CHAMBER OF MINES OF SOUTH AFRICA

EXAMINATION PAPER

SUBJECT:	EXAMINER:
CERTIFICATE IN ROCK MECHANICS 3.2 (COAL)	W. Mahne
SUBJECT CODE:COMRMC3.2	**MODERATOR:**
	L. Prinsloo
EXAMINATION DATE: ___ MAY 2017	**TOTAL MARKS:** [100]
TIME: ______	**PASS MARK:** 60%

NUMBER OF PAGES: 8 (Including cover page)

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 ID 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. Show all calculations on which your answers are based.
7. Illustrate your answers by sketches of diagrams wherever possible.
8. In answering these questions, full advantage should be taken wherever necessary of your practical experience as well as of the data given.
9. Answers must be given to an accuracy that is typical of practical conditions.
10. In presenting answers, candidates are encouraged to use tabulations and diagrams.
11. Cell phones are **NOT** allowed in the examination room

QUESTION 1

1.1. Complete the table below on the CMRR classifications.

CMRR Class	CMRR Region	Geological conditions (Rock types)
Weak	0-45	Claystones, Mudrock, Shales
Moderate	45-65	Siltstone and Sandstone
Strong	65-100	Sandstones

(3)

1.2. Complete the table below on impact splitting classification.

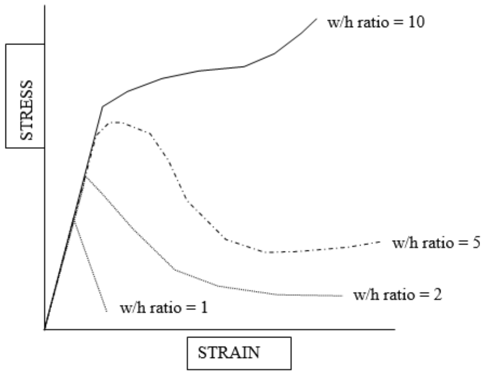
Unit Rating	Rock Class	Roof Rating
<10	Very poor	<39
11-17	Poor	40-69
18-27	Moderate	70-99
28-32	Good	100-129
>32	Very good	>130

(5)

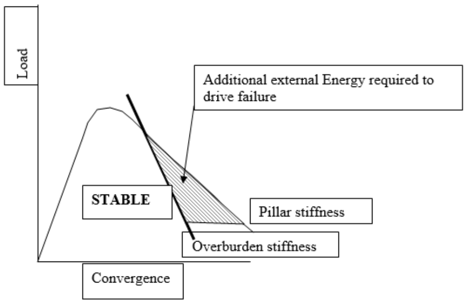
1.3. Discuss the factors (10) that will influence pillar design and pillar stability in an underground coal mine. (5)

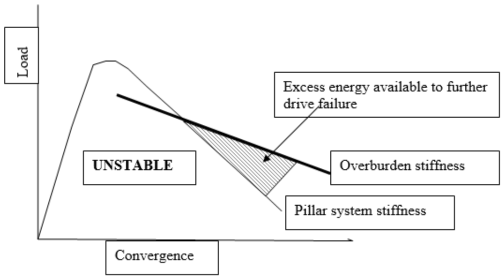
- *Weak host rock (roof, floor & coal (devolatisation, inherently weak – Vaal Basin compared to Witbank Coal fields))*
- *Geological features such as joints, faults, dykes, weak or weathering layers within the coal seam and/or smooth bedding planes*
- *Overburden depth (to coal seam floor)*
- *Seam / mining height*
- *Type of mining e.g. herring bone, D&B,*
- *Possible future pillar extraction*
- *Dipping*
- *Basement anomalies*
- *Surface structures*
- *Multi seam environment*

1.4. Sketch on one graph a typical load-deformation curves to illustrate the influence of pillar width to height ratio on pillar strength and the post-failure behaviour. (4)



1.5. Given that k_o is the local overburden stiffness and k_p is the post failure stiffness at any point along the load-deformation curve for a coal pillar. Illustrate with the aid of diagrams the stable and unstable conditions and explain your answer. (4)





1.6. The mine you are working on is planning optimise the pillars in an old development panel. For a presentation to management you need to;

1.6.1. Discuss the different secondary mining methods to consider. (4)

1.6.2. Give a brief discussion on the Rock Engineering design factors you need consider for the design of the pillars and support. Include the considerations that needs to be taken into account with the physical layout and the mining of the panel. (10)

- *Safety factor*
- *Pillar width to height : ratio*
- *Pillar dimensions (Practical to stoop?)*
- *Pillar life calculation*
- *Barrier pillars – Barriers will contribute to the overall stability & if designed correctly, assist with the sealing strategy*
- *Compared to actual underground.*
- *Caving propensity,*
- *Cave height,*
- *Swell factor,*
- *Strata overhang,*

- *Continuous cave subsidence*
- *Support requirements*

[35]

QUESTION 2

Diagram below indicates a cross section of the different seams. The horizontal gridlines are spaced 5 m apart. No geotechnical information is currently available with regards to the area to be mine.

