Project Report: A new design approach for mine haul road pavements with stabilized layers

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Executive Summary

The overall objective of the proposed research was to develop a new design approach for mine haul road pavements with stabilized layers. To achieve the proposed research, 2D and 3D Finite Element Models (FEM) were first developed and validated. Then, the validated model was used to investigate the effects of stabilization on the strain and deflection of mine haul roads and rural municipal roads. It was found that stabilization reduces the strain and deflection of roads, herein enhancing the performance. Furthermore, the modelling results indicate that stabilization of lower layers was more effective than that of the surface layer in reducing the strain and deflection. After that, a new design approach was developed based on the theories of elasticity and critical strain limit (CSL) to improve the existing CBR design method. The proposed design method was verified through numerical modelling using the validated FEM model. The results have shown that the proposed design method performed better than the existing CBR design method, especially for roads for ultra-large trucks. Also, it was observed that the design thickness could be reduced if the road is stabilized. Lastly, a 3D tire model of off-the-road trucks was established and assembled with the pavement model for the estimation of the rolling resistance. The results from numerical models suggest that the stiffness change due to road stabilization can noticeably reduce the rolling resistance and fuel consumption.

Despite these findings, the current study has its limitations that need continued investigation. Our 2D model observed that a large portion of rolling resistance could be attributed to road roughness, suggesting that the surface roughness should be included in the effects of stabilization on rolling resistance. To further the investigation, experimental work should be carried out to quantify the effects of stabilization on the change in properties of mine haul roads, and incorporated into the numerical models.

1. Background

In mining operations, the mine haul road is a critical component for bulk materials handling (ore and waste). Its structural design directly affects energy consumption, operating costs, and ore productivity. Currently, the design method of haul road structures can be classified into three major categories: 1) the CBR (California Bearing Ratio) design method, 2) the mechanistic design method, and 3) the finite element method (FEM).

With more frequent use of stabilization in haul road construction, how stabilization affects the structural design of haul roads, yet remains unknown. In addition, according to the literature review, none of the current methods have addressed the rolling resistance in pavement design, particularly when the haul road is stabilized. Rolling resistance is a critical aspect of haul road design because a small variation in rolling resistance can cause a substantial change in energy consumption and mine productivity during truck haulage. Therefore, the current design approaches need to be further investigated to explore the effects of stabilization on haul road design regarding mechanical responses and rolling resistance.

To this end, the overall objective of this research is to develop a novel numerical design approach for mine haul road pavements with stabilized layers. In particular, the prediction of rolling resistance will be addressed in this new design approach.

2. Research Objectives

The overall objective of this research is to develop a novel numerical design approach for mine haul road pavements with stabilized layers. Two sub-objectives have been identified to achieve the proposed research:

1) develop FEM models of pavements with a stabilized layer; and
2) numerical modeling for the prediction of rolling resistance.

To achieve the proposed research objectives, five tasks associated with the proposed objectives have been identified, as listed in the following.

1) Development and validation of pavement models
2) Modelling of pavement response after stabilization—mine haul roads
3) Modelling of pavement response after stabilization—municipal roads

4) Development of a new CBR design method
5) Modelling of rolling resistance

3. Methodology

In this research, the primary tool for numerical modeling was the FEM software package ABAQUS of Dassault Systems. ABAQUS is a powerful general-purpose finite element simulation program that can solve a broad range of linear and non-linear problems. As shown in Figure 1, a FEM model was first developed and validated based on data obtained from the literature. Then, this validated FEM model was used in Tasks 2-5. First, the validated model was used to investigate the effects of stabilization on pavement response (e.g., strain and deflection) of mine haul roads and rural municipal roads (Tasks 2 and 3). Second, a new design approach was developed based on the theories of elasticity and critical strain limit (CSL) to improve the existing CBR design method (Task 4). The proposed design method was verified through numerical modelling using the validated FEM model. After verification, the proposed design method was used to examine the effects of stabilization on the structural design of mine haul roads. Lastly, the validated pavement model was assembled with a tire model to estimate the rolling resistance and explore the effects of stabilization on rolling resistance (Task 5).

