Analysis of Slope Stability in the Coal Mining Area of KUD Sinamar Sakato, Jorong Sinamar, Nagari Sinamar, Asam Jujuhan, Dharmasraya, West Sumatra

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Abstract. *KUD Sinamar Sakato conducts mining with open pit mining method, open pit mining will always face the problem of slope stability, if the slope formed from the excavation is not considered properly, it can lead to potential landslides. Based on observation data, KUD Sinamar Sakato has a slope with a height of 78 metres and an angle of 78^o, KUD Sinamar Sakato also does not have information about the physical and mechanical properties of the slope of the Mining Pit, making it difficult for companies to conduct geotechnical studies. Based on the analysis of safety factors using slide v 6.0 software using the Morgenstern-Price method, the slopes of KUD Sinamar Sakato are unsafe in saturated conditions which have FK 1.095, so it is necessary to make improvements to the slope geometry, the improvements made are reducing the slope of the slope to 73^o and the resulting saturated FK is 1.360, the slope is in a safe condition, then the second recommendation is to add a bench without changing the angle, where the bench is added at a height of 35 metres with a bench width of 4 metres, the saturated FK is 1.361, where the slope is in safe condition.*

Keywords: *Safety factor, Slump, Morgenstern-Price, Slope stability, Open pit mine.*

1 Introduction

Mineral and coal mining activities in the open space in the form of excavation and stockpiling will always face slope stability problems. These slopes are active mine slopes, ore/coal stockpile slopes, overburden slopes, and infrastructure building slopes such as mine slopes, slopes around buildings.

The stability of open pit mine slopes in the mining industry is one of the important issues, this is related to the increase in production of mining companies in Indonesia, as a result of which mining companies widen and deepen excavations [1].

KUD Sinamar Sakato conducts mining with the open mining method, which uses excavators to divide the material, KUD Sinamar Sakato will continue to widen and deepen the excavation of course the slopes formed will be higher so as to create the potential for landslides on the slopes in the KUD Sinamar Sakato mining area if not properly considered.

Based on observations during observations on 8 September 2023 - 14 September 2023 in the coal mining pit of KUD Sinamar Sakato, researchers found that the slope of KUD Sinamar Sakato has an overall height of 78 meters with a slope angle of 78^o, which is composed of Sandstone, Claystone and there is a coal seam, because there are still coal reserves on the slope, KUD Sinamar Sakato will continue to excavate and widen the excavation, so that the slopes that will be formed really need to be studied so that the geometry used is a safe geometry against landslides, so that production can run smoothly without any interference.

2 Research Location

The research was conducted at KUD Sinamar Sakato located in Nagari Sinamar, Asam Jujuhan, Dharmasraya, West Sumatra.

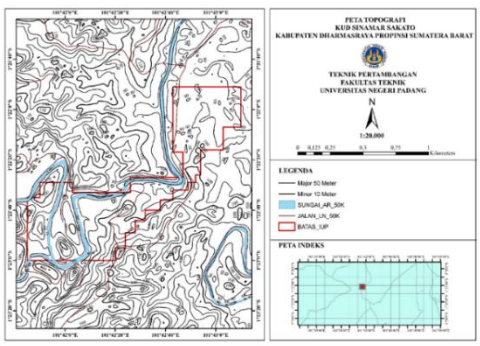


Fig 1.Coal Mining Location Map of KUD Sinamar Sakato.

KUD Sinamar Sakato is located at coordinates 101 41'45" - 101 42'20" East and 001 21'51" - 001 23'00" LS. KUD Sinamar Sakato has an IUP area of 197.33 Ha according to Regional Regulation No.4 of 2009.

3 basic theory

3.1 Slopes

Slopes are the outer layers of the earth that form a certain angle of inclination with a flat plane. Slopes can be both man-made and naturally occurring. Examples of naturally occurring slopes include: river slopes and ravines, while man-made slopes include: excavations and embankments, open pit mine walls and embankments [2].

3.2 Concept of Slope Stability

According to Irwandy Arif (2015:4). In conditions where the retaining force (against landslides) is greater than the driving force, the slope will be in a stable (safe) condition. However, if the retaining force is less than the driving force then the slope is unstable and landslides can occur, to express or weight the level of slope stability, the term safety factor is known [3].

