Preliminary Study Movement Monitoring to Determine Condition Stability of High-Risk Infrastructure Based on the Results of Back Analysis at PT KPC's Bengalon Site

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ABSTRAK: Pemantauan pergerakan lereng menggunakan monitoring prisma merupakan salah satu metode analisis sederhana yang digunakan dalam memantau kestabilan timbunan. Metode pemantauan ini dapat memberikan data pergerakan vertikal maupun horizontal yang menghasilkan total vektor, besaran pergerakan, dan laju pergerakan timbunan dan relatif terhadap waktu pengambilan data. Secara umum penentuan kondisi kestabilan timbunan berdasarkan kurva pergerakan terhadap waktu dibagi menjadi tiga kategori yang dilihat dari pola laju pergerakannya yaitu pola regresif (laju pergerakan mendekati nol), pola linier (terdapat laju pergerakan awal), dan pola progresif (peningkatan laju pergerakan). Setelah melakukan uji balik terhadap kejadian longsor cukup besar pada timbunan beresiko tinggi di site Bengalon yang memiliki rekaman data pembacaan prisma mulai dari kondisi stabil, linier, progresif, kondisi longsor, sampai pada kondisi stabil kembali untuk menentukan batas ambang laju pergerakan. Berdasarkan uji balik tersebut, maka didapatkan nilai laju pergerakan pada interval data 48 jam dapat dijadikan acuan dalam menentukan kondisi kestabilan lereng menjadi empat kategori yang tertuang pada *Trigger Action Response Plan*.

Kata Kunci: monitoring prisma, kestabilan timbunan, ambang batas laju pergerakan

ABSTRACT: Monitoring of slope movement using prism monitoring is a simple analytical method used to monitor embankment stability. This monitoring method can provide data on vertical and horizontal movements that produce the total vector, magnitude of movement, and the rate of movement of the embankment and relative to the time of data collection. In general, the determination of the stability condition of the embankment based on the movement curve against time is divided into three categories based on the pattern of the rate of movement, namely the regressive pattern (the rate of movement is close to zero), the linear pattern (there is an initial movement rate), and the progressive pattern (increased movement rate). After conducting a back analysis on the occurrence of large landslides on high-risk embankments at the Bengalon site which has recorded prism reading data ranging from stable, linear, progressive conditions, landslide conditions, to stable conditions again to determine the threshold for the movement rate. Based on the back analysis, it is found that the value of the rate of movement at a data interval of 48 hours can be used as a reference in determining the condition of slope stability into the four categories contained in the Trigger Action Response Plan.

Keywords: prism monitoring, embankment stability, threshold movement rate

1. INTRODUCTION

PT Kaltim Prima Coal (KPC) is a multinational company engaged in the coal mining and marketing sector for industrial needs at home and abroad since its first production. It was recorded that in 2021 KPC was able to reach 58 million tons of coal production. With the large amount of production and can continue to increase, but also increases the risk of mining, one of which is the risk related to the stability of the embankment slope.

Embankment slope instability is generally preceded by various warning signs, including an increase in the speed of deformation, the appearance of cracks, the presence of bulging at the foot of the embankment or at the embankment foundation, as well as an increase in excess pore pressure in the embankment body or foundation. Some of these warning signs can be observed visually.

There were 4 points of DCP Test and 7 points of Sondir Test to due soil investigation. Soft material thickness range is from 1.6 to 3.2 m according to DCP Test Result. Stiff to very stiff material thickness range is from 0.3 to 0.5 m. Good Condition for bearing capacity is over than 3.0 m depth from surface. But for soft material thickness range is from 1.0 to 4.0 m according to Sondir Test Result. Stiff to very stiff material thickness range is from 1.0 to 1.8 m. Good Condition for bearing capacity is over than 5.0 m depth from surface.

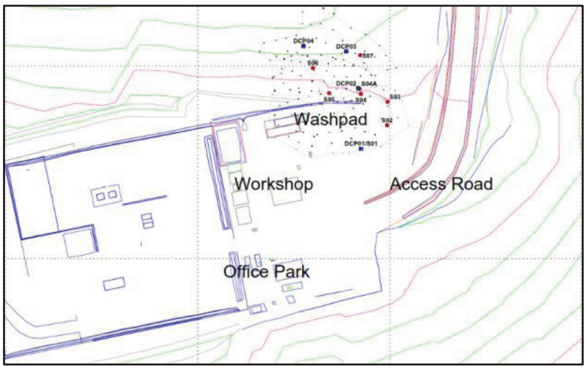


Fig. 1. Proposed Plan DCP Test & Sondir Test of Washpad AEL Magazine at Bengalon.

