Indonesian Geotechnical Journal, August 2023, Vol 2 (2). Page 63 - 71
DOI: https://doi.org/10.56144/igj.v2i2.39
EISSN: 2829-7520
https://indonesian-geotechnical-journal.org/index.php/JGI/issue/archive

Coherence Alarm Implementation upon Post-Blast Impact in Open-Pit Mine

M. Adib Izzuddin[1*], Alden Sinai Yudono[2], Deaz Dewantara[3]
[1]Geotechnical Support Service, PT. GroundProbe Indonesia, Balikpapan, Indonesia, 76114; geotech.support.bpn@groundprobe.com
[2]Geotechnical Support Service, PT. GroundProbe Indonesia, Balikpapan, Indonesia, 76114; geotech.support.bpn@groundprobe.com
[3]Mine Geotech Expert, PT. Pamapersada Nusantara distrik MTBU, Muara Enim, Indonesia, 31471; deaz.dewantara@pamapersada.com
*****Correspondence: adib.izzuddin@groundprobe.com

SUBMITTED 1 March 2023 **REVISED** 25 August 2023 **ACCEPTED** 28 August 2023

ABSTRACT Slope Stability Radar (SSR) is a geotechnical monitoring tool, an array of sophisticated technology which is equipped with features that could be utilized in dynamic mining conditions. One of the features is called coherence and is used to track the impact of blasting activity around the research area. Historically, it has been recorded that fall-of-ground event (bench-scale failure) had occurred after blasting activity around the research area. These two events were recorded perfectly by utilizing coherence attribute measurement, including the time of event and the dimension of the impact area. Therefore, the application of a coherence alarm could be one of the solutions to provide an immediate response to track the blasting impact and provide periodic notification in case of the similar things occurred in the future. There are two alarm parameters in which required some adjustments due to the sensitivity of coherence attribute. The first one, is the alarm mask. It masks out the expected unwanted triggering alarm, such as vegetation area, ramp, machinery area, and mining infrastructures. The second one is the alarm threshold. It requires precise adjustment to maximize the alarm function during the rainfall event. The analysis resulting the threshold values advocated for the alarm are 12 contiguous pixels, 2 scans, and 0.6 coherence value. The alarm configuration parameters are then applied to the coherence alarm system. Notwithstanding that matter, the alarm configuration requires periodic adjustments, accompanied by the competencies of the person in charge for the SSR to be able to comprehensively understand the concept of coherence and its implementation in the research area.

KEYWORDS Slope Stability Radar, Coherence, Blasting Activity, Bench-scale Failure, Alarm

1 INTRODUCTION

Slope stability Radar (SSR) is a geotechnical monitoring tool capable of detecting movement/displacement on the slope surface from a certain distance. As an array of sophisticated technology, SSR is equipped with various attributes that can ensure safe mining operations and aim for peak productivity. One of the SSR attributes that could be used for dynamic mining operations is coherence. By utilizing the coherence attribute measurement, various changes that occur on the slope surface could be detected and recorded, such as landslides, riling materials, blasting activity, rain event, machinery activity, and vegetation.

The research area to be discussed is an open-pit coal mine. The exact area of the pit cannot be disclosed and shall be called Pit X in particular Area Y. The area has a high intensity of blasting activity, as well as the operational activity. Historically, Area Y has experienced slope instability events, leading to fall-of-ground event due to post-blast activities. Therefore, there is a need for comprehensive monitoring using SSR, specifically by utilizing coherence applications. The use of coherence data is also considered as a good fit and capable of detecting fall-of-ground event, even in conditions where the reading of SSR deformation data is considered less representative due to the high vector loss impact.

This study aims to maximize coherence attribute measurement as a type of warning system (alarm) to alert the related parties to carry out evacuation in the field. Appropriate warning system could provide proper handling in critical areas on a post-blast situation, as well as ensuring the continuity of production activities in mining areas.

2 METHODOLOGY AND LIMITATIONS

The research used the data obtained from Slope Stability Radar (SSR) which is placed to monitor the slope movement around Area Y of Pit X. The research area is an active coal mining operation with geological composition consisting mainly of claystone and coal.