Production activities will be disrupted and cause production to be discontinued if the slope formed by the mining process (Pit-slope) is unstable and cannot support mining operations (dams, roads, etc.). Therefore, slope stability analysis is an important step that must be carried out at the design, mining and post-mining stages so as not to disrupt the smooth production and ensure the safety of employees and equipment [3].

To evaluate the level of slope stability, a slope stability analysis is conducted. The term slope stability can be defined as the strength of blocks on an inclined surface (measured from the horizontal line) against collapsing and sliding [4].

3.3 Safety Factor

A common way to express the stability of a slope is with a factor of safety. Slope stability is usually expressed in terms of a factor of safety (FK) which is defined as the ratio between the retaining force that keeps the slope stable, and the driving force that causes a landslide. If the retaining force is greater than the driving force, then the slope is in a steady state. formula of the safety factor [3]:

$$\text{Safety Factor (SF)} = \frac{ResistingForce}{Driving\ Force} \tag{1}$$

Description;
SF < 1 : means the slope is unstable
SF = 1 : meaning that the slope is in a critical state
SF > 1 : means the slope is stable

3.4 Factors Affecting Slope Stability

Slope stability will change over time. This is caused by changes in pore water pressure, shear stress, and slope load, leading to changes in the shear strength of the material. These changes are generally caused by seasonal changes and weathering processes. Here are some factors that affect slope stability [5]:

3.4.1 Slope Geometry

Geometry that affects the stability of the slope such as height and angle of the slope, the higher and greater the angle of slope of a slope then the stability of the slope will be reduced.

3.4.2 Human Activity

Mining activities can affect slope stability such as vibration from haulage and loading equipment.

3.4.3 Geological Structure

The structure includes cracks, bedding planes, folds, joints, and defects. To reduce slope stability, structures are weak points and locations where water seeps in.

3.4.4 Water Presence

Slope stability is significantly affected by the presence of water, especially groundwater. Due to pore water pressure in the groundwater, uplift forces can occur that weaken the shear strength and make the slope more prone to slipping.

3.4.5 Physical and Mechanical Properties of Slope Constructing Materials

Physical properties that affect the stability of the slope include content weight, porosity and moisture content. In addition to the influence of physical properties, slope stability is also influenced by the mechanical properties of the slope constituent materials such as shear strength with cohesion parameters and inner shear angle. The stronger the constituent material, the more stable the slope, and the less likely a landslide will occur. To determine the physical and mechanical properties, laboratory testing was conducted to obtain the content weight, cohesion and inner shear angle.

a. Specific gravity

$$\text{Specific gravity} = \frac{Wo}{Wo-Ws} \tag{2}$$

b. Content Weight

Natural content weight $= \frac{Wn}{Ww-Ws}$ (3)

Dry content weight $= \frac{Wo}{Ww-Ws}$ (4)

Saturated content weight$= \frac{Ws}{Ww-Ws}$ (5)

c. Direct Shear Strength

The values of cohesion (c) and Friction Angle(Φ) were obtained from laboratory tests, namely direct shear strength tests. To find out the value of cohesion and inner shear angle, it is expressed in the Mohr-Coulomb equation as follows:

$\tau_{nt} = \sigma n \tan \Phi + c$ (6)

Description;

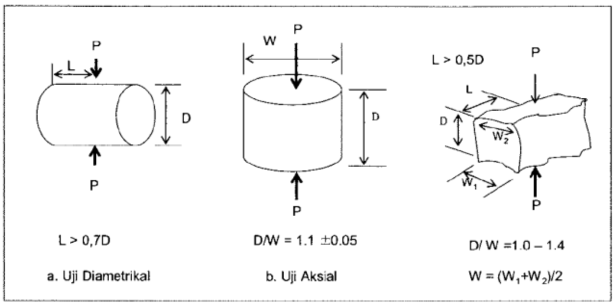
Wn = Natural weight of sample (g)
Ww = Saturated weight of the sample that has been put into the desiccator for 24 hours (g)
Ws = Weight of sample floating in water (g)
Wo = Weight of sample that has been in the oven (g)
Tnt = shear stress (Kn/m^2)
σn = normal stress (Kn/m$^{2)}$
Φ = Friction Angle(◦)
C = Cohesion (Kn/m^2)

3.4.6 Weather/Climate

Temperature is affected by climate change. Rapid temperature variations that accelerate the weathering process will cause landslides.

