Simple Slope Stabilization on Quartz Sandstone using Horizontal Drain

by Supandi .

IJE TRANSACTIONS A: Basics Vol. 34, No. 04, (April 2021) 1046-1051

International Journal of Engineering

Journal Homepage: www.ije.ir

Simple Slope Stabilization on Quartz Sandstone using Horizontal Drain

S. Supandi*

Department of Mining Engineering, Institut Teknologi Nasional Yogyakarta, Indonesia

PAPER INFO

Paper history:
Received 15 November 2020
Received in revised form 31 January 2020
Accepted 08 February 2021

Keywords:
Depressurization
Dewatering
Hydrogeology
Slope
Stabilization
Horizontal Drain

ABSTRACT

Maintaining stability of public facilities, especially public roads, is very necessary, so the stabilization efforts must be carried out. The water from seepage that comes out of sandstone layer carries material with fine particles and this causes the rock cohesion to decrease and thus leading to scouring. As a result of the scouring, the layer becomes overstep and can disturb road stability. This study was conducted to provide simple but measurable recommendation for maintaining road stability after the previous stabilization effort failed. The method used a fluid mechanics approach in which water from the formation was given space to come out of the formation without carrying fine particles (cement). The analysis was carried out using the finite element method by installing horizontal drain pipe. The result of analysis shows that the horizontal drain installation helps water to come out without creating an overstep layer. The recommended horizontal drain is 8 m long with a slope of at least 3% and a length of 1 m that must enter the sandstone formation as a water source. With this method, the road stability can be maintained and the stabilization can be carried out in an easy, inexpensive, and applicable way.

***doi**: 10.5829/ije.2021.34.04a.31*

NOMENCLATURE

σ'	Effective stress	Re	Reynolds number
σ_n	Normal stress	ρ	Water density
u	Pore pressure	v	Velocity of water flow
τ	Shear strength	D	Inner diameter of pipe
φ	Friction angle	μ	Viscosity of water
c	Cohesion	K	Hydraulic conductivity

1. INTRODUCTION

Slope stabilization is mandatory to maintain existing infrastructure around the location. The stabilization must be carried out using a way that is able to function optimally, which means that technically it is capable of maintaining stability but economically the cost is minimum. In a failure of stabilization effort on a slope adjacent to the public road, the scouring occurred on the slope which was led to overstep and disturbed the stability of the public road.

In Figure 1, the reddish brown and the dark gray materials are fill materials that are positioned above the in-situ materials which are mudstone and quartz sandstone units under the soil. On the channel wall, there is a layer of sand that continuously releases seepage throughout the year and leaves scouring in several places. The impact of scouring is the occurrence of overstep and from time to time, the scouring is getting bigger, that it will disturb the stability of public roads if it continues.

The previous research about the flow behavior has been conducted; it explained the vertical and horizontal seepages and their relationship to channel presence [1]. The groundwater will flow most rapidly through material with the greatest hydraulic conductivity to a place with the lower flow potential. In this case, the groundwater flow originating from the in-situ material will go to the exposed part through the fill material until it finally emerges as a spring. Based on the theory of hydromechanical coupling in soil and rock, the presence of groundwater has a direct impact on the material by

*Corresponding Author Email: *supandi@sttnas.ac.id* (S. Supandi)

Please cite this article as: S. Supandi, Simple Slope Stabilization on Quartz Sandstone using Horizontal Drain, International Journal of Engineering, Transactions A: Basics Vol. 34, No. 04, (2021) 1046-1051

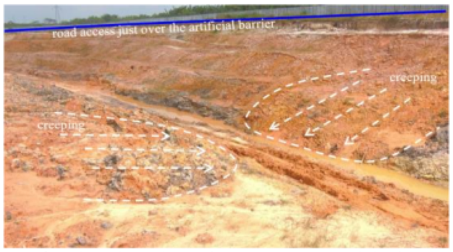

Figure 1. Diversion channel near access road in low water flow condition

increasing the volume of rock mass, especially in soil or pile material [2]. Indirectly, the changes in pore pressure will have an impact on changes in the mechanical properties of the material.

