=specified safety factor and s_i=safety factor computed from the equation.
   Let initial estimate = 10
   $FOS = S = 288\frac{(10)^{2.46}}{125(5)^{0.66}(10+6.5)^2} = 0.8437$

   $\Delta w_1 = 10\frac{(1.6/0.8437)-1}{2.46-(20/17)} = 6.98m \rightarrow w2 = 10+6.98 = 16.98m$

   $Iterate\ using\ w2 = 16.98$

   Corresponding s2 =1.5325, Δw_2 = 0.738.
   Continue iterations until correction becomes smaller than a pre-determined threshold value, e.g 0.004.
   The result of iterative method of solution results in a safe pillar width of w=17.723 (17.8m) (12)

Total: 20 marks

Question 2 Surface subsidence

Question A.

Your mining company is considering buying either of two previously worked coal mines with extensive reserves remaining. You must report on the potential risks to surface at each mine. Without writing a full report detail the main points that you would make and your final conclusions, including any calculations and diagrams considered necessary. Currently in both cases no surface damage is evident.

Mine A.
The seam was mined 15 years ago by drill and blast methods with 11 m pillar centres, 5,5 m bords with a mining height of 2,4 m. No barriers were left between panels. The surface is used for mielie farming.

Mine B.
The workings were worked up to 1999 using 11 road panels on 15 m pillar centres, a 6,5 m bord and 2,1 m mining height using continuous miners. 23,5 m barriers were left between panels. The surface is used for grazing but has a number of dwellings on it and is traversed by a provincial gravel road.

Mine A

13 m	Weathered Overburden
28 m	Interlaminated Sandstone/Shale
30,4 m	Coal
38 m	Micaeous carbonaceous Siltstone

Mine B

20 m	Weathered Overburden
70 m	Interlaminated Sandstone/Shale
100 m	Dolerite
127,9 m	Massive fine grained Sandstone
130 m	Coal
140 m	Sandstone

Ans. $T = \left[\frac{d}{mh^x}\right]\frac{1}{1-x}$

RISK OF PILLAR FAILURE(factor of safety/pillar width to height ratio and probability of failure, time to failure calculations, layout considerations (barrier pillars), geometry considerations, rock strength, depth to span ratio, critical/subcritical span

RISK OF SINKHOLES, Shallow vs Deep, competent massive overburden rocks, % competent

CONSEQUENCE OF PILLAR COLLAPSE, subsidence effects(maximum vertical subsidence, tilt), land use, Reputational, economic and safety risk risk of sinkholes, time to failure,

Total: 30 marks

Mining parameter	Mine A	Assessment	Mine B	Assessment
Depth	32.8	Shallow, risk of sinkholes forming to surface,	132.1	No risk of sinkholes and low risk of spontaneous combustion
Mine w/h	2.3	Shallow guideline satisfied in 2 out of the 4 requirements (w/h 2.3, FOS 2.7, % e>75, & pillar width <6.5. layout potentially unstable	4.0	Yield pillars, low risk of uncontrolled pillar failures
Pillar FOS	2.7	Although FOS is high, factor of safety alone not enough, shallow mine guidelines to be satisfied	1.1(1.3)	Low fos<1.6 common design criteria, POF=0.1252 (0.0492) or 125200 (49200) pillar collapses in a million () after cm adjustment
Time to failure	150 years	15 year old workings, risk is low but not as good mine B	268 years	Better layout in terms of time to failure
Layout (critical span/depth to span ratio)	bad	No barrier pillars, pillar collapses possible over extensive areas (Mining span is infinite vs critical span of 132m)	Good	Barriers provide regional support and compartmentalized panels (combined thickness 57m give a critical span of 374m vs 156m)
Rock strength	weak	Weaker overburden and floor rockmasses (pillar punching possible)	strong	competent sandstone roof and floor (low risk of pillar punching)
Max vert. subsidence	1.4m	Larger footprint (more cost of rehabilitation)	1.1	Lower ground effects, will still affect surface infrastructure.
Consequence & Liability		Farmer compensation, rehabilitation of land, water ponding, potential public safety		Public safety, compensation, relocation of settlers
Overall	Higher		Lower	

	risk		Risk	

Technically the risk of pillar collapse is lower on mine B. Mine has a higher risk of surface disturbance from pillar collapse and sinkhole formation. Sinkholes are known to lead to spontaneous combustion that further destabilize old workings. Although surface is used on both mines, there is sensitive surface infrastructure at mine B with Human settlements and provincial road. Recommend Mine B.