Mining of the different seams are planned via strip mining operations by means of a dragline.

Repetition vague

2.1. As part of the pre-feasibility study you need to give a design for the mining of the pit. Discuss the design process which will includes all rock engineering considerations and risks that needs to be considered for the safe mining of the different coal seams.

Step 1—Statement of the problem (performance objectives) [Design principle 1]

Step 2—Functional requirements and constraints (design variable and design issues) [Design principle 1]

Step 3—Collection of information (site characterization, rock properties, groundwater, in situ stresses) [Design principle 2]

Step 4—Concept formulation (geotechnical model) [Design principle 3]

Step 5—Analysis of solution components (analytical, numerical, empirical, observational methods) [Design principles 3 and 4]

Step 6—Synthesis and specifications for alternative solutions (shapes, sizes, locations, orientations of excavations) [Design principles 3 and 4]

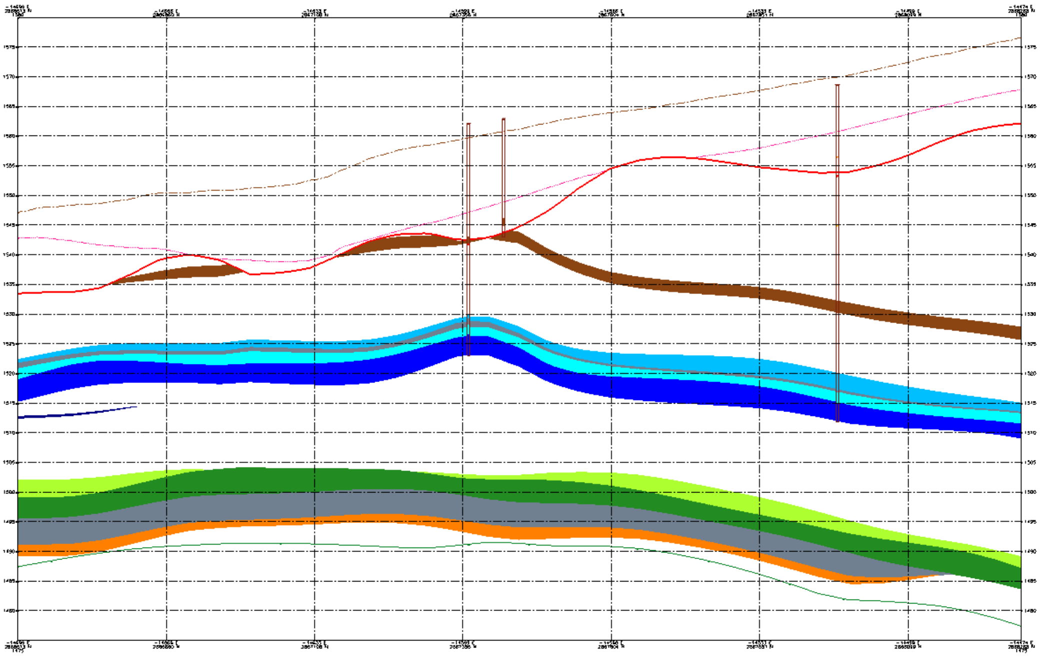
Risks

- Thickness of softs
- Sponcom
- Sinkhole formation
- High benches
- Deep mining
- Lack of geological / geotechnical information
-