3.5 Point Load Index Test (PLI)

The compressive strength value of the tested rock was determined using Point Load Index testing conducted in the laboratory. The UCS value is then obtained by converting the rock compressive strength test results from the PLI test. The point load testing method can be used in the field to calculate the UCS value of rocks indirectly[6].



Source: Made Astawa Rai dkk (2014)

Fig 2. Sample Point Load Index Test

In the calculation there must be a correction factor (F) if the sample diameter is not 50mm, using the following equation.

$$F = \left(\frac{d}{50}\right)^{0.45} \quad (7)$$

After the correction factor is obtained, it is then entered into the equation to get the Point Load Index value, which is as follows.

$$I_s = F \frac{P}{D^2} \quad (8)$$

Description :
F = Correction Factor (if the sample is not 50mm)
d = Sample Diameter (mm)
D = Pressing Conus Distance (mm)
P = Maximum Load of Broken Sample (Newton)
Is = Point Load Index (mpa)

After obtaining the Point Load Index value. UCS can be determined based on the correlation equation between compressive strength and PLI found in the following table.

Table 1. Equation of the relationship between compressive strength and PLI according to experts

Reference	*Equation*	*Rock Type*
Broch & Franklin (1972)	*σc = 24ls(50)*	*Sandstone*
Bieniawski (1975)	*σc = 23 ls(50)*	*Igneous rocks, sedimentary rocks*
Brook (1985)	*σc = 22ls(50)*	-
Singh (1981)	*σc = 18,7ls(50)*	*Sandstone and shale*
Vallejo et al. (1989) - shale	*σc = 12,5ls(50)*	*Shale*
Vallejo et al. (1989) - *sandstone*	*σc = 17,4ls(50)*	*Sandstone*
Kramadibrata (1992)	*σc = 11,82ls(50)*	*Sandstone and claystone*
Gunsallus & Kulhawy (1992)	*σc = 16,5ls(50) + 51*	*Dolostone, sandstone, limestone*
Cargill & Shakoor (1990)	*σc = 23ls(50) + 13*	*Sedimentary rocks, metamorphic rocks*
Kahraman (2001)	*σc = 24ls(50) + 9,51*	*Igneous rocks, sedimentary rocks, metamorphic rocks*
Tsidzi (1990)	*σc*=*Is*(50)0,03 +0,003*Is*(50)	*Metamorphic rocks*

Sumber: Made Astawa Rai dkk (2014)

3.6 Rocklab

The latest iteration of the generalised Hoek-Brown failure criterion is the basis for the Rocklab software application, which is used to determine rock mass characteristics. The Hoek-Brown failure criterion is implemented in a userfriendly and straightforward manner in Rocklab, which allows users to quickly and reliably estimate rock mass properties and visualise how changes in rock mass parameters affect the failure envelope. The software uses the following data input parameters.

3.6.1 Free Compressive Strength (sgics)

This is the Uniaxial Compressive Strength value obtained from laboratory testing.

3.6.2 Rock Parameters (mi)

The Intact Rock Parameter (Mi) value is known based on the type of lithology in the rocks that make up the opening hole. The Mi value of a rock can be seen on the Pick Mi Value tab in the Rocklab software.

3.6.3 Geological Sterngth Index (GSI)

Geological Strength Index (GSI) proposed by (Marinos and Hoek 2005). This method emphasises geological observations for rock mass characteristics, material description, developed structures, geological history, and specific development for estimation of material properties of rocks. The purpose of this method is to estimate the properties of rock masses. This assessment is based on the parameters of lithology, structure, and surface conditions of discontinuities in the rock mass, and it is estimated from visual assessment of the rock mass in the outcrop.