The analysis conducted in this study focused on one of the attributes in SSR, called coherence. The use of coherence attribute is intended to detect blasting activity around Area Y, as well as detect any instability on the slope surface/fall-of-ground materials as a post-blast effect. The accumulation of changes on the surface of the slope is then interpreted as an estimate of the dimensions of the fall-of-ground materials. The analysis is then applied as a coherence alarm. The threshold value parameter to trigger the alarm has considered the derivation in coherence value caused by the impact of rain events, as rain event is one of the external factors that might reduce the sensitivity of the alarm.

In this study, the coherence alarm is only implemented to detect changes in the slope surface on a post-blast situation of Area Y. The analysis of total displacement of the designated materials and failure forecast as the impact of blasting activities are not explained in detail.

3 SLOPE STABILITY RADAR

Interferometry is the technique used by SSR for data acquisition. The technique uses phase measurement between consecutive scans. At even interval, a signal is sent and received, in order to measure data at a specific position. The phase of reflected signal is then interpreted. As the SSR transmits the signal continuously, the phase being transmitted and received is compared. When there is deformation, a “phase change” will be detected (figure 1 (left)).

In this study, the Slope Stability Radar (SSR) used a real aperture-type of antenna, also known as real aperture radars, often abbreviated as RAR. The real aperture radar used in this research creates a pencil-like beam, in which a narrow beam is focused on a slope and directed to move in a scanning pattern (figure 1 (right)). The radar antenna will move in two dimensions (azimuth and elevation), forming a 3-dimensional image of slope deformation. SSR will then divide the entire scanning area into several independent pixels. Each pixel will have different information which represent the current condition of the wall surface.

SSR technology has the advantage of being able to perform deformation analysis with coverage up to 3,500 meters. Another advantage of interferometric technique allows SSR to obtain data without reflectors on the slope surface. The radio wave signal emitted by the Real Aperture SSR can operate in various weather conditions, such as rain, snow, dust, and fog.

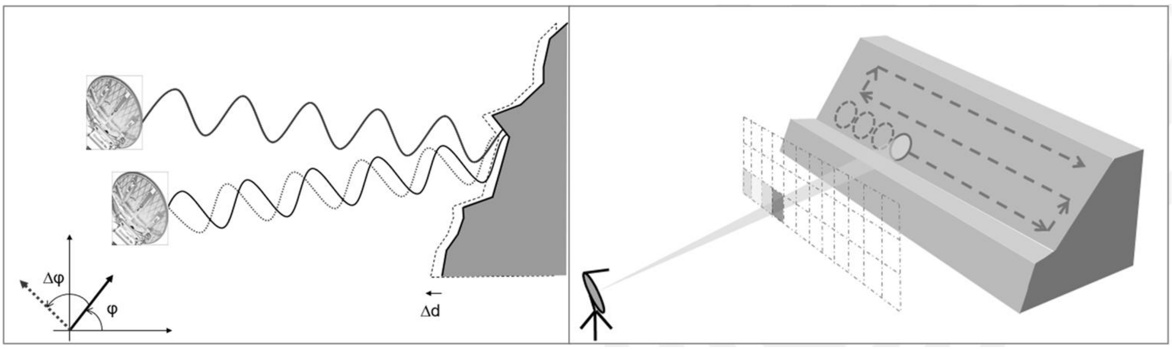

Figure 1. (Left) Interferometry method in SSR. (Right) 3D RAR’s raster scan movement.

4 COHERENCE

Coherence alarm implementation needs to consider several factors that have impact to the alarm sensitivity. Upon the obstacles that will be faced, it is necessary to understand the concept of coherence value and as well as the alarm implementation.

4.1 Coherence Measurement

Coherence on the Slope Stability Radar (SSR) describes the consistency of a slope surface between preceding scan in the same area. Coherence has a value from 0 to 1. The higher the coherence value, the more consistent the slope surface, while lower coherence value indicates low consistency of slope surface.

Coherence could not be separated from the influence of the amplitude and range (Figure 2). In a sinusoidal wave diagram, the amplitude is the wave height that could interpret the intensity of the wave energy. The amplitude value is implemented on the SSR to provide information about the intensity or strength of the return signal when the SSR waves are transmitted to the surface of an area/object. In general occasion, high amplitude values are produced by the returning signal of a solid metallic objects, while low amplitude values mostly indicate an object that is located far from the source of the transmitted wave. Range is defined as the distance between the SSR and a certain location within the scanned area. This measurement refers to the time-of-flight of an area that has the highest return signal strength when SSR waves are transmitted to the surface of the designated area.