To overcome the existing hydrogeological condition, depressurization is required to increase the stability of material slope [3]. The effectiveness of horizontal drain installation is indicated by the increasing factor of safety (FoS) after the horizontal drain installation compared to the pre-installation condition. The horizontal drain installation should have been positioned as low as the location that is likely to be a slip surface [4]. In this study, the installed horizontal drain on fill material was not carried out by drilling, but by excavating and then backfilling after the casing had been installed.

The Installation of horizontal drain in slope stability aims to control and remove water from the material (desaturation) and depressurization [5]. When the groundwater is removed from the material, the ground water level will decrease; thus, resulting in a decrease in pore pressure in the material. The construction of vertical drain using column gravel will be reducing potential liquefaction or increasing pore pressure [6]. The design and success rate of this effort depends on local condition. The effectiveness of horizontal drain configuration includes the location, length, and spacing; slope geometry; as well as the characteristics of slope-forming material. The effectiveness of horizontal drain installation is indicated by the increasing factor of safety (FoS) after the horizontal drain installated [7].

The integration of geotechnical and hydrogeological aspects in slope stability analysis is very interesting but the implementation is still limited [8]. Water content has relationship with mechanical properties of rock and soil, where increasing water content will decrease mechanical properties of rock/soil [9-10]. This study aims to evaluate the stabilization effort using horizontal drain that was carried out in the study area to increase the effectiveness of the installed horizontal drain. This study will discuss the conditions before and after the installation of horizontal drain, and then compare their effects on slope stability.

The effective stress theory explains the behavior of soil and rocks in relation to the presence of groundwater (shown in Equation (1)) [11]. The effective stress (σ') is expressed as normal stress (σ_n) minus pore pressure (u) at a point. For geotechnical material, the strength of material is described by the Mohr-Coulomb law (shown in Equation (2)) as effective stress for a point along slip surface; where τ is shear strength at a point of interest, φ is friction angle, and c is cohesion.

$$\sigma' = \sigma_n - u \quad (1)$$

$$\tau = c + (\sigma_n - u)\tan\varphi \quad (2)$$

Based on these two equations, it can be concluded that the greater the pore pressure in a material, the lower the strength of the material, and vice versa. Ideally, horizontal drain installation is positioned as low as possible at a location that is likely to be a slip surface. Given that hydraulic conductivity of filling material is much less than the conductivity / velocity of water flowing through a 3″ pipe in the same cross-sectional area, the flow in the pipe occurs freely without any over pressure.

The maximum velocity of flow in the pipe with free condition is calculated by the Reynolds number (Equation (3)) [12]. Basically, the seepage potential of in-situ material can be overcome by the layer of fill material. The stabilization effort using galam wood piles was carried out, but they could not cope with the movement of material.

$$Re = \frac{\rho \times v \times D}{\mu} \quad (3)$$

Diversion channel is an infrastructure designed to accommodate and drain water. Various studies on diversion channel have been conducted including physical dynamics of river and diversion channel due to water flow [13], implication of channel diversion [14], problem-solving method related to river diversion [15], design failure remediation [16], channel restoration, geometric design of channel [17], as well as case studies and reviews of river diversion in various locations [18].

The preliminary result analysis showed that wooden-pile installation can withstand material movement. In practice, creep of fill material occurred over time, causing design failure. Based on field investigation, the creep was identified and strongly believed, it is caused by groundwater flow (hydrogeology) factor in the fill material. This parameter has not been accommodated properly in preliminary analysis. For this reason, modeling and management of hydrogeological condition are required in the context of material stabilization.

