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Geotechnical comparative analysis of quarry A and quarry D at PT Indocement Prakarsa Tbk, Palimanan–Cirebon Unit

Rifki Adhy Santika[1]
[1] Jenderal Achmad Yani University
Correspondence: rifki.adhy253@email.com

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ABSTRACT=
The limestone mining industry plays a strategic role in supporting infrastructure development in Indonesia. PT Indocement Tunggal Prakarsa Tbk, Palimanan-Cirebon Unit, is one of the leading companies engaged in limestone mining using the quarry method. This study aims to analyze the geotechnical conditions and slope stability of Quarry A and Quarry D through a qualitative descriptive-inductive approach. Data were obtained through geotechnical mapping, scanline measurements, rock mass classification using the RMR method, as well as stereographic analysis and slope safety factor (SF) calculations. The results show that both quarries have generally good rock quality, with RMR values ranging from 60–75 and safety factor values mostly above 1.0, indicating relatively stable slope conditions. Identified potential failure types include wedge and planar failures. A comparison between the two sites shows that Quarry A tends to have slightly better rock quality than Quarry D. The study recommends routine slope monitoring, additional scanline measurements in vulnerable areas, and enhanced safety education for mining workers.

INTRODUCTION

According (Saputra & Widianti, 2024) Indonesia is an archipelagic country rich in natural resources and one of the world's leading producers of coal to meet global market demand. Most coal mining activities in Indonesia use the open-pit mining method. In this system, the deepening and steepening of the pit often occur, resulting in slopes with high inclinations that are susceptible to landslides due to increased loads and external forces. Slope stability in mining operations is influenced by various factors, such as geological conditions, overall slope geometry, and groundwater level position. Additionally, the stability of rock slopes also depends on the presence of weak planes or discontinuity surfaces. The excavation process can alter the balance of forces acting on a slope, potentially triggering slope failures.

The limestone mining industry plays an important role in Indonesia's economy, contributing significantly to infrastructure development and the construction sector. PT Indocement, as one of the leading cement producers in Indonesia, holds a key role in supplying limestone needed for cement production. Therefore, the limestone mining operations of PT Indocement have a substantial impact on the national industry and the overall economy.

PT Indocement Tunggal Prakarsa Tbk, Palimanan-Cirebon Unit, is a limestone and coal mining company located in Gempol District, Cirebon Regency, West Java. The mining method used at this site is the quarry method, which is an open-pit mining system for extracting non-metallic minerals.

Based on the findings of the Geotechnical Study Team of PT Indocement Prakarsa Tbk, Palimanan-Cirebon Unit (Tim Unisba Geoteknik, 2019), a geotechnical assessment was conducted to evaluate potential slope instability problems in order to ensure that the constructed slopes remain safe and do not pose any hazards. Therefore, this study is expected to provide valuable information and serve as a reference in slope design to mitigate potential challenges that may arise during ongoing mining operations.

Theoretical Framework

General Conditions of the Research Area

Based on field observations and the collection of secondary data from various references, it was found that the geological formations in the study area consist of limestone, breccia, claystone, and sandstone. In addition, each mining location within the research area possesses limestone of varying quality levels. Each quarry site is divided into several points based on elevation levels above sea level.

Local Geology

Geographically, the study area is located in Cirebon Regency, West Java Province, within the latitude range of 6°30' to 7°00' South and longitude range of 108°40' to 108°48' East. Cirebon Regency covers an area of 990.36 square kilometers, divided into 40 districts. With its geographic position in the southern part of West Java, the regency has diverse natural resource potentials.

Figure 1. Map of West Java
Source: (petatematikindo.wordpress.com, n.d.)

Geology

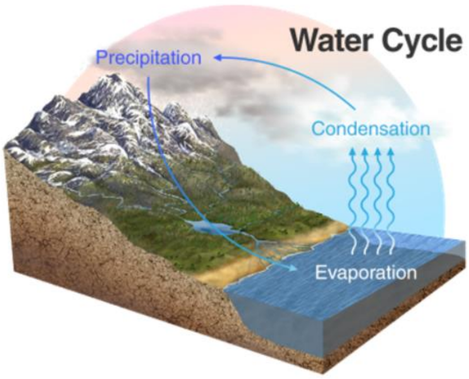

Figure 2. Hydrological Cycle
Source: (Minyak.up45.ac.id, n.d.)