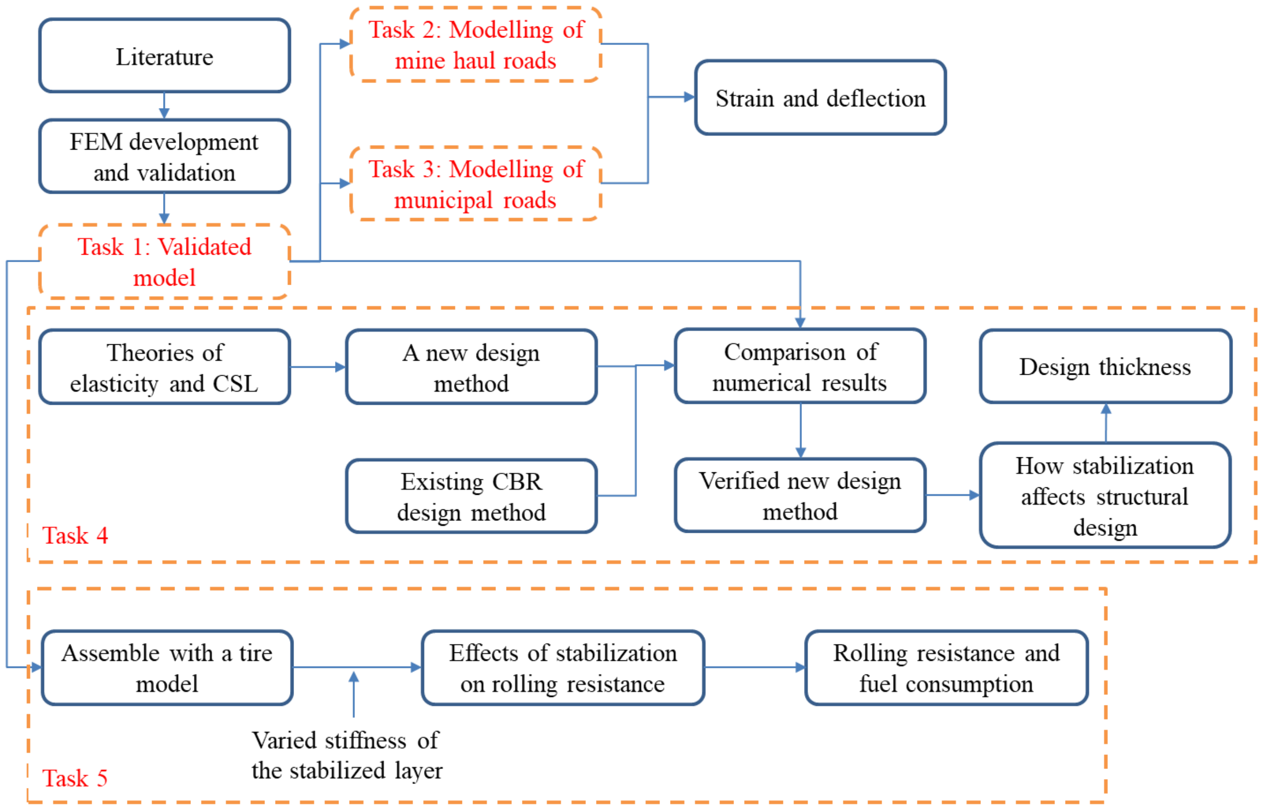

Figure 1. A flowchart of the overall methodology

4. A Summary of Results

4.1. Mechanical Responses of Pavements with Stabilized Layers

4.1.1. Development and Validation of Pavement Models

In this study, data was obtained from the literature for model development and validation (see Table 1 and Table 2). An ABAQUS model was first developed based on the study by Coffey (Coffey, 2015). The FEM model is shown in Figure 2. The interaction between the wheels of a truck and the pavement was simplified as static loads were applied to the pavement surface. A sensitivity analysis suggests that the number of wheels does not noticeably affect the strain distribution in the pavement. Therefore, only one load was applied to the pavement surface to simplify the model.

Table 1. Truck specifications in Coffey's study

Truck type	Tire type	Tire pressure, KPa	Payload, t	GVWR, t	Wheel load, t
Komatsu 830E	50/80 R57	758	227	408	68

Table 2. Thickness and modulus of the pavement in Coffey's study

Pavement layer	Thickness, m	Modulus, MPa
Base 1	2	393
Subgrade 1	2	304
Subgrade 2	3	310
Subgrade 3	6	341
Subgrade 4	7	420

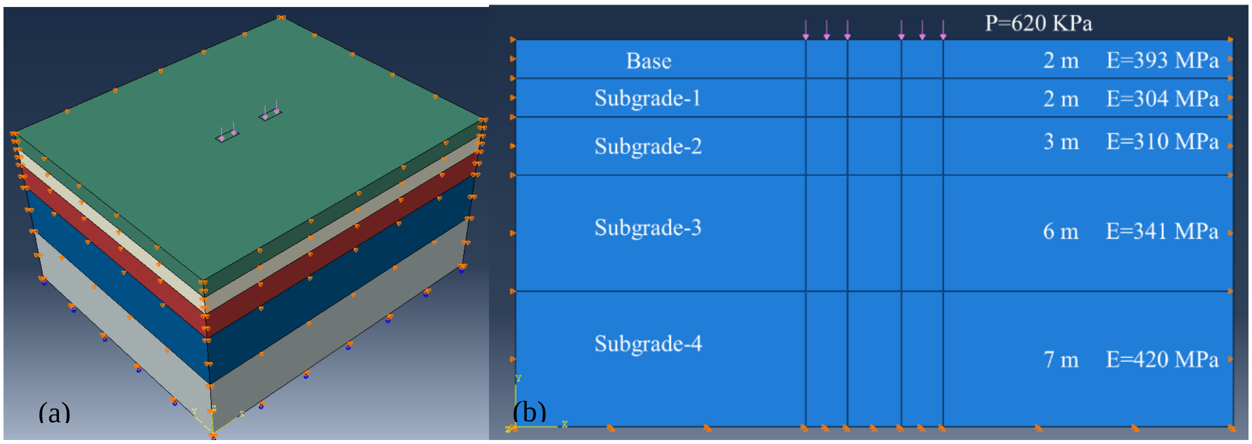

Figure 2. 3D model of the pavement under static load: (a) 3D view; (b) 2D view

To verify the ABAQUS model, a pavement model was established using a different software, COMSOL Multiphysics. The results (e.g., strain and deflection) are listed in Table 3. It was concluded that the developed ABAQUS model led to similar results as those from COMSOL Multiphysics, indicating that the ABAQUS model was correctly developed.

For validation of the model, the deflections in the pavement from the ABAQUS model were compared with those from the measured values in Coffey's study. As shown in Table 3, the surface deflection from our numerical model was similar to that from Coffey's study, suggesting a high accuracy of the developed numerical model (model validated).

Table 3. Modelling results—surface deflection

Payload, t	Wheel load, KPa	Deflection, mm		
		Coffey's study	ABAQUS model	COMSOL model
0	311	1.4	1.76	1.69
220	620	2.4	2.52	2.4

4.1.2. Numerical Investigation of Mine Haul Roads with Stabilization

Using the validated ABAQUS 3D model, a study was carried out to investigate the effects of layer stabilization on pavement strain and deflection. Mine haul roads normally consist of three layers above the in-situ subgrade layer: sub-base, base, and surface course. It is assumed that all pavement layers can be stabilized, and the stabilization of pavement layers would only increase their elastic modulus. In total, four models were established for different cases: a reference case without stabilization, a case with a stabilized surface layer, a case with a stabilized base layer and a case with a stabilized sub-base layer. Table 4 shows the model setup for the four cases. The modelling results are demonstrated in Figure 3 and Figure 4. It was found in Figure 3 that the stabilization of road layers was able to reduce the max strain in the pavements. For example, the stabilization of the surface layer reduced max strain from 1644 micron (reference case) to 1547 micron. In addition, the strain distribution in Figure 4 suggests that the stabilization of lower layers (e.g., base and sub-base) showed more significant influences on the strain distribution in the pavement; the strain curve showed a larger amount of offset from that of the reference case. This suggests that the stabilization of lower layers was more effective than that of the surface layer in reducing the design thickness.