2. MATERIALS AND METHODS

The research was conducted at one of the creek diversions in South Kalimantan, Indonesia, which is located right beside a public road. In general, the materials at research location are in the Warukin formation which is composed of sandstones, claystones, and coal with low hardness [19-22]. The sandstones are composed of clay-to-sand-sized quartz sandstones with brownish gray color [23]. The groundwater level is relatively high, about 10 m from the surface. The type of aquifer found is confined aquifer where the sandstone layer is bordered by claystone at the top and bottom. The seepage is found on the surface of sandstone slopes and water discharge is stable in either rainy or dry season. The water from the seepage that comes out all year round, than its mixed with very fine material.

The stabilization effort has been carried out by covering the sand layer with laterite material consisting of sand, clay, and gravel, so it covers the entire surface of the sand, and installing sheetpiles using galam wood. Both of these methods were unsuccessful because the laterite material deteriorated due to addition of water from seepage and the galam wood as a barrier was unable to hold it.

Based on the above conditions, the stabilization effort was carried out by keeping the seepage out of the formation without carrying rock cement so that soil cohesion can be maintained. A channel with perforated pipe was made for the water from the seepage to come out without carrying cement. The perforated pipe was made using PVC pipe in general and given a geotextile coating as a filter. In detail, the pipe is Schedule 120 PVC pipe which is 6″ in length with outer diameter of 6.625″ (141.3 mm) and inner diameter of 5.434″ (121.1 mm) and has collapse pressure of 370 psi (2551 kPa) (Figure 2).

The perforated pipe was only in the part that was being buried; however, at the outlet, it was solid. It was installed 1 m at the seepage, passing through the embankment zone before exiting the channel. The horizontal drain inclination is 5°, with the target of quartz sandstone unit contact. The total length of horizontal drain that has been installed, it is approximately 6 m, it is slightly entering the in-situ quartz sandstone material.

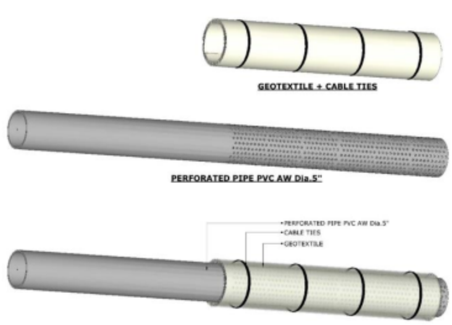

Figure 2. Design of perforated pipe for horizontal drain

The analysis was performed using combination limit equilbirum and finite element method with stratigraphy based on drilling data around the location. The geotechnical parameters were obtained based on laboratory analysis using triaxial and uniaxial methods with testing standard of ASTM. The determination of material properties on bedding contact referred in previous research in this area with value material properties is Cohesion 0 kPa, density 13 kg/cm^3 and friction angle 13 degree [24]. The failure was identified on the backfilling material only and determination bedding ratio was not applied [24].

3. RESULTS AND DISCUSSION

Based on field identification result, creeping only occurs in the fill material, while the landslides do not occur in the in-situ material. Therefore, the slope stability analysis was focused on the fill material. On surface of the embankment under fill material, there is sedimentation which is a mixture of slurry material and fill material on the channel bed that is also considered in the analysis. Probability analysis was performed based on the properties of fill material and sedimentation material (Table 1).

The values for hydraulic properties of in-situ material and embankment identified in the field are shown in Table 2. The in-situ material has a bedding that causes the vertical hydraulic conductivity to be smaller than the horizontal, which is normal to the bedding plane; for this reason, it is determined to have ratio of 1:10. Meanwhile, the soil material and embankment have a greater vertical conductivity ratio than in-situ material due to their loose condition, which is determined to be 1:1.