Geology is a branch of earth science that studies everything related to planet Earth and its contents. It is a scientific discipline that discusses the properties and materials that form the Earth, as well as the structural processes that occur both within and on the Earth's surface.

Geology is generally divided into two main branches — physical geology and dynamic geology. Physical geology focuses on studying the Earth's physical properties, such as the structure and composition of materials that make up the planet, along with the layer of atmosphere surrounding it, particularly the part that interacts directly with the Earth's surface. These interactions are driven by solar energy and the force of gravity. The processes involved include weathering, erosion, transportation, and deposition.

The diagram above illustrates the interrelationships and mutual influences among the lithosphere (the Earth's outermost solid layer), atmosphere, and hydrosphere, which together create the biosphere — the region of the Earth where all three systems interact and support life. This interaction results in the Earth's dynamic nature. The biosphere encompasses all forms of life, extending from the ocean floor upward through several kilometers of the atmosphere, forming a continuous and interconnected zone of life on Earth.

Geotechnical Engineering

According to (Prof. Dr. Ir. Irwandy Arif, n.d.) geotechnical engineering is an applied field of earth science that deals with the study and application of engineering principles to the Earth's materials. Geotechnical studies are always related to natural materials, both from the surface and subsurface of the Earth, in the form of soil and rock.

In engineering terms, soil can be defined as a loose aggregation of minerals, organic materials, and sediments containing fluids and gases that fill its pores. Meanwhile, rock is a compact and solid mass composed of one or more minerals. Although definitions of these materials may vary across disciplines, in geotechnical engineering the aforementioned definitions are used as the standard reference.

Classification of Mass Movements

The terms landslide and mass movement are often used interchangeably, as both refer to the displacement of soil or rock mass from its original position. To define landslide accurately, it is necessary to first understand mass movement.

Mass movement refers to the movement of soil or rock mass vertically, horizontally, or diagonally from its initial position due to gravitational forces. This category includes creep, flow, and landslide phenomena.

Based on this definition, a landslide is considered one type of mass movement. If vertical movement of soil or rock mass occurs—causing bulging or deflection due to foundation failure—it can also be classified as a form of mass movement. Therefore, the term encompasses a wide range of ground displacement processes driven primarily by gravity and influenced by factors such as material composition, slope geometry, and external loading.

Slope Stability

A slope is considered stable (safe) when the resisting forces acting against sliding are greater than the driving forces. Conversely, when the resisting forces are smaller than the driving forces, the slope becomes unstable and failure (landslide) occurs.

To express the degree of slope stability, the concept of the Safety Factor (SF) is used. The safety factor indicates the stability level of a slope and is essential for preventing future landslide hazards.

From the diagram (not shown here), it can be observed that the forces acting on a slope include the gravitational force, which produces both driving and resisting forces. To ensure that the material on the slope does not fail, the slope angle must be calculated according to the desired safety factor.

According to (Tuerah et al., 2021) the stability of a slope is determined by the ratio between the resisting shear strength (τ) and the driving shear stress (s), expressed through the equation of the safety factor (F):

$F = \tau / s$

Where:

If $F > 1$, the slope is categorized as stable.

If $F < 1$, the slope is considered unstable or has potential for failure.

If $F = 1$, the slope is in a state of equilibrium but may fail with minor disturbances.

This study adopts the criterion $F \geq 1.3$ as an indication of slope stability. Simulation results yielding $F < 1.3$ indicate unstable slope conditions, consistent with the regulations of the Ministry of Energy and Mineral Resources (Keputusan Menteri ESDM Nomor 1827 K 30 MEM 2018, 2018) concerning slope safety factors in mining areas.

Table 1. Safety Factor (SF) Criteria

Type of Slope	Consequence of Failure (CoF)	Acceptable Criteria	Static SF (min)	Dynamic SF (min)	Probability of Failure (PoF, SF ≤ 1)
Single Slope	Low to High	–	1.1	–	25–50%
Inter-ramp	Low	–	1.15–1.2	1.0	25%
	Medium	–	1.2–1.3	1.0	20%
	High	–	1.2–1.3	1.1	10%
Overall Slope	Low	–	1.2–1.3	1.0	15–20%
	Medium	–	1.3	1.05	10%
	High	–	1.3–1.5	1.1	5%

Geotechnical Analysis

Based on the geotechnical study by the (Tim Unisba Geoteknik, 2019), several aspects must be considered to obtain comprehensive data for geotechnical analysis, including: a) General overview of the company, b) Slope stability analysis, and c) Recommendations for slope design.