Fig. 2. Field Documentation in Location.

Properly managed drainage system should be developed to minimize water ponding, erosion, and recharge water through the base of the design. Any water ponding could increase ground water level and soften materials. Actual ground water level higher than used in this assessment could trigger failure. The problem in the field is that there is seepage from the storage pool above the slope that enters the valley. The groundwater level used in this assessment was assumed all terrain height (fully saturated) of proposed design. For sampling soil in situ, they have to summaries on Table 1.

This condition is unstable land, therefor slope stability monitoring needs to be assisted by several slope monitoring instruments until finally a slope monitoring system is formed that is simple, reliable, and capable of measuring parameters with an acceptable level of accuracy, as well as an acceptable response speed to changes in the measured parameters, Clayton et al. (1995).

Table 1. Soil Strength Parameters in Used for Actual Condition in Washpad Megazine – Bengalon.

Material	Unit Weight (ton/m^3)	Strength Parameter c (kPa)	Phi (degree)
Soft Soil (Depth: 0.0 – 4.0m)	1.91	13.4	5.1
Stiff Soil (Depth: 4.0 – 6.0m)	1.89	14.0	6.1
Fill Subsoil Material	1.78 (Saturated)	12.3	5.9
	1.48 (Unsaturated)	17.9	15.9
Floor Material	Bedrock parameter		

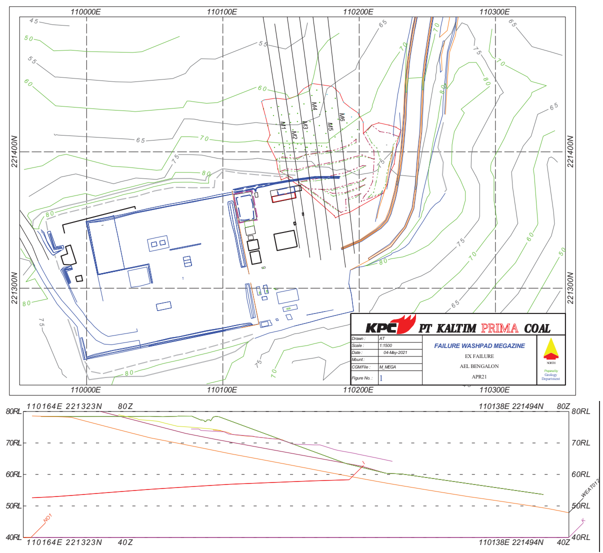


Fig. 3. Map & Section Line for Infrastructure Project Slope Stability Analysis.

One of the goals of a mine slope monitoring system according to Hawley & Cunning (2017) is that it can provide further warnings regarding the development of slope instability so that mitigation actions can be applied to reduce or avoid the impact of the instability. Based on the diagram Fell et al. (2000), to show the development of slope instability can be interpreted through the slope deformation pattern with time (Fig. 4) which divides it into three levels, namely primary (decrease in strain rate), secondary (constant strain rate) and tertiary (increase in strain rate) before the slope experiences completely collapse.

The comparison diagram of the deformation pattern against time can be obtained through the slope monitoring method using a prism, where this method provides data on vertical and horizontal movements that produce the total vector, relative movement, and rate of slope movement from each data collection time. However, the reading of the curve through this interpretation is very dependent on the geotechnical experience of each individual so that it is possible to have different results in determining the condition of slope stability.

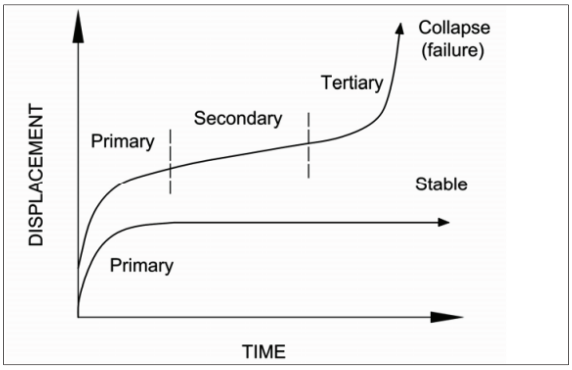


Fig. 4. Slope Movement Stage Diagram.