The implementation of coherence is to interpret the cause of disturbance that affects the slope surface. This tool was very useful to predict the vegetation and mining activity location on the scanned area, to perceive occurrence of failure and rockfall, and even to record blasting activity and rain/snow event (Table 1).

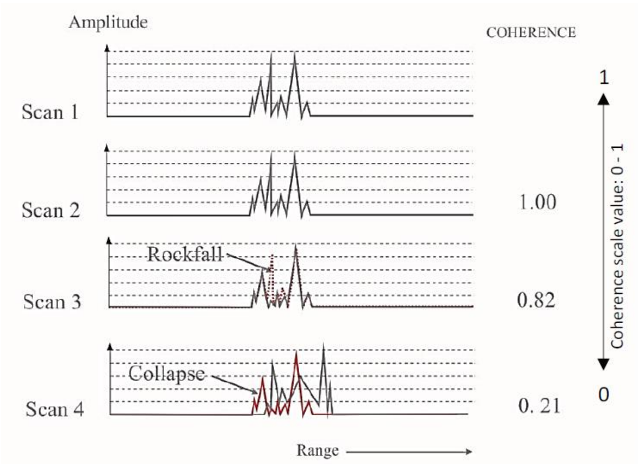

Figure 2. Simplified concept of coherence measurement (Source: GroundProbe internal document)

Table 1. Geotechnical uses and meaning based on coherence value (Source: GroundProbe internal document)

Scale	Possible Geotechnical Interpretation
1	Wall surface does not change.
0.9 – 0.95	Low impact blast.
0.85 – 0.95	Structurally controlled deformation.
0.8 – 0.9	Small disturbance on the rock face. Some toppling or small failure.
0.7 – 0.85	Slow deformation on soft rock or soil. . Medium impact blast.
0.5 – 0.6	Medium speed deformation of a ductile material.
0.3 – 0.5	Structurally controlled collapse. Active snow or rain event. High impact blast.
0.2 – 0.3	Landslide in soil-type materials. Rapid creep.
0 – 0.5	Machinery noise from very high to very low contamination

4.2 Coherence Alarm

Alarm on the Slope Stability Radar (SSR) is one of the features which function as an early warning system for things that could endanger the continuation of mining activities. The most common use of the alarm is to warn against any indication of slope instability, such as high deformation values of slopes and rockfalls. To maximizer alarm application, it requires competency and deep understanding regarding the characteristics of the site material.

Alarms have several general settings that must be defined before commencement. They are as follows:

a) **Tag**: The name of the alarm that indicates the purpose of the alarm or the name of the area which the alarm is alerting.
b) **Type**: There are two types of alarms, urgent (red alarm) and requiring geotechnical engineer attention (orange alarm). These two types are distinguished based on the purpose or application of the approved triggered action response plan (TARP).
c) **Movement**: The direction of deformation with respect to the SSR. There are three types of movement, namely the movement approaching toward the SSR (towards), away from the SSR (away), and movement in both direction (both).
d) **Contiguous pixels**: The area that is interpreted as the number of pixels that are interconnected. This value will be one of the alarm threshold parameters.
e) **Number of scans**: The number of scans as one of the alarm threshold parameters.
f) **Coherence alarm details**: Determination of a coherence value that acts as one of the threshold parameters (threshold).

5 METHODOLOGY AND RESULTS

This section starts by discussing back analysis of slope instability events, including the coherence derivation sequence and the analysis of coherence data. The back analysis is then used to determine the alarm threshold to be implemented as the coherence alarm system around Area Y.