Table 4. Model setup

Layer	**CBR, %**			
	Ref	**Surface stabilized**	**Base stabilized**	**Sub-base stabilized**
Wearing course	100	120	100	100
Base course	60	60	75	60
Sub-base	15	15	15	30
Sub-grade	5	5	5	5

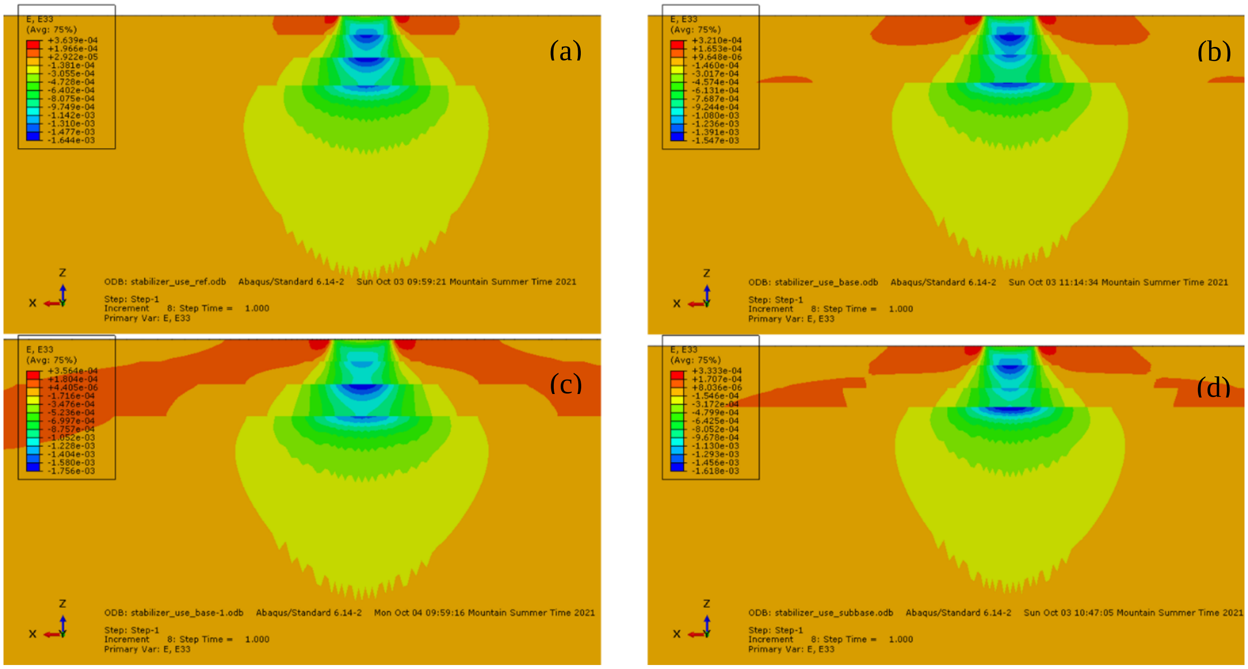

Figure 3. Strain distribution with varied stabilization layer: (a) Reference; (b) Surface stabilized; (c) Base stabilized; (d) Sub-base stabilized

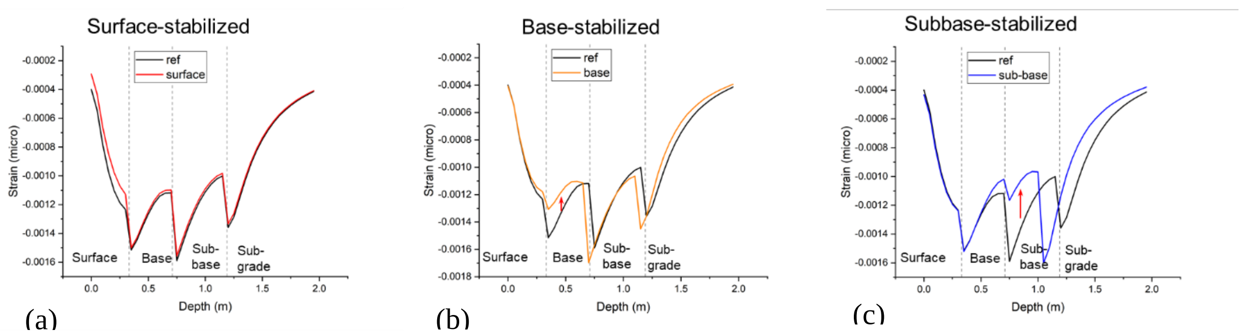

Figure 4. Strain with depth—varied stabilization layer: (a) Surface stabilized; (b) Base stabilized; (c) Sub-base stabilized

4.1.3. Numerical Investigation of Rural Municipal Roads with Stabilization

Then, the validated numerical model was further used to examine the effects of stabilization on rural municipal roads around the city of Brandon, MB (see Table 5) (Cram, 2020; Gaboury, 2016). Municipal roads include two construction layers: A-Base (surface layer) and C-Base (base layer). For each road, two models were established, one with stabilized surface and one without surface stabilization. An example of strain and deflection distribution was shown in Figure 5 for the

Pioneer Road; both the max strain and strain distribution were reduced when the surface layer was stabilized. The modelling results are summarized in Table 6. It was found that the stabilization was able to significantly reduce the max strain and surface deflection in the pavement; the max strain was reduced by as high as 14.5%, while the largest decrease of surface deflection was 4.21%, indicating significant improvement in pavement performance after stabilization.

Table 5. A summary of examined municipal roads

Project No.	Location	Original CBR, %	Stabilized CBR, %	Stabilized thickness, m
1	Lori Road	25.88	39.2	0.15
2	Patricia Ave	49.83	219.03	0.15
3	Pioneer Road	37.85	76.79	0.15
4	Curries Landing Road	37.85	70.86	0.2
5	Baker Road	37.85	106.18	0.15

