Project Report: Sillmat design

M.Eng in Engineering Science

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EXECUTIVE SUMMARY

The effective and secure extraction of ore from zones with steep dips presents considerable challenges in the field of mining engineering. The crucial component of mine backfill design—more especially, the engineering of sillmats in underground mining operations—is the subject of our group project for these course. The research aims to maximize both cost and safety by investigating the application of consolidated backfill as a structural support in the mining of moderately wide ore zones that drop sharply.

Here, the term "sillmats" refers to more than just cement backfill; it also refers to the stope that contains the full column of cement paste backfill, which is vulnerable to undermining from mining operations. A number of complicated variables combine to determine the stability of these sillmats, such as the amount of binding agent and the natural characteristics of the backfill material—whether it be hydraulic, slurry paste, high-density backfills, or rockfill.

Our study explores both established and emerging approaches to the stability design of cemented backfills. Our thorough investigation includes the usage of tailing materials for backfilling and the economic factors in binder selection.

Enhancing the stability and integrity of mining operations, this project aims to create safe, affordable, and efficient backfill solutions. Our objective is to provide significant contributions to the field of mining engineering, specifically with difficult ore extraction conditions, by means of a thorough examination of laboratory experiments, stability design, and economic impact.

The paper examines conventional and new stability design methodologies while taking economic considerations into account and analyzing different backfill materials and binding agents. To improve mining operation stability in difficult ore extraction conditions, the objective is to build secure, affordable backfill systems. The discipline of mining engineering benefits greatly from insights gained from laboratory experiments.

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1. Introduction – Project Overview:

Goal and Purpose: It focuses on the use of consolidated (cemented) backfill for structural support, favoring low cement content to decrease costs while preserving safety and efficiency. The project's major goal is to improve the design of mine backfills used in steeply dipping ore zones. Creating and evaluating stronger sillmats to support the backfill takes up a large portion of the project.

An Overview and importance: The potential for fill mass failure, financial losses, and safety risks are some of the particular difficulties faced by miners in steeply dipping ore zones. The initiative aims to create more stable, economical, and safe mining operations by addressing these issues through innovation in backfill design.

Procedure: The project encompasses a combination of theoretical and practical methodologies, encompassing laboratory studies and the utilization of analytical and numerical models. A thorough examination of the many kinds of backfills, including hydraulic, slurry paste, high-density, and rockfill, is included. The study also looks at the backfill design's economics, with a focus on binding agent selection.

Important Problems and Their Fixes: The project offers creative designs and materials for sillmats that can provide sufficient support with less cement content. Ensuring the stability of the backfill while undercutting in mining operations is one of the main concerns.

Impact and anticipated Results: The project is anticipated to provide the mining sector with important insights and workable solutions, especially in the area of recovering ore from difficult areas. Its goal is to produce an optimized design for mine backfills that balances cost, safety, and efficiency. As a result of the findings, mining operations may adopt more environmentally friendly procedures.

This endeavor underscores the significance of innovation in conventional mining methods, linking it to the wider framework of sustainable mining practices.

2. Laboratory Investigation:

1) A number of physical and mechanical characteristics of the paste backfill and the tailings material itself must be identified in order to evaluate the stability of cemented paste backfill in mining operations. The main characteristics are outlined below:

Physical Properties of Tailings Materials: Backfill's composition is made up of solid particles combined with air or water that are trapped in the pores or empty spaces between the solid particles. Saturation and Water Content: In situ, the moisture content of paste and slurry fill materials can vary from 15% to 22%. Void Ratio: Slurry backfills usually have porosity values between 0.42 and 0.48 and voided ratios between 0.25 and 0.75. Specific Gravity, Bulk Density, and Unit Weight: The majority of cemented backfill materials have a specific gravity of 2.6 to 4.0. Particle Friction and Cohesion: By using physical bonds to hold solid particles together, binders like cement improve fill cohesion. The concepts of permeability and percolation rate are crucial in order to guarantee proper drainage and reduce the likelihood of fill liquefaction. The significance of particle size in percolation is demonstrated by the significantly reduced percolation rates of categorized and de-slimed tails compared to the arbitrary rate of 10 cm/h.

Mechanical Properties of Cemented Paste Backfill: Through these tests, the backfill's unconfined compressive strength (UCS), Poisson's ratio (v), and Young's modulus (E) are ascertained. The water-to-solids ratio, particle size distribution, type, combination, and cure time of the binder are some of the elements that affect the UCS of cemented backfill. The stability of the backfill in both analytical and numerical models is largely dependent on shear strength factors. The pore pressure response behavior and stress-strain behavior during undrained shear can be established with the help of these tests. These experiments also show how liquefaction-prone the backfill is, which is a crucial factor to take into account while mining near the backfill. When the structural integrity of the cemented paste backfill is crucial, it is essential to comprehend these mechanical qualities in order to guarantee the stability and safety of mining activities.