5.1 Back Analysis

Analysis of the coherence sequence on the slope surface refers to the visualization of coherence image on the scanned area (Figure 3). This aims to provide a better visualization of the impact of blasting activities on the slope surface. An explanation of the sequence of changes on the slope surface is explained in detail as follows:

a) Pre-Blast Phase
Coherence data indicate that there was no significant change in the slope surface before the blasting. There were several spots that were expected to have reduction in coherence values due to the presence of vegetation and mining activities (Figure 4A).
b) Blast Phase
Blasting activity was recorded by coherence data at 12:31, February 16th, 2022. It was estimated to affect a surface area of 13,189 m^2 (Figure 4B).
c) Post-Blast Phase: Slope Instability Event (Benchmark for Failure)
Blasting activity caused slope instability around the research area. Coherence data on the SSR recorded an area of 731.554 m^2 experienced material detachment at 12:50, February 16th, 2022 (Figure 4C). Coherence data revealed that after the blasting activity, the area continued to experience riling of material until it reached a stable phase.
d) Post-Blast Phase: Stable
Based on coherence data records, a stable phase was reached at 17:03, February 16th, 2022. Around 5 hours after the first recorded slope instability. Referring to Figure 4D, no significant movement was observed in the observation area, indicated by coherence value of 1.

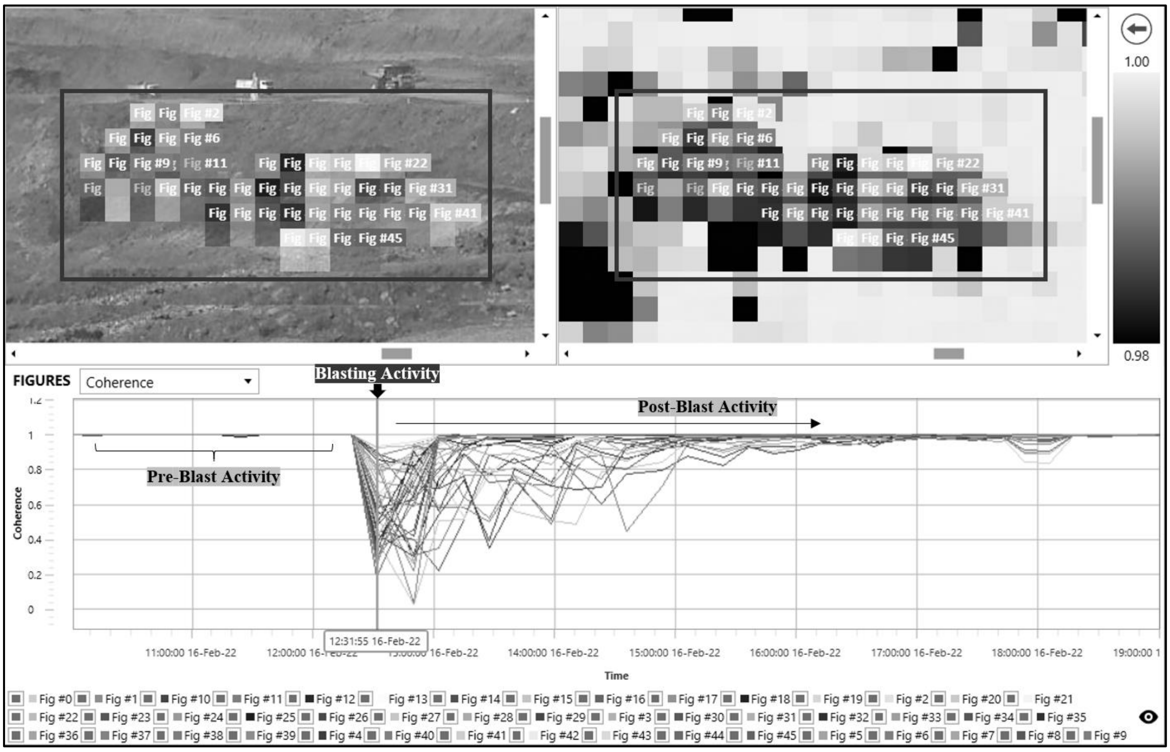

Figure 3. Visual image, coherence image, and coherence time graph around the observation area.