Depth, H (m)	Height, h(m)	Bord, w(m)	Center, c(m)	w	Load	strength(5)	SF(5)	W/h ratio	e%	Span(m)	B	Span, Lc	Sm	Parting	Time to failure
30.4	2.4	5.5	11	5.5	3.0	8.8	2.9	2.3	75.0%	115.5	60.4	131.6	1.4	8.14	150.1024448
32.8	2.4	5.5	11	5.5	3.3	8.8	2.7	2.3	75.0%	115.5	60.4	133.4	1.4	8.14	150.1024448
130	2.1	6.5	15	8.5	10.1	11.8	1.2	4.0	67.9%	156.5	56.9	374.2	1.1	11.1	268.7476011
132.1	2.1	6.5	15	8.5	10.3	11.8	1.1	4.0	67.9%	156.5	56.9	378.4	1.1	10.8	268.7476011

Relevant formula:

$$\boxed{Load, L = 0.025 * H * \frac{C_1 + C_2}{w_1 + w_2}}$$

$$\boxed{Strenth, \sigma_s = 7.176 \frac{w^{0.46}}{h^{0.66}}}$$

$$\boxed{FOS = \frac{strength}{Load}}$$

$$\boxed{FOS_{cm} \Rightarrow \eta_{cm} = \eta * (1 + \frac{\Delta w}{w})}$$

$$\boxed{Span, L_c = 2 * T * \sqrt{k + \frac{\beta}{D} + 2(H - D) * Tan(\phi)}}$$

$$\boxed{\beta = \frac{1.53}{\gamma_m} - 0.8} \qquad \boxed{k = 1.5?}$$

$$T = \left[\frac{d}{mh^x}\right]^{\frac{1}{1-x}}$$

Question 3

Draw on the same graph the complete Stress vs Strain diagram for a typical Brittle and Plastic Material and label all relevant points. What determines the difference between the Pre and Post failure characteristic of the sample?

Stress

Strain

Settling point

Young's Modulus, elastic area,

Yield point,

Peak strength,

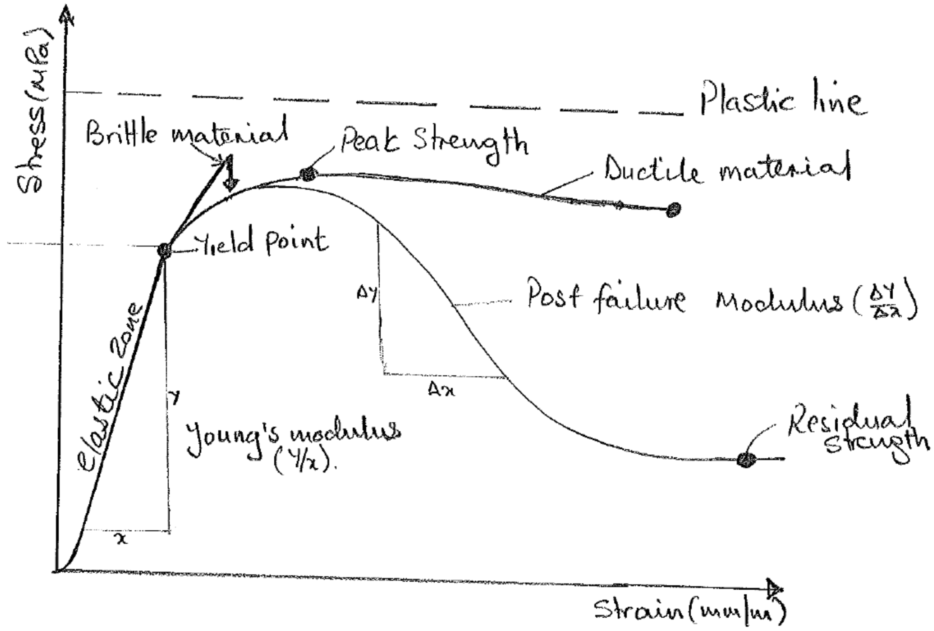
Post failure Modulus,

Residual strength,

Plastic line

Brittle line

Ductile = Plastic (one mark each)



Difference is Pre Failure is a material property (4 marks) and Post Failure is the width to height ratio of the specimen (4 marks).

Total 20 marks

Question 4 Rockmass classification

An incline shaft is to be driven through slightly weathered sandstone with a dominant joint set dipping at 60^o against the direction of the drive. Index testing and logging of diamond drilled core give typical Point-load strength index values of 8 MPa and average *RQD* values of 70%. The slightly rough and slightly weathered joints with a separation of < 1mm, are spaced at 300 mm. Development conditions are anticipated to be wet.