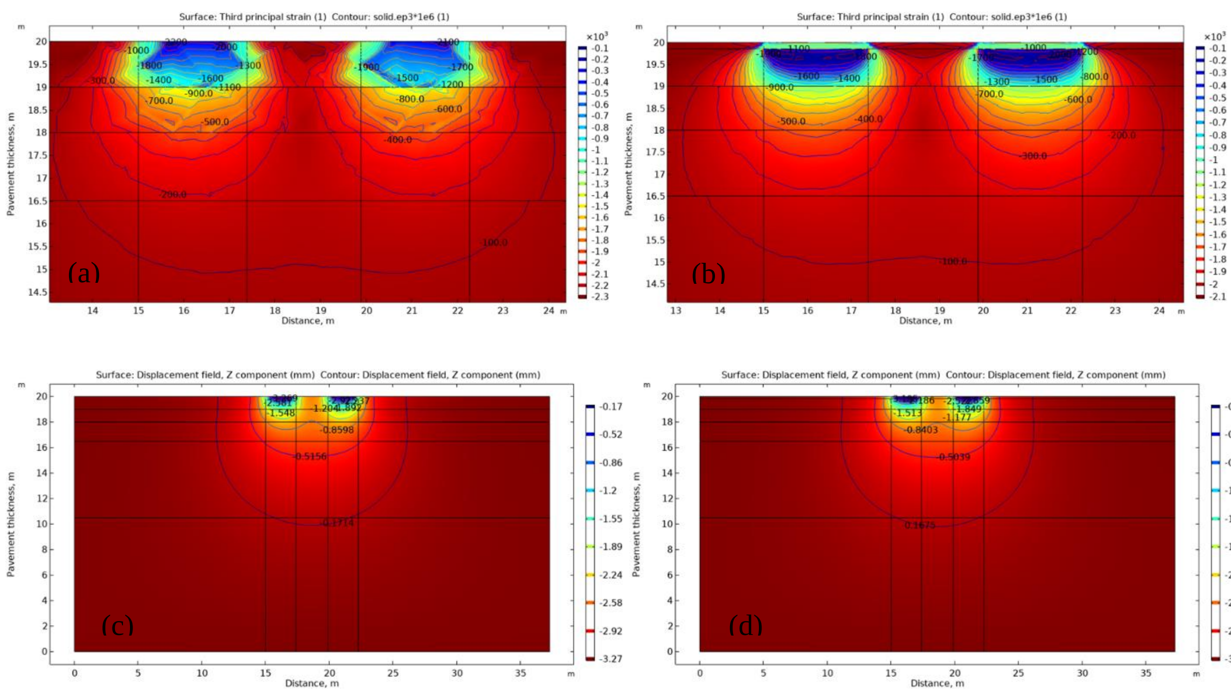

Figure 5. Strain and deflection distributions before and after stabilization (Pioneer Road): (a) strain before stabilization; (b) strain after stabilization; (c) deflection before stabilization; (d) deflection after stabilization.

Table 6. A summary of modelling results

Project No.	Location	Strain, micro		Reduction, %	Deflection, mm		Reduction, %
		Before stabilization	After stabilization		Before stabilization	After stabilization	
1	Lori Road	3040	2600	14.47	3.996	3.9	2.40
2	Patricia Ave	1850	1680	9.19	3.09	2.96	4.21
3	Pioneer Road	2300	2050	10.87	3.44	3.36	2.32
4	Curries Landing Road	2300	2060	10.43	3.44	3.34	2.91
5	Baker Road	2300	2050	10.87	3.44	3.33	3.220

A municipal road normally consists of two construction layers: the surface layer and the base layer. In order to investigate how stabilization affects pavement design, a series of models were established to simulate two cases (see Table 7 and Table 8). In the first case, the surface layer is stabilized, while in the second case, the base layer is stabilized. For comparison, a reference model without stabilization was generated for each case. Then, models with a stabilized layer were established. In these models with a stabilized layer, the thickness of the base layer varied from 0-0.9m. The modelling results are summarized in Table 9-10 and Figure 6-7. The reduced construction cost was also calculated according to an internal report (ENG-TECH Consulting Limited, 2020) by comparing the construction cost after stabilization with that of the reference model. In the case when the surface layer is stabilized (see Figure 6), the reference model had a max strain of 529.5 microns. After stabilization, the thickness of the base layer can be reduced from 0.8m to 0.33m, and the construction cost can be reduced by more than 40%. Similar findings can be found in the case when the base layer is stabilized. As shown in Figure 7 and Table 10, the stabilization of the base layer was able to reduce the thickness of the base layer from 0.9m to 0.69m, and the construction cost by ~20%.

Table 7. A summary of model setup (surface layer stabilized)

Layer	Thickness, m		Modulus, MPa	
	Reference	Stabilized	Reference	Stabilized
A_base	0.2	0.2	219	353
C_base	0.8	0-0.8	300	300
Subgrade	19	19	200	200

Table 8. A summary of model setup (base layer stabilized)

Layer	Thickness, m		Modulus, MPa	
	Reference	**Stabilized**	**Reference**	**Stabilized**
A_base	0.15	0.15	213.74	213.74
C_base	0.9	0-0.9	144.79	189.61
Subgrade	18.35	18.35	100	100

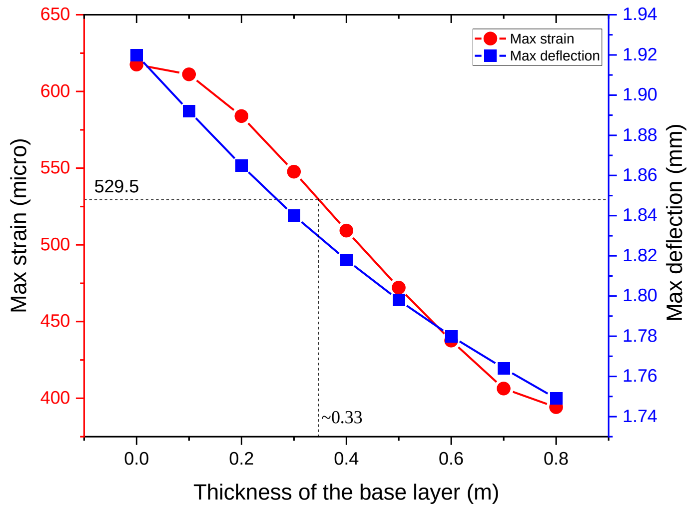

Figure 6. Max strain with the thickness of base layer (stabilized surface layer)

Table 9. Max strain and reduced cost (stabilized surface layer)

ID	Thickness of base layer, m	Strain, micro	Reduced cost	
			k$/km	**%**
Ref	0.8	529.5	/	/
C-0.7	0.7	406.3	32.56	8.14
C-0.6	0.6	437.6	72.56	18.14
C-0.5	0.5	472.1	112.56	28.14
C-0.4	0.4	509.3	152.56	38.14
C-0.3	0.3	547.7	192.56	48.14

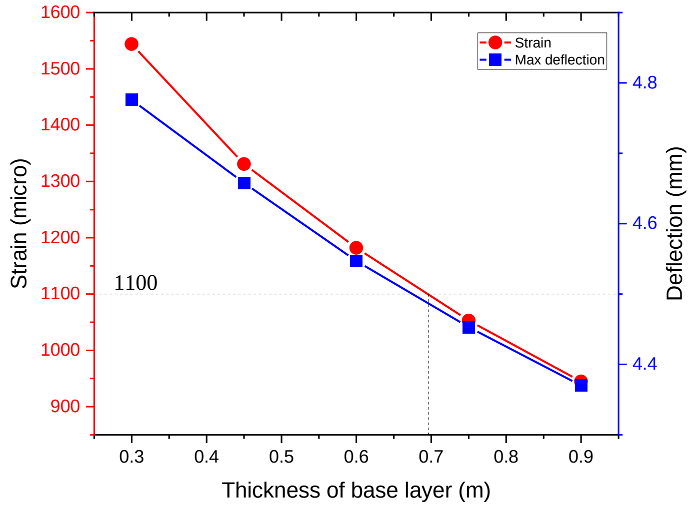

Figure 7. Max strain with the thickness of base layer (stabilized base layer)