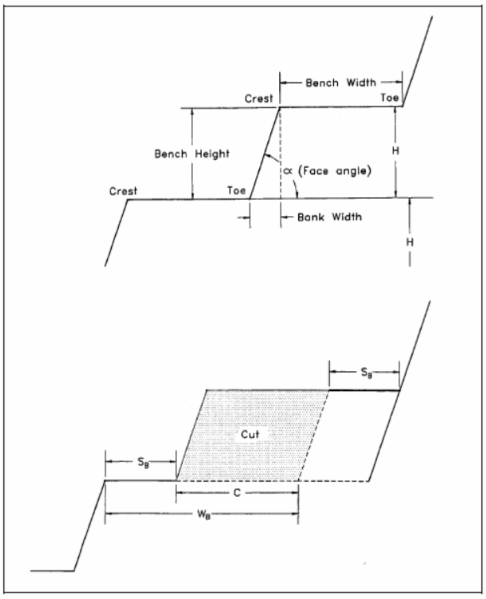
-

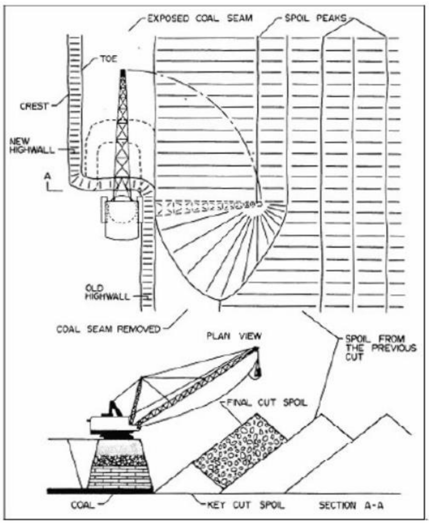
(15)

2.2. Describe the mining process and sequence of mining the different seams. Use annotated sketch(s) to assist with the explanation. (10)



Seam	Notes
Overburden	Highly weathered overburden (≈10 m)
S5	Virgin
S4U	Virgin
P4	Parting - Shales
S4T	Lower quality roof
S4S	Previously Mined / Planned Select
P4L	Parting
S4L	Virgin
S2T	Lower quality roof
S2S	Previously Mined / Planned Select
P1	Parting
S1	Mined in places

e.g. 



- Removal of soft ≈ 10 m – Sequence that make sense (e.g. for about 2 strips)
- Drilling and blasting of the hard overburden
- Removal of 5 seam
- Benches to be left – Size to make sense
- Take into consideration the S4S and S2S was mined previously therefore buffer blasting should be done with cladding (≈ 60°). This would influence the sizes of the benches as you would need to have enough space left in the pit.
- Sinkhole formation to be assessed

[25)

QUESTION 3

3.1. Assume a 6.2m coal seam at a depth of 82m. It is intended to mine the total seam height in two steps. The primary extraction is at a 4m mining height to the true floor. In the second operation the rest of the seam is taken to the true roof. A final safety factor of 1.40 is decided on at a bord width of 6m. (Salamon and Munroe formula is used)

Find the initial and final volumetric extraction and equivalent working height.

- *State formula used – with CM adjustment or not.*

The pillars are designed for the final geometry:

W=12.2m (H=88.2m; h=6.2m; B=6m; and SF=1.4)

After the primary extraction the following parameters apply:

H=88.2m; h=4m; w=12.2m; B=6m.

On the basis of case 1, the safety factor is found to be S=1.83 which is considered high enough to prevent pillar run.

The areal extraction therefore is:

ea=1-(w/((w+B)))2=55.07%

This is also the final volumetric extraction.

The equivalent working heights after the primary and sec¬ondary extraction are h=2.20 m and 3.41 m respectively.

$V=he/h_s$

The volumetric extraction after primary extraction is 35.48 % (5)

Section	SF Calc S&M VdM FCT	C1	C2	Pillar Width (m) [Optional]	Mining Height (m)	Depth to Floor (m)	Bord Width (m)	Mining Method (DB or CM)	W:H	SF	PoS vdM 2013	Scaling Distance	PLI vdM 2013
3.1	S&M	18.0	18.0	12.0	6.2	82.0	6.0	db	1.9	1.46	98.95	3.69	815
3.1	S&M	18.0	18.0	12.0	4.0	82.0	6.0	db	3.0	1.95	100.00	4.89	9953
3.1	S&M	16.5	16.0	10.2	6.2	82.0	6.0	cm	1.6	1.40	96.03	2.52	172
3.1	S&M	16.5	16.0	10.2	4.0	82.0	6.0	cm	2.5	1.87	99.92	3.64	2970

3.2. There is a 3m thick coal seam at a roof depth of 153m. It is recommended to have 6.5m bords and 25m wide pillars.

- *State formula used – with CM adjustment or not.*
- *Calculate W:H ratio (>5)*
- *State the formula used (Squat or for what reason not)*

Formula in sheet is incorrect ($V^{0.0067}$ vs $V^{0.0667}$)

$$\sigma = \frac{.0786}{V^{0.0067}}\left\{R^{2.5} + 181.6\right\} \quad \text{vs} \quad \sigma = \frac{.0786}{V^{0.0667}}\left\{R^{2.5} + 181.6\right\}$$