1) Show how you would determine the RMR and estimate a value along the shaft. (9)

The RMR value for the example under consideration is determined as follows:

Table	*Item*	*Value*	*Rating*
4:A1	*Point load Index*	*8Mpa*	*12*

4:A2	*RQD*	*70%*	*13*
4:A.3	*Spacing of discontinuities*	*300mm*	*10*
4:A.4	*Conditions of discontinuities*	*Note 1*	*22*
4:A.5	*Ground water*	*Wet*	*7*
4:A.6	*Adjustment for joint orientation*	*Note 2*	*-5*
Total			*59*

2) Determine suitable roof and ribside support for the shaft given that it is planned to be 10m wide. (3)

Ans.

- *For the case considered earlier, with RMR = 59, Table 4 suggests that a tunnel could be excavated by top heading and bench, with a 1.5 to 3 m advance in the top heading.*
- *Support should be installed after each blast and the support should be placed at a maximum distance of 10 m from the face. Systematic rock bolting, using 4 m long 20mm diameter fully grouted bolts spaced at 1.5 to 2 m in the crown and walls, is recommended.*
- *Wire mesh, with 50 to 100 mm of shotcrete for the crown and 30 mm of shotcrete for the walls, is recommended. (3)*

3) Enumerate the 6 parameters used to determine the value of Q and explain the meaning of the 3 combinations of these parameters used in the Q system. (12)

RQD is the Rock Quality Designation
Jn is the joint set number
Jr is the joint roughness number
Ja is the joint alteration number
Jw is the joint water reduction factor
SRF is the stress reduction factor (6)

The first quotient (RQD/Jn), representing the structure of the rock mass, is a crude measure of the block or particle size.

The second quotient (Jr/Ja) represents the roughness and frictional characteristics of the joint walls or filling materials.

The third quotient (Jw/SRF) consists of two stress parameters. SRF is a measure of: 1)
loosening load in the case of an excavation through shear zones and clay bearing rock,
2) rock stress in competent rock, and 3) squeezing loads in plastic incompetent rocks.

It can be regarded as a total stress parameter. The parameter Jw is a measure of water pressure, which has an adverse effect on the shear strength of joints due to a reduction in effective normal stress. Water may, in addition, cause softening and possible outwash in the case of clay-filled joints. *(6)*

4) Explain the similarities and differences between the 2 classification systems. (6)

- *RMR uses compressive strength directly while Q only considers strength as it relates to in situ stress in competent rock.*
- *Both schemes deal with the geology and geometry of the rock mass, but in slightly different ways.*
- *Both consider groundwater, and*
- *both include some component of rock material strength.*
- *The greatest difference between the two systems is the lack of a stress parameter in the RMR system.*
- *The differences between the systems lie in the different weightings given to similar parameters and in the use of distinct parameters in one or the other scheme*

Total 20 marks

Table 1 Rock Mass Rating System(after Bieniawski 1989)

A. CLASSIFICATION PARAMETERS AND THEIR RATINGS

	Parameter		Range of values						
1	Strength of intact rock material	Point-load strength index	>10 MPa	4 - 10 MPa	2 - 4 MPa	1 - 2 MPa	For this low range - uniaxial compressive test is preferred		
		Uniaxial comp. strength	>250 MPa	100 - 250 MPa	50 - 100 MPa	25 - 50 MPa	5 - 25 MPa	1 - 5 MPa	< 1 MPa
	Rating		15	12	7	4	2	1	0
2	Drill core Quality *RQD*		90% - 100%	75% - 90%	50% - 75%	25% - 50%	< 25%		
	Rating		20	17	13	8	3		
3	Spacing of discontinuities		> 2 m	0.6 - 2 . m	200 - 600 mm	60 - 200 mm	< 60 mm		
	Rating		20	15	10	8	5		
4	Condition of discontinuities (See E)		Very rough surfaces Not continuous No separation Unweathered wall rock	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Slickensided surfaces or Gouge < 5 mm thick or Separation 1-5 mm Continuous	Soft gouge >5 mm thick or Separation > 5 mm Continuous		
	Rating		30	25	20	10	0		
5	Groundwater	Inflow per 10 m tunnel length (l/m)	None	< 10	10 - 25	25 - 125	> 125		
		(Joint water press)/ (Major principal σ)	0	< 0.1	0.1, - 0.2	0.2 - 0.5	> 0.5		
		General conditions	Completely dry	Damp	Wet	Dripping	Flowing		
	Rating		15	10	7	4	0		