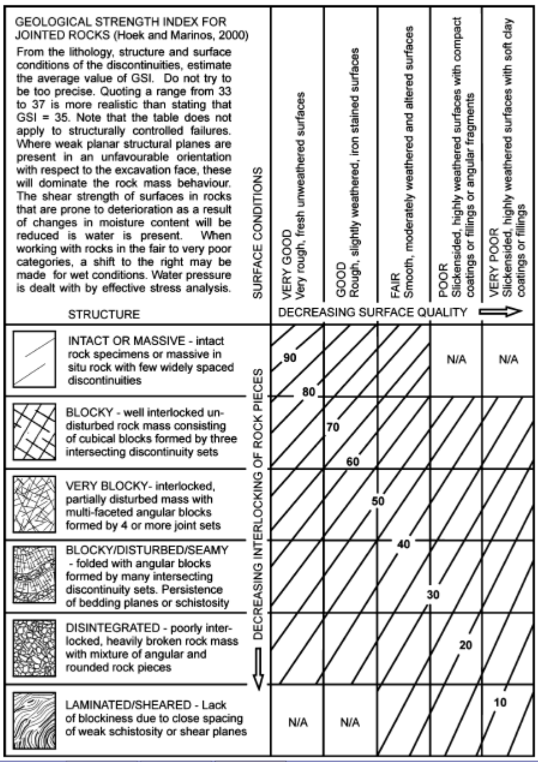


Fig 3. Geological Strength Index oleh Hoek and Martinos (2005)

3.6.4 Distraction Factors (D)

Represents the effect of blasting on the study site, if there is no blasting activity then D is 0.

3.7 Slope Stability Analysis Method

In this study the authors used the slice method, namely the Morgenstern-Price Method is a method with a boundary equilibrium basis developed by Morgenstern and Price in 1965, the method fulfils all force and moment equilibrium conditions. and the method can be applied to slopes with circular and non-circular landslide types, also well applied to slopes with homogeneous and layered materials [7].

4 Research Methods

4.1 Research Design

4.1.1 Type of Research

Quantitative research was used in this study. This is because numerical data will be used in the investigation. According to Kontjojo (2009:11), quantitative research is a method of discovering knowledge that uses numerical data to analyse information about observed topics.

4.1.2 Object of Research

The object of research is the slope in the coal mining pit of KUD Sinamar Sakato.

4.1.3 Research Time

Field observation activities were carried out on 8 October 2023 - 27 October 2023..

4.2 Types and Sources of Research Data

4.2.1 Primary Data

The data can be in the form of slope geometry, rock samples, and test results of physical and mechanical properties.

4.2.2. Secondary Data

Secondary data is pre-processed data that can be obtained from companies, research reports, and some other literature, such as topographic maps, geological maps, and stratigraphic data.

4.2.3 Data Processing Technique

a. Testing the physical and mechanical properties of the previously prepared samples, to obtain parameters such as content weight, cohesion and inner shear angle.

b. Analyse the stability of the slope to determine the value of the slope safety factor in natural, dry and saturated conditions. With the help of slide 6.0 software using the Morgenstern-Price method. If the safety factor shows that the slope is unstable, an evaluation of the slope geometry will be carried out.

c. valuate the geometry of the slope to fulfil the safety factor standard based on KEPMEN Number 1827K/30/MEM/2018.

5. RESULTS AND DISCUSSION

5.1 Research Data

5.1.1 Research Location

The research site is located on the slope of the mining pit of KUD Sinamar Sakato, jorong Sinamar, Nagari Sinamar, Asam Jujuhan District, Dharmasraya Regency, West Sumatra Province. The slope is located at coordinates X: 800311; Y: 9847515 with an elevation of 37-101 masl.

5.1.2 Physical Properties Testing Data

Table 2. Claystone Physical Properties Test Result Data

	Sampel Code	Wn (g)	Ww (g)	Ws (g)	Wo (g)
Claystone	CC-1	98.87	104.45	46.12	91.23
	CC-2	67.16	72.67	31.52	60.56
	CC-3	78.96	82.78	36.17	72.34

Table 3. Sandstone Physical Properties Testing Data

	Sampel Code	Wn (g)	Ww (g)	Ws (g)	Wo (g)
Sandstone	SS-1	73.47	75.78	43.57	69.34
	SS-2	50.37	54.53	31.25	49.25
	SS-3	65.32	69.12	36.78	59.45

Table 4. *Coal Physical Properties Testing Data*

	Sampel Code	Wn (g)	Ww (g)	Ws (g)	Wo (g)
Coal	BB-1	102.38	112.33	27.29	92.34
	BB-2	80.95	89.58	21.86	73.43
	BB-3	121.51	130.3	32.21	114.23

Description:
Wn= Natural Weight
Ww= Saturated Weight
Ws= Floating Weight of Sample in Water
Wo= Dry Weight

5.1.3 Mechanical Properties Testing Data

a. Direct Shear Strength Test

Direct shear strength testing is only carried out on claystone and coal materials, to determine the value of cohesion and inner shear angle, because sandstone rocks do not meet the requirements in direct shear strength testing, sandstone is not carried out direct shear testing. The following data is the result of direct shear strength testing.