The hydrogeological analysis was carried out transiently. The stage of time was used 5 stages: 15 days

TABLE 1. Material statistics applied in probability analysis

Material name	Properties	Dist.	Mean	Min.	Max.
Fill material	Cohesion (kPa)	Normal	13.75	11.75	15.75
Fill material	Phi (°)	Normal	7	6	8
Fill material	Unit weight (kN/m^2)	Normal	17	16	18
Sediment	Cohesion (kPa)	Normal	1	0	2
Sediment	Phi (°)	Normal	7	6	8
Sediment	Unit weight (kN/m^2)	Normal	17	16	18

TABLE 2. Hydraulic conductivity of material

Material unit	Hydraulic conductivity	Kv/Kh	a (bedding angle)
Sandstone	8.25×10^{-05}	0.1	3.125
Mudstone	1.00×10^{-07}	0.1	3.125
Coal	3.65×10^{-06}	0.1	3.125
Fill material	4.00×10^{-04}	1	-
Soil	4.00×10^{-05}	1	-
Sedimentation	1.95×10^{-07}	1	-

(over 2 weeks), 30 days (1 month), 45 days (1.5 months), 60 days (2 months), and 90 days (3 months). The determination of stage is intended to know the short and long term variation of the effectiveness of installed horizontal drain.

3. 1. Horizontal Drain

In the analysis, the length of horizontal drain was simulated with a length of 4 m, 8 m, and 12 m to the quartz sandstone with the same output position (stick out). The water flow in horizontal drain is considered to be free flow (laminar/non-turbulent) with Re $\leq$ 2000. By applying Equation (3), if the viscosity of water (μ) = 10^{-3} kg/(m.s), water density (ρ) = 1000 kg/m^3, and inner diameter of the Pipe 6" (D)= 0.1211 m, then the hydraulic conductivity is:

$$v = \frac{Re \times \mu}{\rho \times D} = \frac{2000 \times 10^{-3}\,\mathrm{kg/(m.s)}}{1000\,\mathrm{kg/m^3} \times 0.1211\,\mathrm{m}} = 0.0165\,\mathrm{m/s}$$

$$K \approx v = 0.0165\,\mathrm{m/s} = 1.65 \times 10^{-2}\,\mathrm{m/s}$$

Based on the above calculation, the hydraulic conductivity of horizontal drain is 1.65×10^{-2}m/s. This value is an approximation of the maximum value of the horizontal drain hydraulic conductivity used in the hydrogeological analysis.

3. 2. Innitial Condition Before Horizontal Drain Instalation

The back analysis was carried out in initial condition before the horizontal drain installation. The analysis was carried out as an initial basis and validation of analysis before continuing the next analysis. The landslides occurred in the initial condition, but it did not occur immediately. This indicates that the value of stability factor was in a critical condition (FoS approaches 1.0), with a relatively high probability factor.

The back analysis was carried out in the initial condition at the stage of 15-90 days with stability factor value of 1.013-1006 and failure probability of 39.6-44.73%. Over time, there was saturation in the material which was caused by the decrease in the slope stability, that was accompanied by an increase in the probability of failure. This condition is considered to reflect the condition of the embankment, where the landslides did not occur at once but slowly creeping. Figure 3 shows the result of back analysis on stage of 90 days. The surface of fill material slope is a groundwater accumulation zone, where the flow in that part is the greatest. This is in accordance with the result of field identification that has been carried out that the groundwater condition greatly affects the stability of fill material.

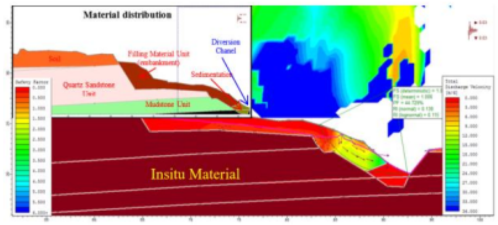

Figure 3. Back analysis on stage of 90 days showing total discharge velocity and accumulation on the slope surface of the fill material embankment. Insert shows material boundaries distribution

The series of analysis was carried out by the means of limit equilibrium and the failure probability analyses integrated with transient groundwater finite element analysis on the criteria that has been mentioned. Based on the results of the analysis, it is known that the most significant change in groundwater level in the study area occurred in the first 30 days. After 30 days, the changes in groundwater condition still occurred limitedly, but the changes were not so significant.