2)a. Tailings Characterization: This involves assessing any unused material that is normally meant for surface impoundment or disposal, as well as determining the availability of tailings as a source for backfilling. A number of aspects need to be considered when determining whether tailings are suitable for backfill application, including porosity characteristics and possible process chemical agent contamination.

The Assessment of Particle Shape Distribution in Tailings: This test seeks to identify the tailings' particle size classification, or more specifically, the distribution of different particle sizes within the constituent material. Because some size distributions may be too coarse or too fine for the planned fill operation, it is important to understand how tailings behave as a backfill material.

b. Standard Static Model Testing:

The following tests must be conducted in order to meet the requirements of the cemented paste backfill formulas listed in Table 1:

The ratio (w/c) of water to cement: In a mixture, it is a measurement of the proportion of water to cement. It is essential to do research to ascertain the ideal amount of water to mix with the cement, as the strength and durability of the backfill depend on this ratio. Stronger and longer-lasting backfill is the outcome of a lower water-to-cement ratio (w/c).

Equipment that will be used: Instruments such as sieves and laser-diffraction particle size analyzers can be used for particle size distribution analysis. Triaxial test equipment for triaxial strength testing and hydraulic presses for measuring uniaxial compressive strength are required for strength analysis.

An evaluation of strength: Static model tests are a common way to determine the strength properties of the backfill and evaluate its mechanical attributes. The assessment of the backfill's strength under different stress scenarios may entail the execution of triaxial and uniaxial compressive strength tests.

3. Stability Analysis Using Analytical Modeling:

Answer 3.1:

Backfill sillmat stability analysis: Below we will show the backfill sillmat stability analysis calculation for binder content.

For Sample 1: According to table 2 and 3, sillmat thickness is 3m and binder content is 3%.

Here, Stope width = 3m

Stope length = 15m

Stope height = 30m

Sillmat thickness = 3m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	3	3	27	3	515.16		572.25	280.31	209.09
Length	15			7		57.09		522.16	217.06
Height	30								

Now, we shown below the calculation of (FS)

FS for Smooth boundaries:

a. Slippage failure:

Slippage failure is estimated to occur when the vertical stress due to loading above the sillmat plus the product of sillmat thickness and unit weight of the cemented sillmat is greater than twice the shear strength in the fill rock wall contact zone times the sine square of the stope or hanging wall/footwall dip angle.

We know,

$$(\sigma_v + d\gamma) \geq 2\left(\frac{\tau_f}{\sin^2(\beta)}\right)\left(\frac{d}{L}\right)$$

$\sigma_v \ = \ vertical\ stress\ due\ to\ loading\ above\ sillmat\ (kPa)$

d = silimat thickness

γ = unit weight of the cemented sillmat(kN/m3)

$\tau_f \ = \ shear\ strength\ in\ the\ fill\ rock\ wall\ contact\ zone\ (kPa)$

β = stope or hanging wall/footwall dip (degrees)

L = stope or sill width (HW to FW distance) (m)

After calculation, we find out

Fs = 1.60

FS for Rough boundaries:

$$(\sigma_v + d\gamma) \geq 2\left(\frac{\tau_f}{\sin^2(\beta)}\right)\left(\frac{d}{L}\right)$$

$\sigma_v \ = \ vertical\ stress\ due\ to\ loading\ above\ sillmat\ (kPa)$

d = silimat thickness

γ = unit weight of the cemented sillmat(kN/m3)

$\tau_f \ = \ shear\ strength\ in\ the\ fill\ rock\ wall\ contact\ zone\ (kPa)$

β = stope or hanging wall/footwall dip (degrees)

L = stope or sill width (HW to FW distance) (m)

After calculation, we find out

Fs = 3.01

FS for Caving Failure:

Caving failure: Caving failure is assumed to extend to a stable arch of height half the sill width (L/2), where L is the sill width. All unreinforced sills should be designed with a thickness greater than half the sill width, and caving would develop when the product of sill width and unit weight of the cemented sillmat is greater than eight times the tensile strength of the cemented sillmat times pi.