RESEARCH METHODS

The research methodology plays a crucial role in conducting a study as it serves to discover, develop, and verify facts or data related to the research object. In general, methodology refers to a systematic and standardized procedure used to collect and analyze data.

In this study, a qualitative method with a descriptive-inductive approach was applied. The descriptive approach aims to present an overview and explanation of the data and information gathered during the research process, while the inductive approach is based on reasoning and observation of empirical facts obtained from the field.

Data Processing and Analysis

According (Ririn, Budhi, n.d.), the process of data processing and analysis includes several stages as follows:

1 **Rock Structure Analysis** Geological structure illustration is carried out using the stereographic projection (stereonet) method to visualize the orientation of discontinuity planes. This analysis includes:
   a. Plotting the orientation of discontinuity planes,
   b. Determining the direction and plunge of the intersection line between two planes,
   c. Determining the angle of intersection between planes, and
   d. Plotting the direction of the internal friction angle.

2 **Slope Stability Analysis** Slope stability analysis is performed by identifying potential types of slope failure based on field geotechnical conditions, namely:
   a. Planar failure,
   b. Wedge failure,
   c. Circular failure, and
   d. Toppling failure.

3. Rock Mechanical Property Data Processing
   The mechanical properties of the rock are analyzed based on laboratory testing and slope geometry measurements, including:
   a. Determining slope geometry parameters, and
   b. Conducting indirect tensile strength testing (Brazilian test) to determine the rock’s tensile strength.

RESULTS AND DISCUSSION

Geotechnical Comparison Analysis of Quarry A and D

The purpose of the geotechnical comparison analysis is to compare the mechanical, physical, and environmental characteristics of various types of soil or geotechnical materials. This comparison is essential in designing construction or mining slopes according to planned configurations. The determining factors include:

1. Geotechnical mapping,
2. Sampling and geotechnical testing results, and
3. Slope stability analysis of the quarries.

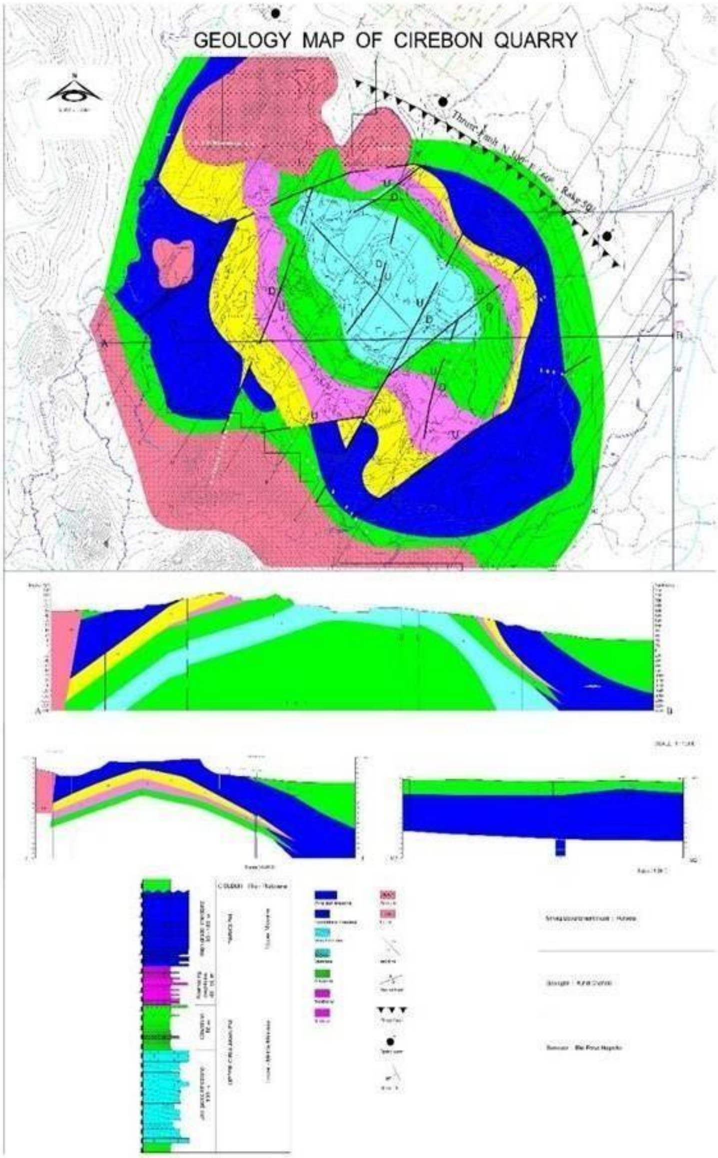

Figure 3. Geological Map of the Quarry
Source: Mining Department

The geological map of the quarry area illustrates the distribution and types of rock formations present at the mining site. Based on the map, the study area consists of several rock units such as limestone, claystone, sandstone, and breccia, which are distributed both laterally and vertically. The dominant geological formation is the Kromong Complex Limestone, a high-quality carbonate rock characterized by a high CaO content.

In addition, the presence of volcanic formations and andesitic intrusions indicates past tectonic and volcanic activity in the region. The map also shows geological structural patterns such as folds and joints, which are critical factors in slope stability analysis and mine design.

The existence of folded hill morphology and the orientation of discontinuity planes serve as key indicators for assessing landslide potential and for planning safe mining operations.

General Conditions of the Research Area

Figure 4. Research Location
Source: (Google Earth, n.d.)

The research area is located in Cirebon Regency, West Java Province, with local geological characteristics consisting of limestone, breccia, claystone, and sandstone. The physiography of the region includes steep to undulating hills, divided into several geomorphological units such as folded hill morphology, volcanic morphology, and fluvial morphology. The main geological structure found in this area is an anticlinal fold, composed predominantly of reef and clastic limestone formations.
The lithology of the study area consists of the Kromong Complex Limestone, Kaliwungu Formation, Andesite and Hypersthene Andesite Intrusions, and Kromong Complex Breccia.

Identification of Quarry A
Geotechnical Mapping and Rock Mass Classification (RMR)

Table 2. Scanline Data

Kuari	Kode Pengamatan	Arah Lereng *(Strike)*	Arah *Scanline (Strike)*	Nilai RQD
A	AP1	N 68ºE	N 76ºE	77.8%
	AP2	N 170ºE	N 170ºE	79.1%
	AP3	N 170ºE	N 170ºE	77.64%
	A'P1	N 76ºE	N 76ºE	76.05%

Source: Mining Department

The scanline measurements show varying Rock Quality Designation (RQD) values. Based on the Rock Mass Rating (RMR) classification method, Quarry A is categorized as having good rock quality, with the highest RMR value reaching 74. The A' Quarry location represents the main mining area, which contains the highest CaO concentration.

Stereographic Analysis

The stereographic analysis of Quarry A's slope identifies the presence of weak planes or joints that have the potential to cause wedge and planar failures. These structural discontinuities play an important role in assessing slope stability and in determining safe slope design configurations for continued quarry operations.

Table 3. Slope Stability Analysis of Quarry A

Quarry	Section	Elevasi (m)	Tinggi (m)	Sudut (º)	Faktor Keamanan (FK)			
					MAT 5	MAT 5	MAT 3	MAT 3
A	1	76	77.54	24	1.12	1.01	1.43	1.24