The possibility to be able to quantify the Slope Movement Stages, one of which was introduced by Sullivan (2007) by connecting the velocity of the mine slope movement with time (Fig. 5) which further divides the mine slope movement based on the speed of its movement into 5 stages, namely: Elastic, Creep, Cracking and Dislocation, Collapse, and Post Failure Deformation. Broadbent et al. (1982) proposed the consideration of the calculation period in calculating the speed of slope movement.

The strain component in the mine slope-forming material can be an illustration in determining the stages of instability, Coetsee et al. (2020), so that the differences in the geomechanical properties of each site make it possible to have different threshold values in each stage of slope movement according to Fig. 5. Therefore, this study aims to determine the threshold value in order to be able to quantify the condition of the embankment slope in a site-specific manner so that it can then be used as a reference in determining the necessary actions.

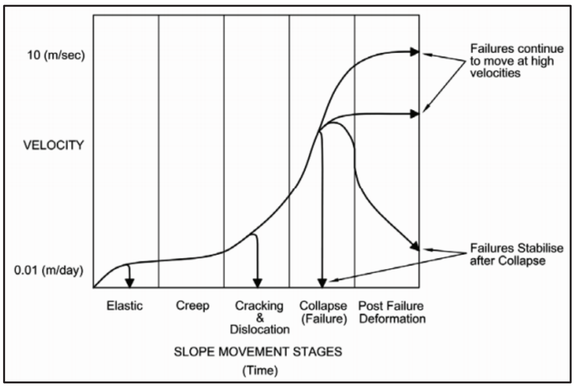


Fig. 5. Schematic Illustration of Five Stages of Slope Movement Referring to the Value of the Rate of Movement.

2. RESEARCH METHOD

2.1 *Data Collection*

The collection of all observational data on the stability of the slopes of the PT Kaltim Prima Coal at Site's Bengalon for embankment through prism monitoring for further selection based on the completeness of the observation data, capturing slope movement patterns ranging from stable to complete landslides.

Based on the results of the selection, then two data are obtained that match the criteria and the landslide time is determined through a combination of interpretation of the movement curve against time and validation of the information contained in the failure report.

2.2 *Stages of Slope Stability*

The distribution of the stages of slope stability in the data that supports this research is carried out through interpretation referring to the diagram of changes in movement against time according to Fell et al. (2000) and diagrams of changes in velocity with time according to Sullivan (2007). The formula for calculating changes in movement and velocity consistently refers to the first data when the prism is first installed according to equations (1) and (2).

$$\Delta D_i = \sqrt{(Xi - X_0)^2 + (Yi - Y_0)^2 + (Zi - Z_0)^2} * 100 \quad (1)$$

The equation above shows that ΔD_i is the magnitude of the displacement with respect to the initial position (cm), X_i is the position of easting coordinates at the time of data collection to 'i' (m), X_0 is the initial easting coordinate position (m), Yi is the position of northing coordinates at the time of data collection to 'i' (m), Y_0 is the initial northing coordinate position (m), Z_i is the elevation at the time of data collection to 'i' (m) and Z_0 is the initial elevation (m).

$$v_i = |(\Delta D_i)/(t_i - t_0)| \tag{2}$$

The equation above shows that v_i is the magnitude of the speed at the 'i' data retrieval to the initial position (cm/hari), t_i is the 'i' data collection time (day), and t_0 is the prism installation time (day).

2.3 *Calculation of Threshold Determination of Slope Stability Stages*

The calculation of the threshold to determine the stages of embankment slope stability in this study used the experimental method. The accepted threshold criteria are considered to be able to provide the optimal distance between the threshold value and the time of the full landslide heap, a distance that is too close does not provide sufficient time to carry out mitigation actions. While the distance that is too far allows for a production loss that is greater than it should be.

2.4 *Conclusions and Recommendations on the Use of Thresholds*

At this stage an evaluation is carried out regarding the limitations of the use of the threshold value, both the value and the formula so that it can be effectively applied through TARP (Trigger Action Response Plan).

3. RESULTS AND DISCUSSION

3.1 *Determination of the Stability of the Embankment Slope*

The data set consisting of two prism observation points recorded the stability condition of the embankment slopes in the Bengalon area, PT KPC starts from December 1, 2020 to May 15, 2022 with daily data collection, which is one data collection per day. Based on the curve in Figure 9, it shows that there is an increase in movement over time which is then interpreted interpretively into four patterns of slope movement to be used as a basis for determining slope stability conditions.