The correlation between pore pressure and time stage at query points located in the in-situ material contact with the fill material shows the most significant change in pore pressure from 15 days stage to 30 days stage. It was the case for all horizontal drain lengths that were analyzed. For the next stage, a decline in pore pressure value was identified but very small. Thus, the most striking changes in stability from the value of either stability factor or failure probability can be only observed up to the 30 days stage (Tables 3 and 4). It shows that the optimum effectiveness of horizontal drain installation in the study area was achieved after the 30 days stage.

Figure 4 shows the correlation between pore pressure and query point distance along a query line for

TABLE 3. Summary of limit equilibrium analysis

Horizontal drain length	FoS in stage of				
	15 days	30 days	45 days	60 days	90 days
Initial (none)	1.013	1.007	1.007	1.007	1.006
4 m	1.037	1.037	1.037	1.037	1.037
8 m	1.093	1.099	1.099	1.099	1.099
12 m	1.100	1.100	1.100	1.100	1.100

TABLE 4. Summary of failure probability analysis

Horizontal drain length	PoF in stage of				
	15 days	**30 days**	**45 days**	**60 days**	**90 days**
Initial (none)	39.60%	43.78%	44.35%	43.82%	44.73%
4 m	22.30%	22.40%	22.40%	22.40%	22.40%
8 m	2.70%	2.40%	2.30%	2.30%	2.30%
12 m	2.30%	2.20%	2.20%	2.20%	2.20%

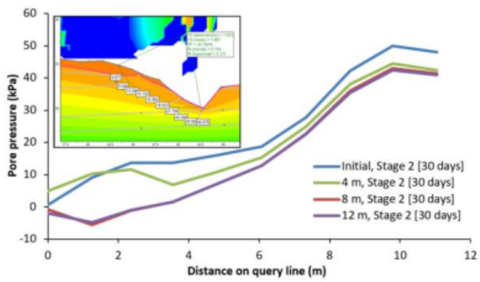

Figure 4. Pore pressure on each of the query points along query line for initial and various lenght of horizontal drain. Negative pore water pressures indicate groundwater level bellow the query points

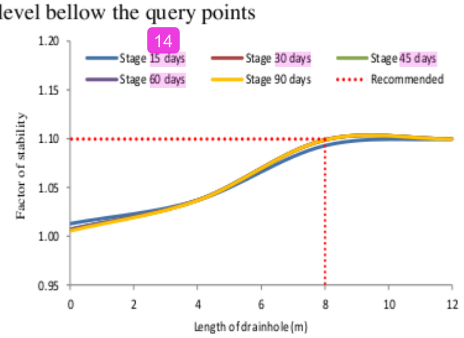

Figure 5. Corelation between length of horizontal drain and factor of stability on various stages of time

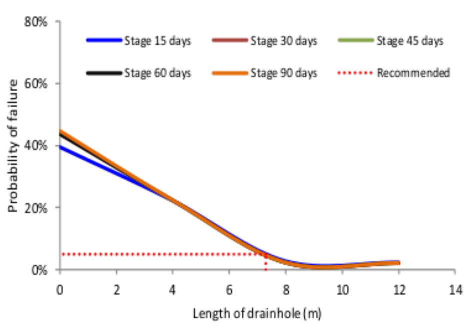

Figure 6. Corelation between length of horizontal drain and probability of failure on various stages of time

slope sections at different initial condition and horizontal drain. The query line was determined at fixed coordinate with 10 query points used to identify pore pressure at the contact zone.