Table 5. Claystone Direct Shear Strength Test Result Data

Sampel Code	weight (kn)	Shear stress (kn)	Diameter (cm)	Area (cm^2)
CC-1	1	1	5.3	22.0507
CC-2	2	1.5		
CC-3	3	2.2		

Table 6. Coal Direct Shear Strength Test Result Data

Sample Code	Weight (kn)	Shear Stress (kn)	Diameter (cm)	Area (cm^2)
BB-1	1	0.85	5.3	22.0507
BB-2	2	1.4		
BB-3	3	1.9		

b. Point Load Index (PLI*)*

PLI testing is carried out on sandstone samples, which later the PLI value will be converted to the UCS value.

Table 7. Sandstone Load Index Point Testing Data

Sample Code	Diameter (mm)	Length (mm)	Conus Distance (mm)	P	
				KN	N
SS-1	53	86.9	50.9	0.583	583
SS-2	53	96.2	50.5	0.673	673
SS-3	52.5	103.3	51.1	0.694	694

5.2 Data Analysis

5.2.1 Analysis of Physical Properties of Rocks Testing Data

Based on the data from the physical properties test results in tables 2,3,4, calculations are carried out using equations 3,4,5 in the theoretical study, so that the results of testing the average physical properties of rocks are as follows.

Table 8. Rock Content Weight Value

Rock Type	Natural content weight (gr/cm3)	Dry content weight (gr/cm3)	Saturated content weight (gr/cm3)
Claystone	1.6737	1.5292	1.7776
Sandstone	2.1548	2.0355	2.2774
Coal	1.2127	1.1116	1.3240

5.2.2 Analysis of Rock Mechanical Properties Testing Data

a. Direct Shear Strength Test

The analysis is carried out by first calculating the normal stress and shear stress, after which a mohr diagram is made to determine the value of cohesion and Friction Anglefrom the mohr diagram equation. So that the cohesion and shear angle in claystone and coal are obtained as follows,

Table 9. Results of Direct Shear Strength Testing Data Analysis

Rock Type	Cohesion (Kpa)	Friction Angle(°)
Claystone	172.18	30.96
coal	149.73	27.7

b. Point Load Index Test

The following are the results of the data analysis of the point load index test results.

Table 10. Table of Data Analysis Results of Point Load Index Testing Results

Sample Code	Diameter (mm)	Conus Sidtance (mm)	F	Is (mpa)	UCS (mpa)
SS-1	53	51.9	1.02657	0.22219	5.33252
SS-2	53	51.5	1.02657	0.26049	6.25172
SS-3	52.5	51.1	1.0222	0.27168	6.52025
Rata-Rata					6.03483

5.2.3 Rocklab Software Analysis Result Value

By entering the Sgics, Mi, GSI, and D data into the rocklab software, we obtained a cohesion of 143 kpa and an Friction Angleof 26.86°.

5.2.4 Safety Factor Analysis Results.

Safety factor analysis using slide 6.0 software using the Morgenstern-Price method, so that the safety factor of the KUD Sinamar Sakato Coal Mining Pit slope is obtained as follows.