3.2.1. Calculate the FOS for the following configuration and comment on the answer: (5)

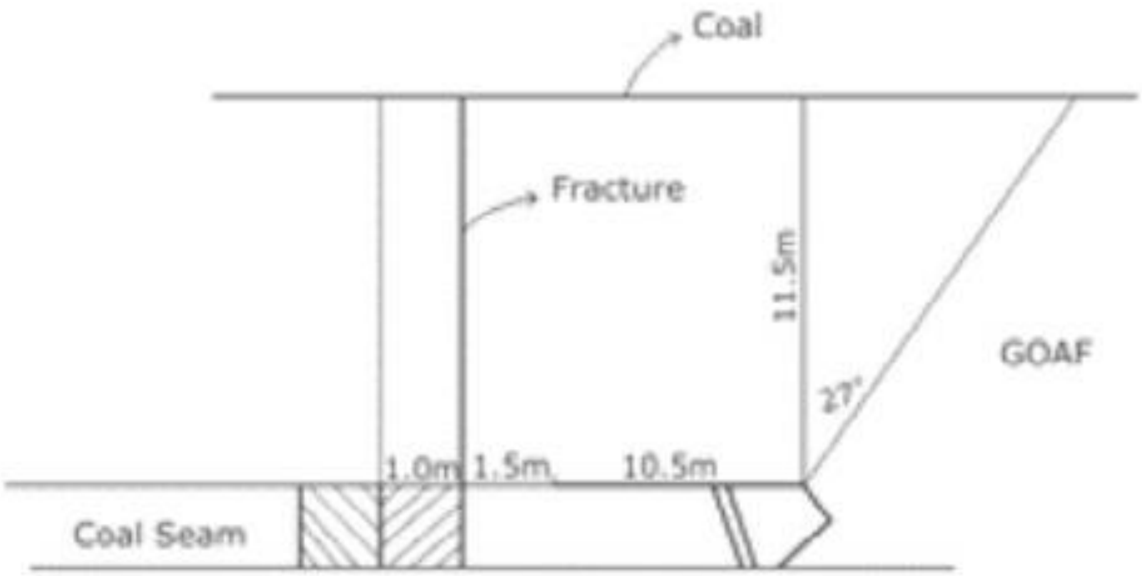
3.2.2. Calculate the pillar width to provide an FOS of 1.6. Maintain bord width of 6.5. Pillar stress

Section	SF Calc S&M VdM FCT	C1	C2	Pillar Width (m) [Optional]	Mining Height (m)	Depth to Floor (m)	Bord Width (m)	Mining Method (DB or CM)	W:H	SF	PoS vdM 2013	Scaling Distance	PLI vdM 2013
3.2.1 (Wrong formula)	Squat	31.5	31.5	25.0	3.0	153.0	6.5	db	8.3	4.70	100.00	13.05	1321745
3.2.1	Squat	31.5	31.5	25.0	3.0	153.0	6.5	db	8.3	2.99	100.00	13.05	1321745
3.2.2	Squat	23.0	22.0	16.0	3.0	153.0	6.5	db	5.2	1.65	100.00	6.59	81271
3.2.2	S&M	23.0	22.0	16.0	3.0	153.0	6.5	cm	5.2	1.80	100.00	6.59	81271
3.2.2	Squat	21.0	21.0	15.0	3.0	153.0	6.0	db	5.0	1.61	99.99	6.05	57555
3.2.2	S&M	21.0	21.0	15.0	3.0	153.0	6.0	cm	5.0	1.77	100.00	6.05	57555

(5)

3.3. Use diagram below and calculate the estimated load on the shield/m of face, immediately before and after the shearer has cut 1 web of coal. (5)

State all assumptions



Assumptions:

- *The supported block detaches from the coal stringer at 11.5m in the roof, and at a face fracture,*
- *The canopy is approximately 10.5m long,*
- *The canopy tip to face distance is 1.5m before cutting the web and 2.5m after.*

The support is holding up a trapezoidal block consisting of a rectangular and triangular portion. The mass of this block needs to be determined.

Volume of rectangular block = 1m x 11.5m x 12.0m = 138m3

Unknown distance of overhang of triangular block

11.5 x Tan 27° = 5.9m *11.5 x Tan 37° = 8.6 m*

Volume of triangular block = 1m x 0.5 x 11.5m X 5.9m = 33.9m3 *49.5*

Supports carrying (138 + 33.9)m3 x 2.5t/m3 = 429.75t

401kN/m

After cutting a 1m web of coal

Volume of rectangular block = 1m x 11.5m x 13.0m = 149.5m3

Supports now carry (149.5 + 33.9)m3 x 2.5t/m3 = 458.5t.