Insert at the upper left of Figure 4 shows the query position in the analysis section for initial condition at 30 days stage. Based on the position sequentially from the top (see insert) or from the left (see chart), query points 1, 2, and 3 are query points for the top of the slip surface; 4, 5, and 6 for the middle; while 7, 8, 9, and 10 are for the bottom of the slip surface. A significant reduction in pore pressure occurred only at the installation of horizontal drain with the length of 8 m. After that, the changes in pore pressure were observed but it is not very significant.

To determine the effect of horizontal drain length on the values of stability factor and failure probability, modeling was carried out by correlating the stability factor (Figure 5) and the failure probability (Figure 6) with the horizontal drain length. In the correlation, the initial condition without drainhole installation is illustrated as the horizontal drain length of 0 m.

5. CONCLUSION

Installation of horizontal drain with specific designed perforated pipe can have a significant impact on slope stability. The groundwater from the formation can still come out to the surface or channel without carrying cement material, so the decline of sandstone cohesion does not occur. Then, with the discharge of water from the formation, the pore pressure decreases and the stability increases. The selection of horizontal drain length is one of the parameters that must be considered to produce optimal stability improvement. The longer the length, the better, of course; but it requires greater effort and cost. From the analysis, it can be seen that the horizontal drain with a length of 8 m and a slope of 3% is the optimal design to increase the stabilization. The horizontal drain may improve slope stability over time and this method is one of the optimum stabilization methods compared to other methods.

6. REFERENCES

1. Tao, Y. Z., Xi, D. Y. "Rule of Transient Phreatic Flow Subjected to Vertical and Horizontal Seepage". ***Applied Mathematics and Mechanics***, Vol. 27, No. 1, (2006), 59-65. DOI: 10.1007/s10483-006-0108-1
2. Price, J., "Implications of Groundwater Behaviour on the Geomechanics of Rock Slope Stability", in 1st Asia Pacific Slope Stability in Mining Conference, Australian Centre for Geomechanics, (2016), 25-48. https://doi.org/10.36487/ACG_rep/1604_0.3_Price
3. Reano, E., Beale, G., Dowling, J., Tejada, L. C., Lacey, M., Hazwezwe, H., "Development of A Mine Dewatering and Pit

Slope Depressurisation Review Process", in International Symposium on Slope Stability in Open Pit Mining and Civil Engineering 2020, Australian Centre for Geomechanics, (2020), 1253-1266. https://doi.org/10.36487/ACG_repo/2025_85