Quarry	Section	Elevasi (m)	Tinggi (m)	Sudut (⁰)	Faktor Keamanan (FK)			
					MAT 5	MAT 5	MAT 3	MAT 3
			91.283	22	1.35	1.15	1.59	1.36
			115.47	24	1.13	0.96	1.43	1.24
		40	129.175	22	1.27	1.08	1.59	1.36
			135.261	21	1.35	1.15	1.66	1.42
			173.948	21	1.22	1.05	1.53	1.32
		10	175.752	20	1.28	1.09	1.56	1.34
			175.641	19	1.34	1.14	1.61	1.36
	2	73	56.11	22	1.57	1.33	1.84	1.53
		40	89.832	20	1.5	1.25	1.78	1.49
			119.832	22	1.21	1.03	1.5	1.28
		10	138.686	20	1.35	1.14	1.59	1.36
			139.829	19	1.31	1.11	1.57	1.33
	3	77	52.87	14	2.59	2.04	2.81	2.14
		40	35.791	19	1.93	1.59	2.29	1.83
		10	53.957	40	1.47	1.22	1.79	1.47
	4	72.5	55.39	24	1.64	1.43	1.94	1.66
		70	65.494	27	1.57	1.35	1.84	1.57
		40	96.615	27	1.34	1.16	1.67	1.43
			99.04	25	1.36	1.19	1.64	1.43
		10	132.956	25	1.12	0.98	1.41	1.23
			137.11	22	1.34	1.15	1.63	1.41
	5	73	39.7	24	2.27	1.97	2.57	2.12
		40	34.45	30	1.6	1.33	1.93	1.61
		10	75.255	30	1.23	1.09	1.52	1.35
			104.188	25	1.5	1.31	1.83	1.58
	6	40	30.853	24	2.48	2.01	2.83	2.25
		10	60.853	40	1.19	1.09	1.53	1.39
			60.853	35	1.33	1.18	1.62	1.43
	7	40	9.142	11	8.78	4.41	9.48	4.5
		10	39.142	19	2.87	2.23	3.23	2.48

Source: Mining Department

Slope Stability Analysis:

The calculation of the Safety Factor (SF) was conducted across various sections with differing elevations, heights, and slope angles. The analysis results indicate that, in general, the SF values are greater than 1.0, signifying that the slopes are in a relatively stable and safe condition.

Identification of Quarry D

Table 4. Scanline Data of Quarry D

Kuari	Kode Pengamatan	Arah Lereng (*Strike*)	Arah *Scanline* (*Strike*)	Nilai RQD
D	SC1	N195°E	N 72°E	95,49%
	SC2	N205°E	N 75°E	96,55%
	SC3	N 205°E	N 73°E	95,68%
	SC4	N 210°E	N 82°E	95,72%
	SC5	N 210°E	N 88°E	96,30%
	SC6	N 230°E	N 79°E	93,60%

Source: Research Journal

Geotechnical Mapping and Rock Mass Classification (RMR)

(Azzahra, 2023) Scanline measurements were conducted to determine the Rock Quality Designation (RQD) values. The rock mass classification using the Rock Mass Rating (RMR) method indicates a good quality rating, with RMR values ranging between 60 and 75. Quarry D is located in the central part of the mining area and serves as one of the main extraction zones, containing high CaO concentrations.

Stereographic Analysis

The stereographic analysis reveals the presence of weak planes or joint sets that have the potential to cause wedge and planar failures. These failure types are influenced by the strike and dip orientations of the discontinuity planes relative to the strike and dip of the slope face. This analysis is crucial for identifying possible failure mechanisms and designing appropriate slope stabilization measures.

Table 5. Slope Stability Analysis of Quarry D

Quarry	Section	Elevasi (m)	Tinggi (m)	Sudut (^{0})	Faktor Keamanan (FK)			
					MAT 5	MAT 5 g	MAT 3	MAT 3 g
D	1	75	47.256	20	2.028	1.709	2.252	1.89
			57.018	48	1.059	0.984	1.52	1.411
		70	56.27	40	1.218	1.112	1.576	1.433
			56.06	35	1.313	1.196	1.62	1.468
			86.139	40	1.095	0.997	1.39	1.26
		40	85.326	35	1.178	1.067	1.48	1.335
			87.888	30	1.311	1.176	1.592	1.429
			112.711	30	1.23	1.108	1.517	1.36
		10	112.22	27	1.305	1.16	1.609	1.434
			117.08	25	1.394	1.235	1.807	1.596
	2	75	43.2	25	1.993	1.733	2.321	2.016
		70	53.888	41	1.038	0.959	1.414	1.302
			56.893	36	1.324	1.198	1.688	1.54
			83.888	41	1.194	1.079	1.479	1.332
		40	87.398	35	1.265	1.136	1.593	1.425
			87.66	32	1.313	1.174	1.629	1.455
			118.407	32	1.103	0.993	1.433	1.282
		10	119.119	30	1.155	1.031	1.49	1.325
			122.49	26	1.301	1.157	1.669	1.472
			123.44	25	1.339	1.187	1.751	1.551
	3	78	51.206	28	1.635	1.44	1.993	1.751
		70	61.906	41	0.991	0.914	1.342	1.236
			60.89	36	1.31	1.195	1.65	1.502
		40	89.923	35	1.164	1.06	1.497	1.358
			85.922	30	1.326	1.183	1.582	1.412
		10	115.842	30	1.079	0.97	1.377	1.233
			127.484	25	1.31	1.163	1.71	1.514