Here,

L= stope width

γ=unit width

σ_t= tensile strength

We know that,

$$FS_{\text{caving}} = \frac{(L\gamma)}{\left(8 \cdot \frac{\sigma_t}{\pi}\right)}$$

$$= \mathbf{6.61}$$

FS for Rotational Failure:

Rotational failure: Rotational failure develops when the shearing resistance in the hanging wall contact is low due to a low dip angle allowing separation in the contact and some allowance for a potential increased vertical stress on the hanging wall side.

$$(\boldsymbol{\sigma_v} + \boldsymbol{\gamma d}) > \frac{\boldsymbol{\sigma_t d^2}}{\boldsymbol{2L(L - d\cot\beta)\sin^2\beta}}$$

We found out, **Fs = 0.19**

FS for Flexural Failure:

Flexural failure: Flexural failure is predicted when the square of the ratio of sill width to sillmat thickness is greater than twice the sum of tensile strength and cemented sillmat compressive strength times the sum of vertical stress due to loading above the sillmat and the product of sillmat thickness and unit weight of the cemented sillmat.

$$\left(\frac{L}{d}\right)^2 > 2\,\frac{(\sigma_t + \sigma_c)}{(\sigma_v + d\gamma)}$$

We find out, **FS= 4.43**

Overall, Factor of safety (FS) for paste backfill sillmat is affected by boundary conditions (rough/smooth), thickness (1-2 times stope width), and lateral closure stress. Flexural, rotational, caving, and sliding failures were identified by FS**.** Now, we analyze these failures to see which one is stable or not.

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
1.6	3.01	6.61	0.19	4.83
stable	Stable	stable	unstable	Stable

For Sample 2: According to table 2 and 3, sillmat thickness is 6m and binder content is 3%.

Given, Stope width = 3m

Stope length = 15m

Stope height = 30m

Sillmat thickness = 6m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	3	6	24	3	457.92		572.10	280.31	209.09
Length	15			7		114.18		522.16	217.06
Height	30								

Now, analyzing the factor of safety below.

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
3.19	6.01	6.61	1.20	19.34
stable	Stable	stable	stable	Stable

For Sample 3: According to table 2 and 3, sillmat thickness is 7.5m and binder content is 3%.

Here, Stope width = 7.5m

Stope length = 15m

Stope height = 40m

Sillmat thickness = 7.5m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	7.5	7.5	32.5	3	620.1		762.83	280.31	209.09
Length	15			7		142.725		522.16	217.06
Height	40								

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
1.2	2.26	2.64	0.14	3.63
stable	Stable	stable	Unstable	Stable

For Sample 4: According to table 2 and 3, sillmat thickness is 15m and binder content is 3%.

Here, Stope width = 7.5m

Stope length = 15m

Stope height = 40m

Sillmat thickness = 15m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	7.5	15	25	3	477		762.45	280.31	209.09
Length	15			7		285.45		522.16	217.06
Height	40								

Factor of safety:

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
2.4	4.51	2.64	0.90	14.51
stable	Stable	stable	Unstable	Stable

For Sample 5: According to table 2 and 3, sillmat thickness is 3m and binder content is 2.5%.

Given, Stope width = 3m

Stope length = 15m

Stope height = 30m

Sillmat thickness = 3m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	3	3	27	2.5	512.46		569.55	216.78	177.83
Length	15			7		57.09		522.16	217.06
Height	30								

Factor of safety:

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
1.46	2.78	6.61	0.19	4.86
stable	Stable	stable	Unstable	Stable

For Sample 6: According to table 2 and 3, sillmat thickness is 6m and binder content is 2.5%.

Given, Stope width = 3m
Stope length = 15m
Stope height = 30m
Sillmat thickness = 6m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	3	6	24	2.5	455.52		569.70	216.78	177.83
Length	15			7		114.18		522.16	217.06
Height	30								

Factor of safety:

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
2.93	5.56	6.61	1.2	19.42
stable	Stable	stable	stable	Stable

For Sample 7: According to table 2 and 3, sillmat thickness is 7.5m and binder content is 2.5%.

Given, Stope width = 7.5m
Stope length = 15m
Stope height = 40m
Sillmat thickness = 7.5m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	7.5	7.5	32.5	2.5	616.85		759.58	216.78	171.83
Length	15			7		142.725		522.16	217.06
Height	40								

Factor of safety:

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
1.10	2.09	2.64	0.14	3.64
stable	Stable	stable	unstable	Stable

For Sample 8: According to table 2 and 3, sillmat thickness is 15m and binder content is 2.5%.

Given, Stope width = 7.5m
Stope length = 15m
Stope height = 40m
Sillmat thickness = 15m

	Stope Size (m)	Silimat Height (m)	Cement content overlying fill height	Binder Content	Parameters				
					Surcharge Stress (kPa)	Silimat self weight (kPa)	Fill/sill self weight (kPa)	Shear Strength at 310kPa	
								Rough Condition	Smooth Condition
Width	7.5	15	25	2.5	474.5		759.95	216.78	171.83
Length	15			7		285.45		522.16	217.06
Height	40								

Factor of safety:

Slip Failure		Caving Failure	Rotational Failure	Flexural Failure
Smooth	Rough			
2.19	4.17	2.64	0.90	14.56
stable	Stable	stable	unstable	Stable

Answer 3.2

Samples 2 and 6 exhibit stable designs, according to the calculations.