4. Rahardjo, H., Hritzuk, K. J., Leong, E. C. Rezaur, R. B. "Effectiveness of Horizontal Drains for Slope Stability". ***Engineering Geology***, Vol. 69, No. 3-4, (2003), 295-308. DOI: 10.1016/S0013-7952(02)00288-0
5. Hill, K., Hodgkinson, R., Harris, D., Newell-Price, P., Field drainage guide: principles, installations and maintenance. Warwickshire: Agriculture and Horticulture Development Board, 2018.
6. Hamedi, A., Marundi, S. M. "Laboratory Studies on the Effect of Vertical Gravel Column Drains on Liquefaction Potential". ***International Journal of Engineering, Transactions B: Applications***, Vol. 24, No. 3, (2011), 209-224. DOI: 10.5829/idosi.ije.2011.24.03b.02
7. Rahardjo, H., Santoso, V. A., Leong, E. C., Ng, Y. S., Hua, C. J. "Performance of Horizontal Drains in Residual Soil Slopes". ***Soils and Foundations***, Vol. 51, No. 3, (2011), 437-447. DOI: 10.3208/sandf.51.437
8. Campbell, R., Mackie, D., Anderson, W. S., "Integrated Slope Stability Assessment in A Complex Geotechnical and Hydrogeological Setting", in International Symposium on Slope Stability in Open Pit Mining and Civil Engineering 2013, Australian Centre for Geomechanics, (2013), 555-567. https://doi.org/10.36487/ACG_rep/1308_36_Campbell
9. Rahmannejad, R., Toufigh, V. "Influence of Curing Time and Water Content on Unconfined Compressive Strength of Sand Stabilized Using Epoxy Resin". ***International Journal of Engineering, Transactions B: Applications***, Vol. 31, No. 8, (2018), 1187-1195. DOI: 10.5829/ije.2018.31.08b.05
10. Mousavi, S. "Effect of Moisture Content on Shear Strength of Offshore Clay Interface Steel Surface". ***International Journal of Engineering, Transactions B: Applications***, Vol. 29, No. 2, (2016), 183-191. DOI: 10.5829/idosi.ije.2016.29.02b.07
11. Grimstad, G., Amiri, S. A. G., Nordal, S. "Relations and Links Between Soil Mechanics Porous Media Physics, Physiochemical Theroy and Effective Medium Theory". ***Frontiers in Physics***, Vol. 7, Article 41, 1-10. DOI: 10.3389/fphy.2019.00041
12. Rott, N. "Note on the History of the Reynolds Number". ***Annual Review of Fluid Mechanics***, Vol. 22, No. 1, (1990), 1-12. DOI: 10.1146/annurev.fl.22.010190.000245
13. Erskine, W. D. "Channel Response to Large-Scale River Training Works: Hunter River, Australia". ***Regulated Rivers: Research & Management***, Vol. 7, No. 3, (1992), 261-278. DOI: 10.1002/RRR.3450070305
14. Shao, X., Wang, H., Wang, Z. "Interbasin Transfer Projects and Their Implications: A China Case Study". ***International Journal of River Basin Management***, Vol. 1, No. 1, (2003), 5-14. DOI: 10.1080/15715124.2003.9635187
15. Yevjevich, V. "Water Diversions and Interbasin Transfers". ***Water International***, Vol. 26, No. 3, (2001), 342-348. DOI: 10.1080/02508060108686926
16. McEwan, A. L., "The Failure of and Remedials to A River Diversion for An Opencast Mine In The Witbank Coalfields of South Africa", in International Mine Water Association Congress 1999, International Mine Water Association, (1999), 79-85. Retrieved January 30, 2021, from http://www.imwa.info/docs/imwa_1999/IMWA1999_McEwan_079.pdf
17. Riyadi, F. A., Cahyadi, T. A., Nurkhamim, Supandi. "Desain Saluran Terbuka Berbasis Microsoft Excel Perhitungan dan Pemodelan yang Praktis dan Efisien". ***Kurvatek***, Vol. 4, No. 2, (2019), 61-78. DOI: 10.33579/krvtk.v4i2.1563
18. Flatley, A., Rutherfurd, I. D., Hardie, R. "River Channel Relocation: Problems and Prospects". ***Water***, Vol. 10, No. 10, 1360, (2018), 1-25. DOI: 10.3390/w10101360
19. Supandi, Zakaria, Z., Sukiyah, E., Sudradjat, A. "The Correlation of Exposure Time and Claystone Properties at The Warukin Formation Indonesia". ***International Journal of Geomate***, Vol. 15, No. 52, (2018), 160-167. DOI: 10.21660/2018.52.68175
20. Supandi, Zakaria, Z., Sukiyah, E., Sudradjat, A. "The Influence of Kaolinite-Illite toward Mechanical Properties of Claystone". ***Open Geosciences***, Vo.11, No. 1, (2019), 440-446. DOI: 10.1515/geo-2019-0035
21. Supandi, Hartono, H. G. "Geomechanic Properties and Provenance Analysis of Quartz Sandstone from The Warukin Formation". ***International Journal of Geomate***, Vol. 18, No. 66, (2020), 140-149. DOI: 10.21660/2020.66.50081
22. Supandi, Hidayat, H., "The Impact of Geometry Bedding toward Slope Stability in Coal Mining", in 4th International Symposium on Geotechnical Safety Risk 2013, Geotechnical Safety Network, (2013), 559-562. https://doi.org/10.1201/b16058-85.
23. Supandi, Zakaria, Z., Sukiyah, E., Sudradjat, A. "New Constants of Fracture Angle on Quartz Sandstone". ***International Journal on Advanced Science, Engineering and Information Technology***, Vol. 10, No. 4, (2020). DOI: 10.18517/ijaseit.10.4.8272
24. Supandi, "Determination Material Properties on Bedding Contact at The Low-Wall Part of Coal Mine", in ISRM European Rock Mechanics Symposium 2014, ISRM, (2014), 903-907. https://doi.org/10.1201/b16955-155