Table 10. Max strain and reduced cost (stabilized base layer)

ID	Thickness of base layer, m	Strain, micro	Reduced cost	
			k$/km	%
reference	0.9	1100	420	/
C-0.9	0.9	944.7	453	-7.86
C-0.75	0.75	1053	388	7.62
C-0.6	0.6	1182	322	23.33
C-0.45	0.45	1331	257	38.81
C-0.3	0.3	1544	191	54.52

4.2. A New CBR Design Method for Mine Haul Roads

Our numerical studies suggest that the current CBR design method for mine haul roads can lead to under-designed results, especially for roads for ultra-large trucks. For example, Table 11 shows a structural design with the original CBR method for truck CAT797B with a gross vehicle mass of 624 t. To examine the design, a numerical model was established, and the max strain in the pavement obtained from the numerical model was compared with the critical strain limit (a strain exceeding which is considered structural failure, a typical value is 2000 micron). The strain distribution in the road designed by the CBR method is shown in Figure 8. It can be observed that the max strain in the road was 2137 microns, which exceeds the critical strain limit of 2000 microns, meaning an under-designed result.

Table 11. Structural design with original CBR method

Road layer	**CBR, %**	**Cover thickness, m**	**Layer thickness, m**
Wearing course	100	/	0.32
Base course	60	0.32	0.83
Sub-base	15	1.15	1.31
Sub-grade	5	2.46	/

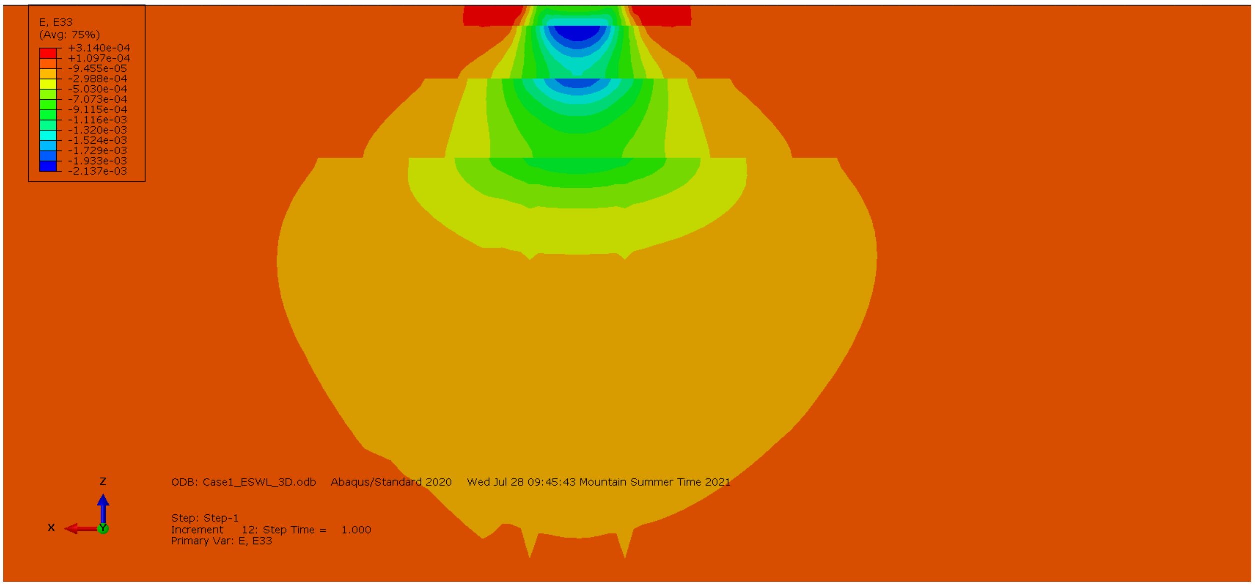

Figure 8. Strain distribution in the road design with the CBR method

Therefore, the current CBR design method needs to be improved. This research proposed a new design approach based on the theories of elasticity and critical strain limit (CSL). The proposed model is shown in Figure 9 and Equation 1.

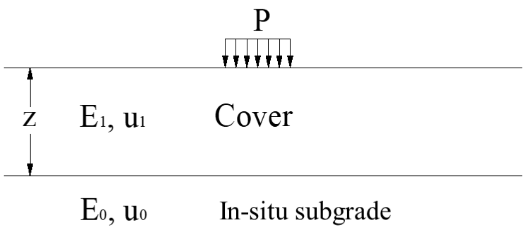

Figure 9. Mechanistic analysis of pavement structures

$$\varepsilon_z = \frac{\sigma_0(1+\mu)}{E_0}\left\{1 - 2\mu + \frac{2\mu\left(\frac{z}{a}\right)}{\sqrt{1+\left(\frac{z}{a}\right)^2}} - \left[\frac{\frac{z}{a}}{\sqrt{1+\left(\frac{z}{a}\right)^2}}\right]^3\right\} = CSL \qquad \text{Equation 1}$$

where ε_z is vertical strain; σ_0 is the stress at road surface; $E = 17.63 \times CBR^{0.64}$ is the resilient modulus of pavement layers; μ is the poisson's ratio, z is the depth from pavement surface; a is the radius of the surface pressure, CSL is the critical strain limit, which can be determined as:

$$CSL = \frac{80000}{N^{0.27}}$$

where N is the number of load repetitions.

To verify the proposed new method, 3D models were established to compare the strain and deflection of pavements designed from the existing CBR method and that from the proposed new method. The results are shown in Figure 10 and Table 12. The modelling results suggested that our proposed model led to better design in road structure, as smaller strain and displacement can be achieved, compared with that of the original CBR method. For example, in Case 1, with a CSL of 1500 micron, the proposed design method led to a higher total pavement thickness of 1.1 m, but the max strain in the pavement was significantly reduced from 2137 micron to 1502 micron, which was closer to the CSL of 1500 micron.

After that, this proposed new method was used to investigate how the stabilization would affect the structural design of mine haul roads. The design results are shown in Table 13. It was found that the stabilization of lower layers can reduce the design thickness more significantly than that of the surface layer. For example, when the sub-base was stabilized, the total thickness was reduced from 1.19 m to 1.04 m, while the stabilization of the surface layer only reduced the total thickness to 1.18 m.