428.37kN/m **[20]**

QUESTION 4

4.1. Derive an expression for resin bond length in terms of hole diameter, tendon diameter, capsule length and capsule diameter. (5)

$$Area\ annullus = \frac{\pi D_h^2}{4} - \frac{\pi D_b^2}{4} = \frac{\pi}{4}(D_h^2 - D_b^2)$$

$$Volumn\ of\ Capsule = \frac{\pi\ D_c^2\ l_c}{4}$$

$$Bond\ length = \frac{Volume\ of\ Capsule}{Area\ Annullus} = \frac{\frac{\pi\ D_c^2\ l_c}{4}}{\frac{\pi\ (D_h^2 - D_b^2)}{4}} = \frac{D_c^2\ l_c}{(D_h^2 - D_b^2)}$$

4.2. Calculate the bond length for a 20 mm diameter rebar installed in a 25 mm diameter hole with one 600 mm long resin capsule with a 23 mm diameter. If reaming of the hole is 1,5 mm what is the loss of resin anchorage length? (5)

Dc	Dh	Db	lc		
23	25	20	600	1410.667	
23	26.5	20	600	1050.124	360.5426

4.3. If a 0,8 m thick mudstone needs to be suspended from a massive sandstone using the bolting system in (b) calculate the minimum bolting density. The contact shear strength of the resin/rock interface is 2 500 kPa and the density of the mudstone is 2 100kg/m3. (5)

Number of bolts = bolts/m2

Number of bolts = $\eta = \frac{SF\ \rho\ g\ t}{P_d} = \frac{1{,}5\ x\ 2100\ x\ 9{,}81\ x\ 0{,}8}{140000} = 0{,}17658$ *bolts/m*^{2}

1/η = Bolt/m2 = 5,663 m2, square root = density of 2,38 m spacing between bolts.

Or

weight of mudstone = density x gravity x thickness = 2100 x 9,81 x 0,8 = 16,48 kN/m2

$$Bond\ Strength = \frac{D_c^2\ l_c\ \tau\ \pi\ D_h}{D_h^2 - D_b^2} = \frac{(0{,}023^2\ x\ 0{,}6\ x\ 2500\ x\ 22\ x\ 0{,}025)}{(0{,}025^2 - 0{,}020^2)} = 277{,}16$$ kN/bolt

kN/bolt

or after applying a Safety Factor of 1,5 = 184,7 kN/bolt

weight of mudstone divided by Bond Strength = 16,48/184,7 = 0,0892 Bolt/m2

4.4. Calculate the bond strength if the hole is overdrilled by 100, 150 and 200 mm.

$$Bond\ Strength = \frac{D_c^2\ l_c\ \tau\ \pi\ D_h}{D_h^2 - D_b^2}$$

D_c	D_h	D_b	l_c	Overdrill	Volume (overdrill)	Volume Resin	Volume resin remain	L_c (new)	Bond strength
23	25	20	600	0	0.00	249385.71	249385.71	600.00	277.10
23	25	20	600	100	49107.14	249385.71	200278.57	481.85	222.53
23	25	20	600	150	82765.18	249385.71	166620.54	400.87	146.09
23	25	20	600	200	98214.29	249385.71	151171.43	363.71	167.97

(5)

[20]

[100]

Equation Sheet

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

Pillars

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

$$\sigma = 5.47\frac{w^{0{,}8}}{h}$$

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

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

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

$$\sigma = \frac{.0786}{V^{0.0667}}\left\{R^{2.5} + 181.6\right\}$$

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

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

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

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

$$Load = \frac{\left[.025(H - T) + .03T\right]C_1C_2}{w_1w_2}$$

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

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

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

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

$$S_{\min} = 0.4$$

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

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

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

$$q = \rho g(t_{s} + t_{w})$$

$$\sigma_{t} = \frac{fq_{c}s^{2}}{2t^{2}}$$

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

$$q_{c} = q_{l} + \frac{q_{u}E_{l} - q_{l}E_{u}}{E_{l} + E_{u}}$$

$$l_{a} = \frac{\rho g s^{2} t_{w}}{\tau_{c}\pi d_{h}} + .05$$

$$\eta = \frac{SF\rho g t}{P_{d}}$$

$$\sigma_{ts} = \frac{4W_{b}}{\pi d_{b}^{2}}$$

$$l_{c} = \frac{l_{a}\left(d_{h}^{2} - d_{b}^{2}\right)}{\left(d_{h} - .002\right)}$$

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

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

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

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

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

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

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

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

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

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

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

$$S = t_l d\theta$$

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

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

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

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

Subsidence

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

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

$$h_e = he$$

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

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

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

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

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

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

$$T_m = 21.6S_m + 7$$

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

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

Physics

$$E_k = \frac{1}{2}mv^2$$

$$v_i = \sqrt{2gd}$$