B. RATING ADJUSTMENT FOR DISCONTINUITY ORIENTATIONS (See F)

Strike and dip orientations		Very favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels & mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-15	-25
	Slopes	0	-5	-25	-50	

C. ROCK MASS CLASSES DETERMINED FROM TOTAL RATINGS

Rating	100 ← 81	80 ← 61	60 ← 41	40 ← 21	< 21
Class number	I	II	III	IV	V
Description	Very good rock	Good rock	Fair rock	Poor rock	Very poor rock

D. MEANING OF ROCK CLASSES

Class number	I	II	III	IV	V
Average stand-up time	20 yrs for 15 m span	1 year for 10 m span	1 week for 5 m span	10 hrs for 2.5 m span	30 min for 1 m span
Cohesion of rock mass (kPa)	> 400	300 - 400	200 - 300	100 - 200	< 100
Friction angle of rock mass (deg)	> 45	35 - 45	25 - 35	15 - 25	< 15

E. GUIDELINES FOR CLASSIFICATION OF DISCONTINUITY conditions

Discontinuity length (persistence)	< 1 m	1 - 3 m	3 - 10 m	10 - 20 m	> 20 m
Rating	6	4	2	1	0
Separation (aperture)	None	< 0.1 mm	0.1 - 1.0 mm	1 - 5 mm	> 5 mm
Rating	6	5	4	1	0
Roughness	Very rough	Rough	Slightly rough	Smooth	Slickensided
Rating	6	5	3	1	0
Infilling (gouge)	None	Hard filling < 5 mm	Hard filling > 5 mm	Soft filling < 5 mm	Soft filling > 5 mm
Rating	6	4	2	2	0
Weathering	Unweathered	Slightly weathered	Moderately weathered	Highly weathered	Decomposed
Ratings	6	5	3	1	0

F. EFFECT OF DISCONTINUITY STRIKE AND DIP ORIENTATION IN TUNNELLING**

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 - 90°	Drive with dip - Dip 20 - 45°	Dip 45 - 90°	Dip 20 - 45°
Very favourable	Favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20 - Irrespective of strike°	
Fair	Unfavourable	Fair	

Table 2 Guidelines for excavation and support of 10m span rock tunnels in accordance with the RMR system(After Bieniawski 1989)

Rockmass class	Excavation	Roof bolts (20mm diameter fully grouted)	shortcrete	Steel sets
I – Very good rock RMR:81-100	Full face 3m advance	Spot bolting		
II – Good Rock RMR:61-80	Full face 1-1.5m advance. Complete support 10m from the face	Locally botls in the roof, 1.5m long, spaced not more than 2.5m apart with occasional Oslo straps	None	None
III – Fair Rock RMR:41-60	Top heading and bench 3m advance in top heading Commence support after each blast Secondary support 10m from the face	Systematic bolts 3.0m long, 4 in a row & spaced 2.0m apart in the roof and ribsides with wire mesh	100-150mm in roof and 30mm in ribsides	None
IV – Poor rock RMR:21-40	Top heading and bench 1.0-1.5m advance in top heading Install support concurrently with excavation	Systematic bolts 4.0m long, 6 in a row & spaced 1.5m apart in the roof and ribsides with wire mesh	150-200mm in roof and 50mm in ribsides	none

Equation Sheet

Candidates may find some of the following equations useful, although other equations may also be used.

Pillars

$$\sigma = 7{,}2\,\frac{w^{0,46}}{h^{0,66}}$$

$$\sigma = 4.5\frac{w^{0,46}}{h^{0,66}}$$

$$\sigma = 4{,}3\left(0{,}64 + 0{,}36\frac{w}{h}\right)$$

$$\sigma = 3.5\frac{w}{h}$$

$$\sigma = k\frac{R_0^b}{V^a}\left\{\frac{b}{\varepsilon}\left[\left(\frac{R}{R_0}\right)^{\varepsilon} - 1\right] + 1\right\}$$

$$\sigma = \frac{.0786}{V^{0.0067}}\left\{R^{2.5} + 181.6\right\}$$

$$w_e = \frac{4A}{C}$$

$$SF_{cm} = SF\left(1 + \frac{0.6}{w}\right)^{2.46} \qquad SF_{cm} = SF\left(1 + \frac{0.6}{w}\right)^{3}$$