Persian Abstract

چکیده

حفظ ثبات تأسیسات عمومی ، به ویژه جاده های عمومی ، بسیار ضروری است ، بنابراین تلاش هایی برای تثبیت باید انجام شود. آب حاصل از تراوش که از لایه ماسه سنگ خارج می شود ، مواد را با ذرات ریز حمل می کند و این باعث می شود انسجام سنگ کاهش یابد و در نتیجه منجر به شستشوبستر جاده شود. در نتیجه تمیز کردن ، لایه بیش از حد می شود و می تواند ثبات جاده را مختل کند. این مطالعه برای ارائه توصیه ای ساده اما قابل اندازه گیری برای حفظ ثبات جاده پس از شکست تلاشهای تثبیت قبلی انجام شده است. در این روش از روش مکانیک سیالات استفاده شده است که در آن به آب حاصل از فضای خالی شکل گرفته است بدون اینکه ذرات ریز (سیمان) از فضای بستر جاده تخلیه کند خارج شود. تجزیه و تحلیل نتایج نشان داده است که خروج آب با استفاده از روش اجزای محدود با نصب لوله تخلیه افقی انجام گردید. نتیجه تجزیه و تحلیل نشان می دهد که نصب زهکشی افقی به خارج شدن آب بدون ایجاد یک لایه بیش از حد کمک می کند. تخلیه افقی توصیه شده ۸ متر طول با شیب حداقل ۳٪ و طول ۱ متر است که بایستی منبع آب شکل گرفته از شن و ماسه و سنگ عبور کند و با استفاده از این روش می توان ثبات جاده را حفظ کرد و تثبیت بستر جاده را به روشی آسان ، ارزان و قابل اجرا در آورد.

Simple Slope Stabilization on Quartz Sandstone using Horizontal Drain

ORIGINALITY REPORT

6%	4%	2%	0%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	mafiadoc.com Internet Source	1%
2	Y. Issa. "Effect of Adding Crushed Glass to Asphalt Mix", Archives of Civil Engineering, 2016 Publication	1%
3	www.geomatejournal.com Internet Source	<1%
4	www.serenityvista.com Internet Source	<1%
5	Supandi. "Engineering geology consideration for low-wall stability analysis in open-pit coal mine", Geotechnical and Geological Engineering, 2021 Publication	<1%
6	docplayer.net Internet Source	<1%
7	dr.ntu.edu.sg Internet Source	<1%

8	edoc.site Internet Source	<1%
9	sazeboresh.ir Internet Source	<1%
10	www.ije.ir Internet Source	<1%
11	Mohd Ashraf Mohamad Ismail, Soon Min Ng, Ismail Abustan. "Parametric study of horizontal drains for slope stability measure: A case study in Putrajaya, Malaysia", KSCE Journal of Civil Engineering, 2016 Publication	<1%
12	Supandi Sujatono. "The determination of mine waste dump material properties through back analysis", Journal of King Saud University - Engineering Sciences, 2021 Publication	<1%
13	mjms.mums.ac.ir Internet Source	<1%
14	polymerupdate.com Internet Source	<1%
15	www.iranstyle.ir Internet Source	<1%
16	"Soil Dynamics and Soil-Structure Interaction for Resilient Infrastructure", Springer Science and	<1%

Business Media LLC, 2018
Publication

17	www.tebinja.com Internet Source	<1%

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	Off		