The movement pattern based on prism readings of GTM 2262, 2263, 2264 & 2265 is divided into 3 phases, starting with the regressive stage (Primary Stage) starting from the beginning of installation (01 December 2020) until 9 April 2021, followed by movement patterns linear (Secondary Stage) indicated from the range of April 10 - 25, 2021. However, there was a slowdown pattern (flat zone) towards a regressive movement pattern from the range of April 27 - November 16 2021 (Primary Stage), and continued again with a linear movement pole (Secondary Stage) from the 17 – 23 November 2021 range. Next, the progressive movement pattern (Tertiary Stage, 1st) is indicated from the 26 November – 7 December 2021 range, and the post landslide pattern (Post Failure, 1st) interpreted after 7 - 24 December 2021.

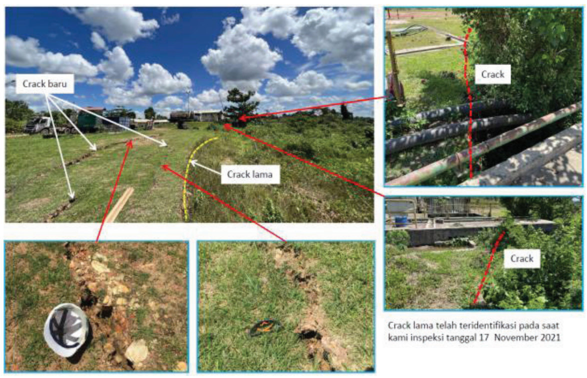


Fig. 6. Crack Finding at Location.

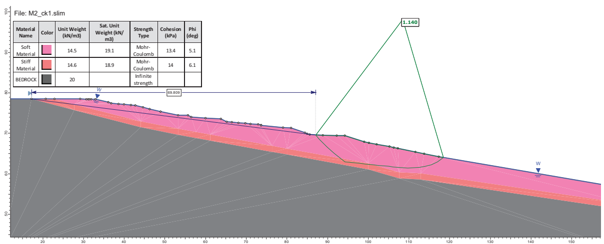


Fig. 7. Back Analysis After Crack and Failure Will Have Fos < 1.2, Unstable Condition Slope.

After December 24, 2021, a regressive movement pattern occurred again (Primary Stage), this was marked by more crack spots and widening of the old crack area around the wash pad, until April 15, 2022. Then followed by a linear movement pattern (Secondary Stage) from the range of April 17 – 25, 2022. Next, it enters the progressive movement pattern (Tertiary Stage) which is indicated from the range of April 26 – May 3, 2022, and the post-landslide pattern (Post Failure).

Based on the failure report, landslides accompanied by the appearance of long cracks along the slip plane were visually recorded twice on December 7, 2021 and May 3, 2022. The four prisms have identical patterns but have different movement values when experiencing changes in movement patterns, one of the things that can affect this is the difference in the position of the four prisms. For prism GTM 2262, the linear movement pattern after experiencing a displacement of 56.092 cm & 100.902 cm and a progressive movement pattern after experiencing a displacement of 61 cm & 111.653 cm. For prism GTM 2263, the linear movement pattern after experiencing a displacement of 128.004 cm & 131.653 cm and a progressive movement pattern after experiencing a displacement of 138.765 cm & 147.942 cm.

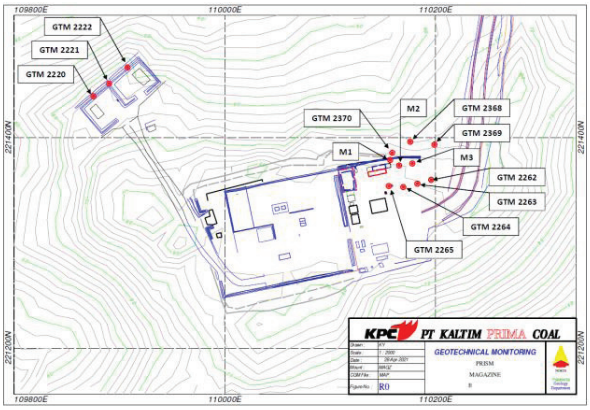


Fig. 8. Layout of the Prism Points for Monitoring the Wash Pad Location, Bengalon Site.

For the GTM 2264 prism, the linear movement pattern after experiencing a displacement of 99.934 cm & 145.998 cm and a progressive movement pattern after experiencing a displacement of 138.765 cm & 107.151 cm & 166.532 cm. As for the GTM 2265 prism, the linear movement pattern after experiencing a displacement of 52.002 cm and a progressive movement pattern after experiencing a displacement of 57.158 cm. From the data of the four prisms, for determining the condition of slope stability based on the displacement value relative to the starting point, it will have a different threshold value for each prism.