$$SF^{/} = SF\left(\frac{w - \Delta w}{w}\right)^{2.46} \qquad SF^{/} = SF\left(\frac{w - \Delta w}{w}\right)^{3}$$

$$SF^{//} = \left(\frac{h}{h + \Delta h}\right)^{0.66} \qquad SF^{//} = \left(\frac{h}{h + \Delta h}\right)$$

$$Load = \frac{\left[.025(H - T) + .03T\right]C_1C_2}{w_1 w_2}$$

$$e\% = 100\left[\frac{h_m}{h_s}\left(1 - \frac{w^2}{C^2}\right)\right]\frac{W}{W + P}$$

$$E_{cp} = \frac{0,562 w_e}{h} - 2,293$$

$$R = m\left[\frac{h}{T}\right]^x$$

$$d = w - \left[0,00714 S_{\min} HhC^2\right]^{0,333}$$

$$S_{\min} = 0.4$$

$$T = \left[\frac{d}{mh^x}\right]^{\frac{1}{1-x}}$$

Region	m	x
Vaal Basin, Klip River and South Rand	1,3888	0,804
Witbank No 2 and 4 Seams	0,1624	0,8135
Witbank No 5 Seam	0,105	-0,3061

Roof Support

$$\sigma_t = \frac{qB^2}{2t^2}$$

$$q = \rho g(t_s + t_w)$$

$$\sigma_t = \frac{fq_c s^2}{2t^2}$$

$$s = 1.414 t_{\min} \sqrt{\frac{\sigma_{tm}}{fq_c}}$$

$$q_c = q_l + \frac{q_u E_l - q_l E_u}{E_l + E_u}$$

$$l_a = \frac{\rho g s^2 t_w}{\tau_c \pi d_h} + .05$$

$$\eta = \frac{SF\rho g t}{P_d}$$

$$\sigma_{ts} = \frac{4W_b}{\pi d_b^2}$$

$$l_c = \frac{l_a \left(d_h^2 - d_b^2\right)}{\left(d_h - .002\right)}$$

$$t_{sb} = \frac{fk\rho g B^2}{2\sigma_{tm}}$$

$$\tau_b = \frac{3k\rho g B}{4}$$

$$\tau = C_c + C_b + \frac{F_b}{s_b^2}\tan\phi$$

$$F_b = \frac{s}{\tan\phi}\left[\frac{3\rho g k B s}{4} - \sigma_r d_h\right]$$

$$F_T = F_b \rho g k t_{sb} s^2$$

$$l_a = \frac{F_T}{\pi d_h \tau_c}$$

$$\eta = \frac{\gamma B^4}{32Et^2}$$

$$\sigma_s = \frac{4F_T}{\pi d_s^2}$$

$$\beta = \arctan\left(\frac{L/2}{\eta}\right) - \arctan\left(\frac{\eta}{L/2}\right)$$

$$R = \frac{L/2}{Cos\beta}$$

$$d\theta = \frac{\pi}{2} - \arctan\left(\frac{R - \eta - h_l}{L/2 - d}\right)$$

$$S = t_l d\theta$$

$$\sigma_r = \frac{\tau_l S_b}{d_b}$$

$$\varepsilon_r = \frac{\sigma_r}{E_r}$$

$$S_r = \varepsilon_r (d_h - d_b) + R_s$$

$$SSF = \frac{S}{S_r}$$

Subsidence

$$S_{m,he} = 0{,}39h\left(\frac{W}{H}\right)^{0{,}32}$$

$$S_{m,pf} = 0.1h_e$$

$$h_e = he$$

$$S_x = \frac{S_{\max}}{2}\left[\tanh\left(\frac{7x}{W} - 1{,}645\right) + 1\right]$$

$$L_c = 2T\sqrt{k + \frac{\beta}{D}} + 2(H - D)\tan\theta$$

$$\beta = \frac{c - b\gamma d}{\gamma_m \tan\phi} - \frac{kl}{2}$$

$$\beta = \frac{1.53}{\gamma_m} - 0.8$$

$$\gamma_m = \gamma_s \frac{D-T}{D} + \gamma_d \frac{T}{D}$$

$$\gamma_m = 0.025\frac{D-T}{D} + 0.03\frac{T}{D}$$

$$T_m = 21.6S_m + 7$$

$$\varepsilon_{m+} = 4.2S_m + 1.7$$

$$\varepsilon_{m-} = -9.1S_m - 2.8$$

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