1. For sample 2 (sillmat thickness = 6 m)
2. For sample 6 (sillmat thickness = 6 m)

Cost Analysis for sample 2: The only samples where the design complies with the specifications stated in the statement, Factor of Security > 1, are samples 2 and 6, so they are the ones where the economic analysis is performed.

NPC T-10:

Sillmat	Backfill
Volume = 6 x 3 x 15 = 270 m3 Weight = 270 x 19.03 =5138 KN =523.93t Weight-cement = 523.93 x 7% = 36.68 t $-cement = 36.68 t x 200 $/t = $ 7335.02	Volume =24 x 3 x 15 = 1080 m3 Weight = 1080 x 19.08 = 20606.4 kN = 2101.26t Weight-cement = 2101.26 x 3% = 63.03 t $-cement = 63.03 t x 200 $/t = $ 12607.56

Total (NPC T-10) = 7335.02 + 12607.56 = $19,942.58

TC-FA:

Sillmat	Backfill
Volume = 6 x 3 x 15 = 270 m3 Weight = 270 x 19.03 =5138 KN =523.93t Weight-cement = 523.93 x 7% = 36.68 t $-cement = 36.68 t x 100 $/t = $ 3668.0	Volume =24 x 3 x 15 = 1080 m3 Weight = 1080 x 19.08 = 20606.4 kN = 2101.26t Weight-cement = 2101.26 x 3% = 63.03 t $-cement = 63.03 t x 100 $/t = $ 6303.00

Total (TC-FA) = 3668.00 + 6303.00 = $9,971.00

The difference in cost = Total (NPC T-10) - Total (TC-FA) = $19,942.58 - $9,971.00 = $9,971.58

Cost Analysis for sample 6

NPC T-10:

Sillmat	Backfill
Volume = 6 x 3 x 15 = 270 m3 Weight = 270 x 19.03 =5138 KN =523.93t Weight-cement = 523.93 x 7% = 36.68 t $-cement = 36.68 t x 200 $/t = $ 7335.02	Volume =24 x 3 x 15 = 1080 m3 Weight = 1080 x 18.98 = 20498.4 kN = 2090.25t Weight-cement = 2090.25 x 2.5% = 52.25 t $-cement = 52.25 t x 200 $/t = $ 10450.00

Total (NPC T-10) = 7335.02 + 10450.00 = $17,785.02

TC-FA:

Sillmat	Backfill
Volume = 6 x 3 x 15 = 270 m3 Weight = 270 x 19.03 =5138 KN =523.93t Weight-cement = 523.93 x 7% = 36.68 t $-cement = 36.68 t x 100 $/t = $ 3668.0	Volume =24 x 3 x 15 = 1080 m3 Weight = 1080 x 18.98 = 20498.4 kN = 2090.25t Weight-cement = 2090.25 x 2.5% = 52.25 t $-cement = 52.25 t x 100 $/t = $ 5225.00

Total (TC-FA) = 3,668.00 + 5,225.00 = $8,893.00

The difference in cost = Total (NPC T-10) - Total (TC-FA) = $17,785.02 - $8,893.00 = $8,892.02

4. Summary and conclusions

In the design exploration project, eight different scenarios were rigorously analyzed for stability concerns. The primary focus was on ensuring that the designs met the minimum safety factor (FS) required for reliable and confident construction. A significant issue identified was the variability in the safety factor for rotational failure, highlighting the need for specific attention to this type of failure during the design phase.

Despite the majority of designs not meeting the required safety factor, scenarios 2 and 6 emerged as promising exceptions. They exceeded the critical safety factor threshold of 1, indicating their potential viability. These scenarios assure technical feasibility and the ability to withstand the anticipated loads and stresses, aligning with engineering best practices and safety protocols.

Particularly notable was Scenario 6, which stood out as the most economically advantageous option. It required a lower quantity of binder, a major cost factor in construction projects. The cost analysis revealed significant savings with this design: NPC T-10 priced at \$17,785.02 and TC-FA at \$8,893.00. This scenario, therefore, represented a balance of economic efficiency and technical viability, making it a strong candidate for final selection.

This project highlights the importance of a dual-focused approach in engineering design, where stability and cost considerations are equally prioritized. It demonstrates the necessity of meticulously evaluating various options to direct resources effectively toward the most feasible and economical designs. This approach not only ensures the safety and structural integrity of the constructions but also positions them as financially sound investments. By optimizing for both safety and cost-effectiveness, the project aims to enhance the overall success and sustainability of construction and engineering endeavors.