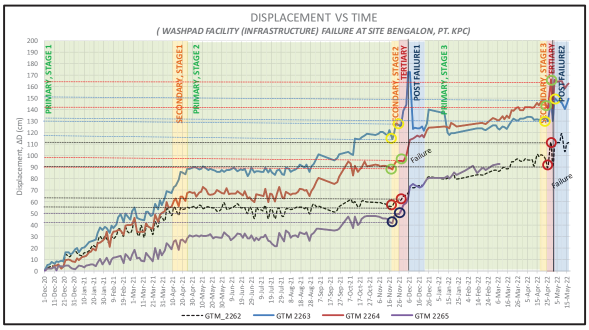


Fig. 9. Prism Displacement Value Curve Against Time in the Bengalon Site Area, PT KPC.

The curve of the comparison between the changes in velocity with time of the four prisms (Fig. 10) which is calculated relative to the prism data when it is first installed also shows the distribution of slope stability conditions is the same. Four categories of slope stability conditions recorded from the prism data collection are: Creep, Cracking and Dislocation, Collapse, and Post Failure Deformation. Like the prism displacement curve, the velocity curve also shows different velocity values for each change in slope stability conditions. For prism GTM 2262, the slope stability condition in the cracking phase starts from the velocity value of 0.160 ~ 0.202 cm/day and the collapse phase starts from the velocity value of 0.169 ~ 0.217 cm/day. As for the GTM 2263 prism, the slope stability condition in the cracking phase starts from the velocity value of 0.263 ~ 0.359 cm/day and the collapse phase starts from the velocity value of 0.288 ~ 0.381 cm/day.

For prism GTM 2264, the slope stability condition in the cracking phase starts from the velocity value of 0.272 ~ 0.292 cm/day and the collapse phase starts from the velocity value of 0.292 ~ 0.324 cm/day. As for the GTM 2265 prism, the slope stability condition in the cracking phase starts from a velocity value of 0.144 cm/day and the collapse phase starts from a velocity value of 0.157 cm/day.

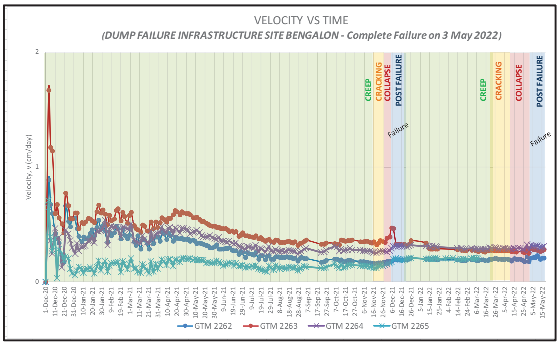


Fig. 10. The Curve of the Value of the Speed of Movement Against Time in the Area of Bengalon Site, PT KPC.

3.2 *Determination of Threshold Value*

Another approach in determining the stability condition of the embankment slopes in the Bengalon area, PT. KPC in order to be quantified is done by modifying the formula for the relative speed of prism movement. Based on the experimental method, it was found that optimally determining the condition of slope stability can be approached through the value of the prism velocity relative to the data of the previous two days by following equation (3).

$$vr_i = |(\mathrm{D}_i - \mathrm{D}_{i-2})/(\mathrm{t}_i - \mathrm{t}_{i-2})| \quad (3)$$

The equation above shows that vr_i is the speed of the prism movement in the 'i' data collection relative to the data of the previous two days (cm/hari), D_i is the magnitude of the displacement with respect to the initial position (cm), D_{i-2} is the amount of data transfer from the previous two days to the initial position (cm), t_i is the 'i' data collection time (day), and t_{i-2} is the time of data collection two days before (day).

Determination of the optimal threshold value which will be the basis for quantitative assessment of the stability condition, resulting from a combination of values and calculation formulas that have the potential not to produce false evacuate alarms and late evacuate alarms. The emergence of false evacuate alarms can cause reduced productivity due to stopped production activities, while the emergence of late evacuate alarms can cause delays in dealing with embankment slopes that will landslide, including delays in evacuating which causes losses in terms of safety to the possibility of fatality.

The comparison of various calculations of relative speed values ranging from relative to the data of the previous day to the previous three days is shown in Figure 11 by taking a sample from the prism of GTM 2262. For the threshold value of the speed value, the results of this study are for early warning 0.16 – 0.34cm/ days, intensive warning 0.36 – 0.38cm/day, and mostly evacuated more than 0.38cm/day.