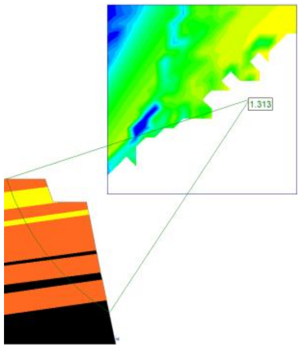


Fig 4. Slope Safety Factor under Natural Conditions

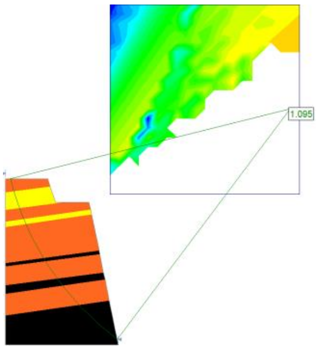


Fig 5. Slope Safety Factor in Saturated State

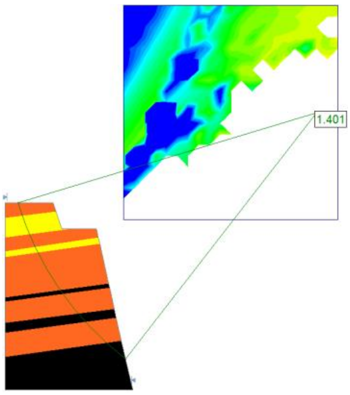


Fig 6. Slope Safety Factor in Dry State

Based on the value of the safety factor in the figure above, it can be seen that the slope of the KUD Sinamar Sakato Coal Mining Pit will be in a critical condition and can occur landslides when the slope is saturated, which has FK 1.095, therefore it is necessary to make efforts to improve the stability of the slope.

5.2.5 Efforts to Improve Slope Stability

Efforts to increase slope stability were carried out with two experiments, the first to reduce the angle and the second to make a bench. The following is the value of slope safety factor in saturated state after modification,

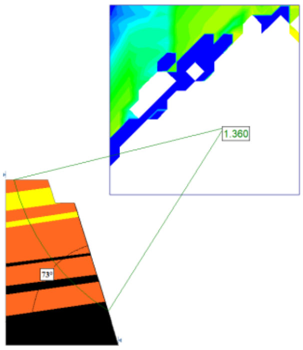


Fig 7.. Slope Safety Factor value after changing the slope angle to 73°

By reducing the slope angle to 73°, in the saturated slope state, a factor of safety of 1.360 is obtained, which means that the slope is already in a safe condition.

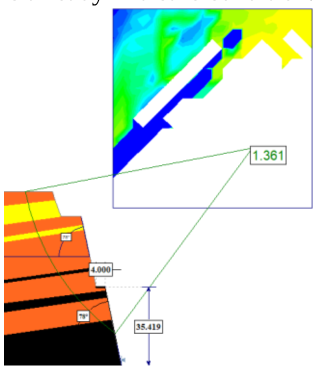


Fig 8. Slope Safety Factor after Bench Addition on Slope

By adding a bench to the slope, where the bench is placed at a height of 35 metres with a bench width of 4 metres, the safety factor of 1.361 is obtained.

6 Conclusions and Suggestions

6.1 Conclusions

Based on the results of the analysis and discussion of research data, the following conclusions can be drawn.

a. Assess the physical and mechanical properties of the rock,

   1) The claystone content weight values obtained are natural content weight of 1.6737 gr/cm^3, dry content weight of 1.5292 gr/cm^3, saturated content weight of 1.7776 gr/cm^3.
   2) The coal content weight values obtained are, natural content weight of 1.2127 gr/cm^3, dry content weight of 1.1116 gr/cm^3, saturated content weight of 1.3240 gr/cm^3.
   3) The sandstone content weight values obtained are, natural content weight of 2.1548 gr/cm^3, dry content weight of 2.0355 gr/cm3, and saturated content weight of 2.2774 gr/cm3.
   4) The results of testing the mechanical properties in the laboratory, namely testing the direct shear strength of the Claystone material, obtained a cohesion of 172.18 kn/m^2, while for the Coal material obtained a cohesion of 149.73 kn/m^2, with an inner shear angle of 27.70o. For PLI testing of sandstone material, the average compressive strength is 6.0.3483MPa, then the data is processed using Rocklab software so that the sandstone cohesion is 143 kn/m^2 with an inner shear angle of 26.86°.

b. Based on the value of the safety factor, the slope of the KUD Sinamar Sakato coal mining pit is not safe when the slope is saturated, which has a safety factor of 1.095.

c. After reducing the slope from 78° to 73°, the slope safety factor value of 1.360 was obtained, while the recommendation of adding a bench at a height of 35 metres with a bench width of 4 metres obtained a safety factor of 1.361, the slope was in a stable and safe condition.

6.2 Suggestion

a. To avoid landslides on mining slopes, KUD Sinamar Sakato is expected to pay attention to the use of safe geometry design.

b. KUD Sinamar Sakato is expected to conduct regular monitoring of slope stability.

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