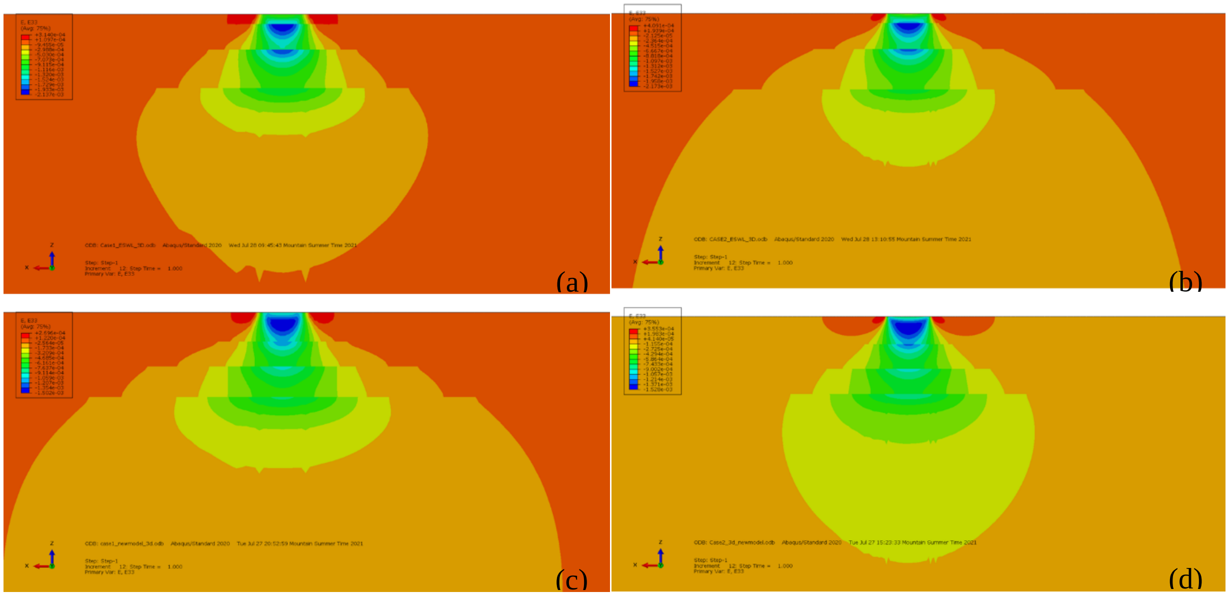

Figure 10. Strain distribution in various conditions: (a) CBR design for Case 1; (b) CBR design for Case 2; (c) New design for Case 1; (d) New design for Case 2

Table 12. Comparison between the existing CBR method and proposed method

	Total thickness, m		Strain, micro		Displacement, mm	
	CBR method	New model	CBR method	New method	CBR method	New method
Case 1	0.96	1.1	2137	1502	2.508	2.10
Case 2	2.46	2.51	2173	1528	5.75	4.78

Table 13. Structural design of mine haul roads with varied stabilization layers

Layer	**Reference**		**Surface stabilized**		**Base stabilized**		**Sub-base stabilized**	
	CBR, %	**Thickness, m**	**CBR, %**	**Thickness, m**	**CBR, %**	**Thickness, m**	**CBR, %**	**Thickness, m**
Wearing course	100	0.33	120	0.32	100	0.33	100	0.33
Base course	60	0.38	60	0.38	75	0.33	60	0.38
Sub-base	15	0.48	15	0.48	15	0.48	30	0.33
Sub-grade	5	/	5	/	5	/	5	/
Total thickness		**1.19**		**1.18**		**1.14**		**1.04**

4.3. Numerical Modelling for the Prediction of Rolling Resistance

4.3.1. Model Development and Validation

To develop the model for rolling resistance prediction, a pavement model was first established based on the study by Coffey (Coffey, 2015). After that, a tire model was developed based on the truck specification in Coffey's study and then assembled with the pavement model (see Figure 11). A friction coefficient of 0.7 was applied between the tire and road. Then, the modelling process was divided into three steps (see Figure 12). First, a static pressure of 758 KPa was gradually applied on the tire inner surface to inflate the tire within 0.3 s, and then kept constant until the end of modelling (7.3 s). Second, a concentrated force of 620 KN was gradually applied to the tire center to simulate the truck load from 0.3 s to 1.8 s. Lastly, the tire was accelerated from 0 km/h to a speed of 30 km/h (0.3 s to 2.3 s) and then rolled at the speed until the end of the modelling. Figure 13 shows the deflection of the road surface. The max deflection (2.48 mm) obtained from the ABAQUS model was similar to that of the field measurement (2.5 mm) in Coffey's study, meaning a validated model. In addition, the rolling resistance force from the ABAQUS model is plotted in Figure 14. It is observed that from 0 to 0.3 s, there was no rolling resistance during tire inflation. After that, the rolling resistance force drastically increased to more than 140,000 N during tire acceleration, followed by a sharp decrease until it reached a stable status when the tire was rolling at a constant speed of 30 km/h. Also, the rolling resistance force showed significant fluctuation with time. Tire rolling resistance was calculated by averaging the values when the tire was rolling at a constant speed of 30 km/h. The calculated rolling resistance force was 11314 N, and rolling resistance coefficient was 1.823%. Compared with that from Coffey's study (2.05%), the rolling resistance coefficient obtained from the ABAQUS model was slightly smaller. A possible reason was the absence of roughness in the ABAQUS model. Further study is required to include the effect of surface roughness on rolling resistance.