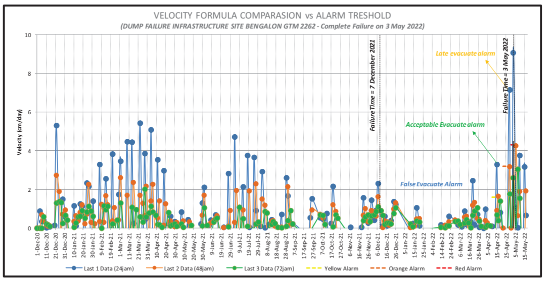


Fig. 11. The Curve of Relative Movement Speed Vs. Time in the Area of Bengalon Site, PT KPC.

3.3 *Evaluation of the Use of Threshold Values*

Threshold values of 0.16 – 0.34 cm/day (yellow alarm), 0.36 – 0.38 cm/day (orange alarm), and more than 0.38 cm/day (red alarm) were then applied in the field to evaluate the use of these values (Fig. 12). On the prism of GTM 2263, the orange alarm is triggered on November 23, 2021 (12 days before the landslide) and the red alarm is triggered on November 30, 2021 (5 days before the landslide). While the prism of GTM 2265 triggered orange alarms but not continuously, the closest to the landslide position was on November 30, 2021 (5 days before the landslide) and the red alarm was triggered on December 5, 2021 (2 days before the landslide).

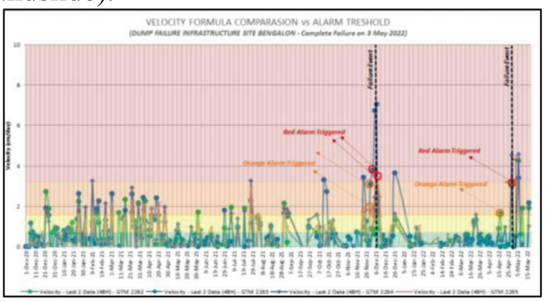
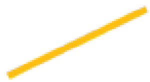
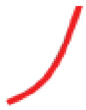


Fig. 12. The Curve of the Value of Movement Velocity Against Time in the Bengalon Site Area, PT KPC.

3.4 *Preparation of Trigger Action Response Plan*

Quantitative assessment of the condition of embankment slope stability by entering a threshold through the value of the relative movement speed can be one of the points in the preparation of the Trigger Action Response Plan (TARP). Table 1 shows an example of the TARP applied with the additional parameter value of relative movement speed so that it is divided into four slope stability criteria, namely: Green Condition (Safe), Yellow Condition (Monitor), Orange Condition (Alert), and Red Condition (Evacuation).

Tabel 1. Example of Application of TARP (Trigger Action Response Plan).

Item	Green Condition TARP Trigger 1 (Safe)	Yellow Condition TARP Trigger 2 (Monitor)	Orange Condition TARP Trigger 3 (Alert)	Red Condition TARP Trigger 4 (Evacuation)
Status	Safe conditions to work	Safe conditions for working with supervision	Alert conditions to work with intensive supervision	Dangerous conditions to work and evacuate immediately
Relative Speed (48 hours)	< 0.16 cm/hari	0.16 – 0.34 cm/hari	0.36 – 0.38 cm/hari	> 0.38 cm/hari
Deformation Graph				
Action Required*	Supervision and normal operational activities	The intensity of supervision is increased by regular checks on a regular risk	Supervision is attached to operational activities	Immediate cessation of operational activities. Carry out the evacuation process

Information:
*Adjusts to the duration of the prism reading and the number of prisms

4. CONCLUSION

a. Assessment of the stability condition of the embankment slope at Washpad – Site's Bengalon, PT KPC can be quantified by using the value of the movement speed relative to the data of the previous two days (48 hours).
b. Based on the relative speed of movement, the necessary actions can be adjusted to the stability status of the ABC Pit embankment slope which is categorized into four namely Green – Safe Condition (<0.16 cm/day), Yellow Condition – Monitor (0.16-0.34 cm/day), Orange Condition – Alert (0.36-0.38 cm/day), and Red Condition – Evacuation (>0.38 cm/day).
c. Team geotechnical have recommended for slope protection and reinforcement to decrease velocity and deformation, and maintain stability on the slope by gabion, geocomposite and others slope protection.

It is necessary to continuously validate the latest prism movement data to increase confidence in the threshold value and the formula for calculating the relative movement velocity used.

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