Source: Mining Department

Slope Stability Analysis

The slope stability analysis of Quarry D across various sections shows varying Safety Factor (SF) values. In general, the SF values are greater than 1.0, indicating that the slopes are in a relatively safe and stable condition.

Geotechnical Comparison Analysis of Quarry A and D

The geotechnical comparison analysis between Quarry A and Quarry D aims to compare the mechanical, physical, and environmental properties of the geotechnical materials at both sites. Key factors in this comparison include geotechnical mapping, geotechnical testing results, and slope stability analysis.

Both quarries exhibit good rock mass characteristics and show similar potential failure types—mainly wedge and planar failures—as indicated by stereographic analysis. The slope stability analysis also shows that both quarries generally have acceptable slope safety levels, although certain areas with lower SF values require closer monitoring.

a. Quarry A shows an RMR classification of 67–74, indicating good rock quality with variable geological structures. Stereographic analysis reveals potential wedge and planar failures. The average SF values exceed 1.0, confirming stable slope conditions.
b. Quarry D has RMR values between 60–75, with moderate to good rock quality. The slope stability analysis also shows that the quarry is in a safe condition. Overall, both quarries are stable, but Quarry A tends to have slightly better rock quality than Quarry D.

CONCLUSION

The study concludes that both Quarry A and Quarry D exhibit adequate slope stability. It is recommended to conduct routine monitoring, add additional scanline measurements in critical areas, and improve mine worker education regarding slope stability and landslide risk mitigation.

Conclusions

1. General Conditions of the Study Area
   a. The study area is located in Cirebon Regency, West Java Province, characterized by unique geological formations, soil types, geological structures, and geological history.
   b. The region's physiography consists of steep to undulating hills, including folded hills, volcanic hills, and fluvial morphology.
   c. The main geological structures include anticlines and several faults, with lithological variations such as Kromong Complex Limestone, Kaliwungu Formation, Andesite and Hypersthene Andesite Intrusions, and Kromong Complex Breccia.
2. Quarry A
   a. Scanline Measurements were carried out at several points to determine RQD values, providing information on the quality of the rock mass.
   b. The Rock Mass Rating (RMR) classification shows good quality, with the highest rating reaching 74.
   c. Stereographic analysis on Quarry A slopes indicates potential wedge and planar failures, influenced by the strike direction and discontinuity planes.
   d. Slope stability analysis was performed across several sections with varying elevations, slope heights, and angles.
   e. The Safety Factor (SF) values obtained were generally greater than 1.0, confirming that the slopes are relatively safe.
3. Quarry D
   a. Scanline Measurements were conducted at various points to determine RQD values, providing insights into the rock mass quality, essential for assessing slope strength.
   b. The RMR classification indicates that most sections fall under the good rock quality category (60–75).
   c. Stereographic analysis helped identify potential failure mechanisms, particularly wedge and planar failures, influenced by the orientation of the discontinuity planes relative to the slope face.
   d. Slope stability analysis was conducted at multiple sections with different elevations, slope heights, and angles.
   e. The Safety Factor (SF) values indicate that the slopes are generally safe and stable.

Recommendations

1. Routine Monitoring: Conduct periodic monitoring of slope conditions in both quarries to ensure that no significant changes occur that could compromise slope stability.

2. Additional Scanline Measurements: Perform additional scanline measurements at critical points, especially in areas with high-risk potential, to obtain more detailed rock quality data and improve understanding of the geotechnical conditions.
3. Risk Mitigation Planning: Develop a comprehensive risk mitigation plan based on the findings of the slope stability analysis. This plan should include specific measures to reduce potential hazards and increase slope safety factors.
4. Education and Training: Provide training and educational programs for mine workers and engineers on best practices for slope monitoring, maintenance, and stability management to enhance safety awareness and operational skills.

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