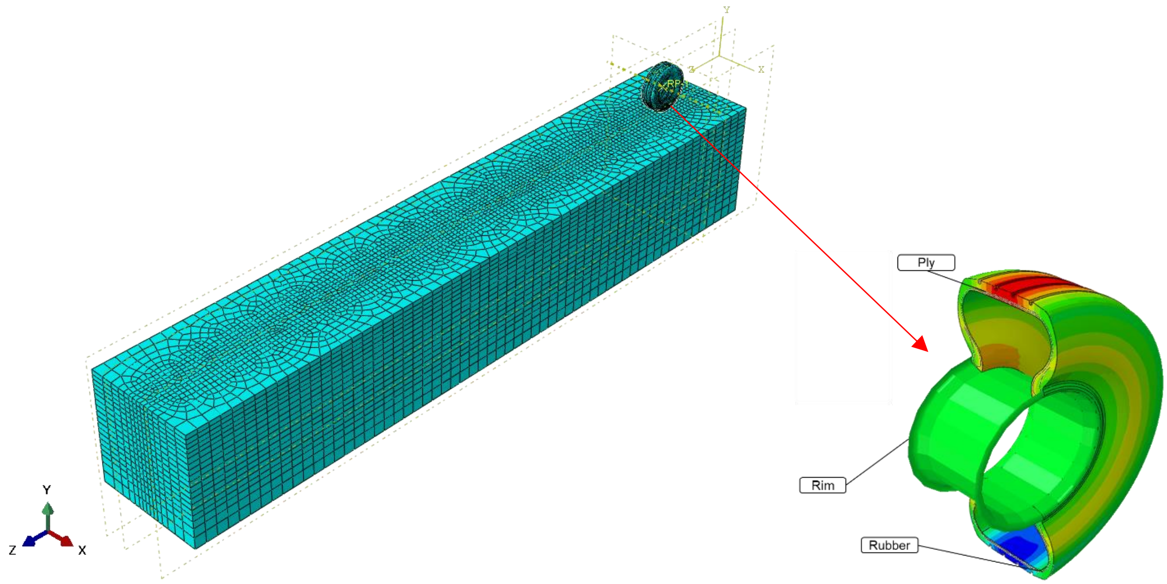

Figure 11. Model setup for predicting the rolling resistance

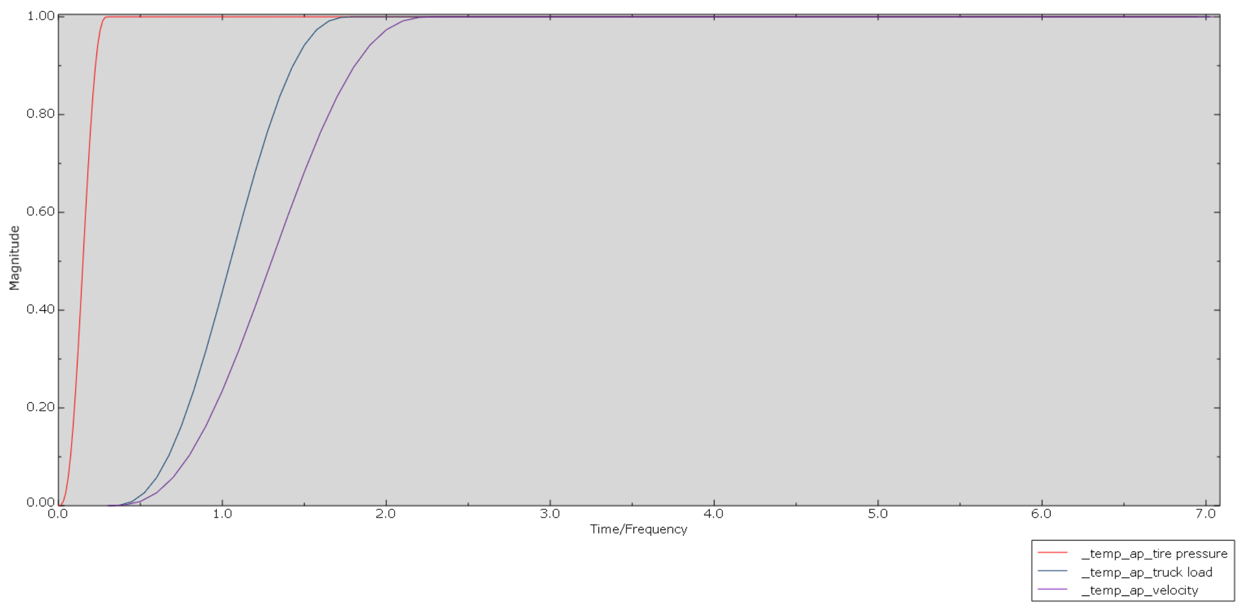

Figure 12. Modelling process for rolling resistance prediction

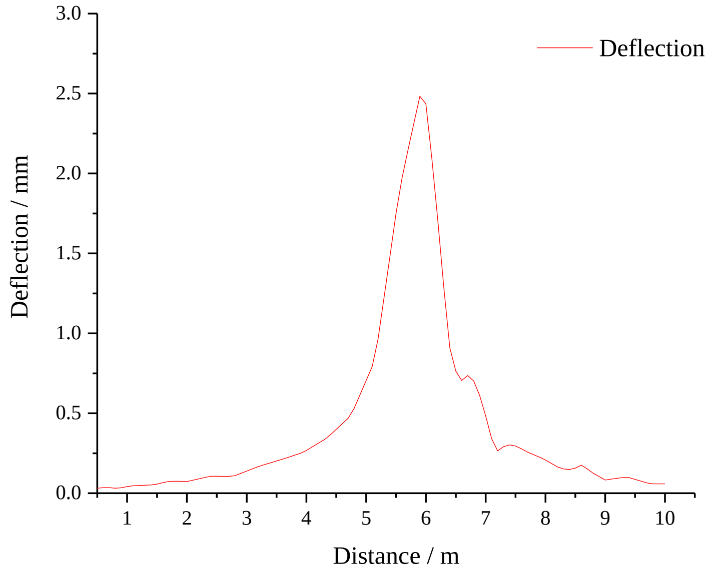

Figure 13. Deflection of road surface

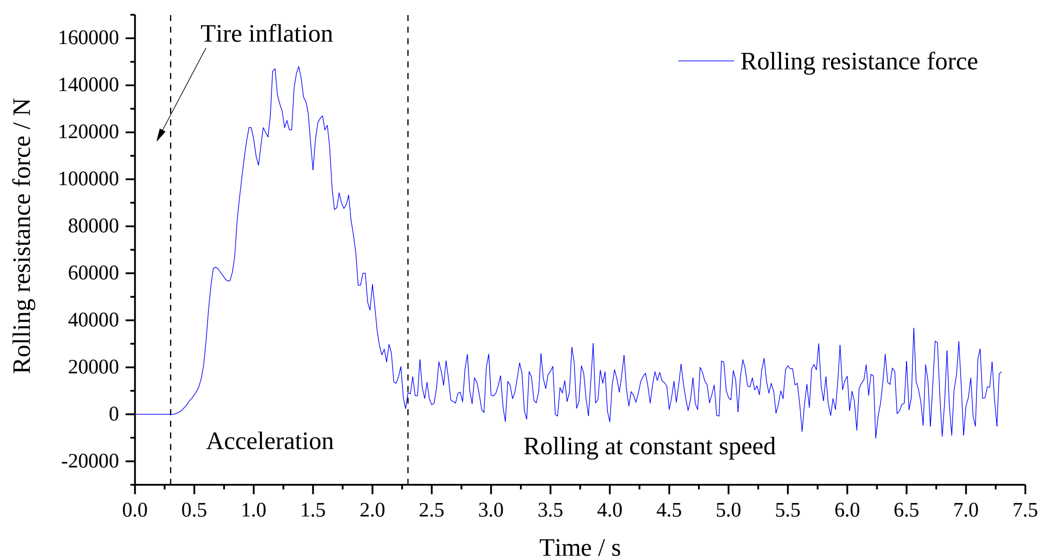

Figure 14. Rolling resistance force with modelling time

4.3.2. Effects of Layer Stiffness

Based on the validated ABAQUS model, a model was established to predict the rolling resistance before and after road stabilization. Since there is a lack of data regarding the properties change of pavement layers caused by stabilization, it is assumed that the stabilization of pavement layers in mine haul roads would only increase the CBR of the stabilized layers. In this study, two scenarios were investigated: 1) the surface layer was stabilized; and 2) the sub-base layer was stabilized. As shown in Table 14, it is assumed that the stabilization increased the CBR of the surface layer from 80% to 100%, while the stabilization of the sub-base layer raised the CBR from 15% to 50%.

Table 14. Pavement properties in the 3D model

Layer	CBR, %	Modulus, MPa	Thickness, m
Surface	80, 100	291, 336	0.3
Base	60	242	0.7
Sub-base	15, 50	100, 215	1
Sub-grade	5	50	8

The modelling results are listed in Table 15 and Table 16. The fuel consumption was calculated according to the study conducted by Thompson (Thompson, 2003).

$$FC = 1.02 + \begin{pmatrix} UVM \times V \times (296 \times TR + 4.5 \times V) \\ +L \times GVM \times V \times (246 \times TR + 0.027 \times V^2) \end{pmatrix} \times 10^{-5}$$

where FC is fuel consumption, ml/s; GVM is gross vehicle mass, t; UVM is unladen vehicle mass, t; V is the travel speed of trucks, km/h; TR is the total resistance, %; L is a logistic variable, 1 for laden trucks, 0 for unladen trucks.

The numerical results demonstrated that the stabilization of pavement layers was able to slightly reduce the rolling resistance. The rolling resistance decreased by 0.035% and 0.022% for surface stabilization and sub-base stabilization, respectively. This reduction in rolling resistance can lead to a reduction of fuel consumption of approximately 5 L/h and 3 L/h, respectively.

Table 15. Modelling results for surface stabilization

Surface	Rolling resistance		Fuel consumption, L/h
	%	N	
CBR 80	1.2992	11576.1886	217.5541
CBR 100	1.2646	11267.9948	212.4013

Table 16. Modelling results for sub-base stabilization

Surface	**Rolling resistance**		**Fuel consumption, L/h**
	%	**N**	
CBR 15	1.2646	11267.9948	212.4013
CBR 50	1.2428	11073.0548	209.1548

4.3.3. Effects of Road Roughness—A Preliminary Study

Despite the positive findings from the 3D models, road roughness has not been included in the study. As the reports (Eco-Road Hero Pty Ltd., 2020) indicate, the stabilization would significantly reduce the roughness of road surface. Therefore, a 2D model was established to qualitatively investigate the effects of road roughness on the rolling resistance. Figure 15 shows the 2D model with a rough surface. The results are listed in Table 17. It is suggested that surface roughness has a significant influence on the rolling resistance. The rolling resistance increased from 0.1% for the smooth surface to 0.39% for the rough surface. This indicates that the roughness change due to stabilization could have a significant influence on the rolling resistance. Further study is required to consider surface roughness for predicting the rolling resistance.

Figure 15. 2D model with a rough surface

Table 17. Rolling resistance fuel consumption under different road conditions

Road condition	Rolling resistance		Fuel consumption, L/h
	%	N	
Smooth	0.1%	-462.85	26
Rough	0.39%	-1971.00	52

5. Limitations and Future Research

Although this study provides an in-depth investigation of the effects of stabilization on mine haul road design, there are still limitations that cannot be covered in this two-year project. First, the roughness of road surface has not been incorporated in the 3D numerical models. Our 2D models have indicated that surface roughness is a key contributor to rolling resistance. It has been suggested by the report (Eco-Road Hero Pty Ltd., 2020) that stabilization can significantly reduce the surface roughness and the risk of structural failure (e.g., potholes and rutting) of the haul roads, meaning that stabilization has the potential to further reduce the rolling resistance. Studies are needed to confirm this hypothesis through 3D numerical modeling. Second, this study assumes that the stabilization of mine haul road increases the CBR of the stabilized layers based on the findings from the applications on rural municipal roads. Currently, there is a lack of available data regarding the properties change of mine haul road layers after stabilization. Experimental and fieldwork should be conducted to quantitatively investigate how the stabilization of mine haul roads affects their properties and incorporate the data into the numerical models.

6. Key Findings and Contributions

Our work on the identified tasks has reached significant achievements and is expected to bring significant contributions.

1) The research findings provide insights into Cypher’s stabilizer products. Numerical study on mine haul roads and rural municipal roads indicates that the stabilization of pavement layers reduces the max strain and deflection in roads, therefore enhancing their performance. It is also noted that the stabilization of lower layers was more effective in reducing the strain and deflection. In addition, it was observed that the total thickness of

pavement could be significantly reduced after stabilization, thereby reducing the construction cost.

2) A new CBR (California Bearing Ratio) design method for mine haul roads was proposed to overcome the issue of under-design with the current CBR design method. It was found that the proposed new method led to better design in road structures, as smaller strain and deflection can be achieved. With the new design method, it was observed that road stabilization could reduce the design thickness of mine haul roads and reduce construction costs.
3) For the first time, a 3D finite element model (FEM) of tire-road interaction was developed and validated to estimate the rolling resistance of tires. The results indicate that road stabilization (stiffness increase) can noticeably reduce the rolling resistance and fuel consumption.
4) A 2D model was established to preliminarily investigate the effects of roughness on rolling resistance. It was found that a large portion of rolling resistance can be attributed to road roughness, suggesting that the surface roughness should be included in the effects of stabilization on rolling resistance. Further investigations are needed.
5) The findings of this research will provide new guidance for the application of Cypher's stabilizer products. First, this research highlights the advantages of Cypher's stabilizers and provides a theoretical base to promote the applications of stabilizers. Second, this research identifies two promising applications of Cypher's stabilizers: 1) design and construction of mine haul roads and 2) stabilization of lower layers in pavement construction. Although the numerical model in this study was verified by Coffey's theoretical work, experimental work is still needed to validate the numerical models. This research is limited to a preliminary investigation.
6) This report is a summary report from the 2-year Mitacs research project. It is not a substitute for professional engineering service or judgement. The contents of this report should be assessed with caution by professionals to determine its suitability when it is used.

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