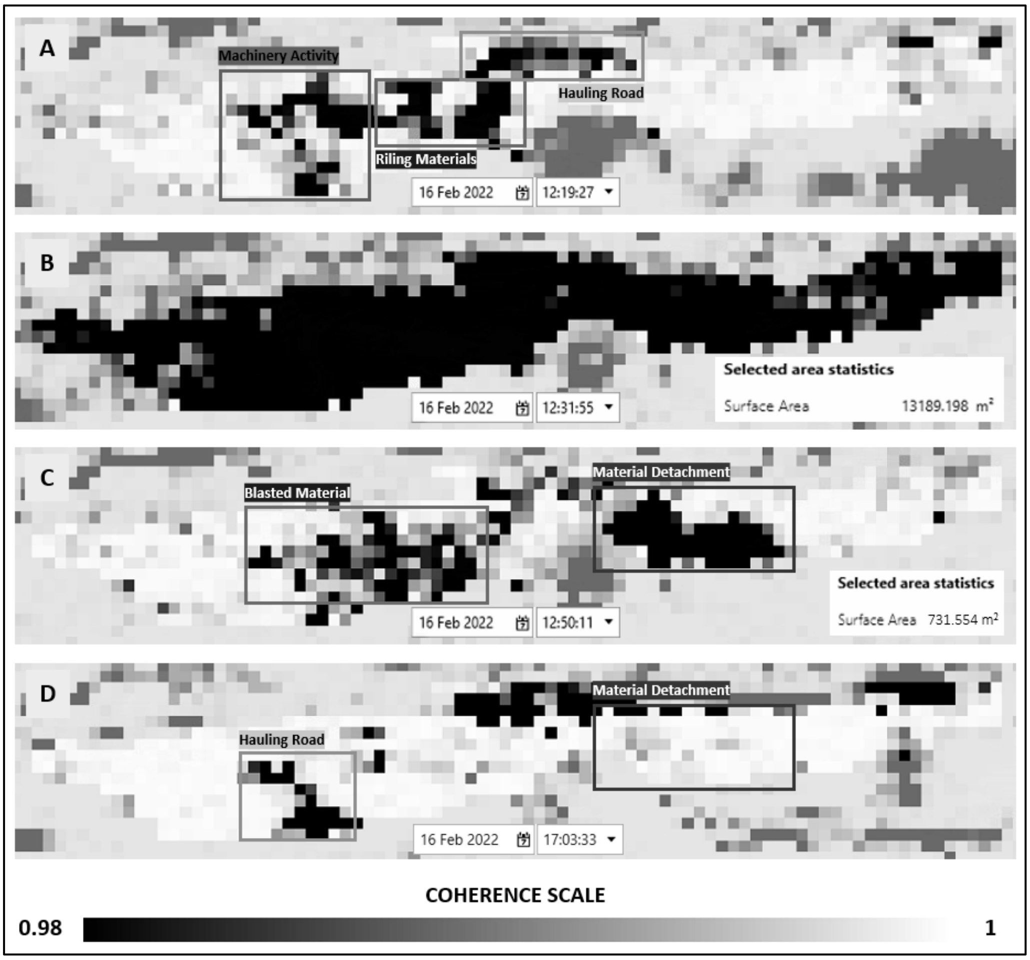

Figure 4. Coherence sequence on the slope surface.

5.2 Alarm Threshold Determination

Based on the back analysis, coherence could detect changes to the slope surface due fall of ground event. It should be noted that there are external factors which could also cause the decrease in coherence values. Certain external factors can even cause great decrease in coherence value, such as significant rain event, vegetation, and machinery activity. Alarm has a feature called alarm mask to minimize false alarm in case of vegetation or operational activity being detected. Presence of those two disturbances were treated as negligible and does not trigger the alarm. However, alarm mask could not be implemented for rain effect, especially the significant ones. This is because rain event affects the coherence reading over the entire part of the scanned area. The application of alarm mask to mask this type of weather condition might affect the alarm function when real fall of ground event occur. Therefore, it is necessary to consider the rain effect to determine the alarm threshold.

The back analysis detected two consecutive scans which showed decrease in coherence values . The first decrease in coherence values was due to blasting activity, and the following decrease in coherence values was due to failure event. In total, there are 44 contiguous pixels that experienced a drop in coherence value within these two scans, with different decrease in coherence values. The decrease in coherence values to values between 0.8 to 0.5 became the object of interest by looking for the accumulated number of contiguous pixels. The coherence values obtained was interpreted based on general geotechnical events in Table 1 in combination with the characteristics of the material detachment behaviour observed in the research area (Figure 3 and 4). Effects of thirteen rain events which occurred between January – March 2022 were also analyzed to determine the accumulation of contiguous pixels, the number of scans, and the decrease in coherence values.

Table 2 and 3 present the derivation of coherence after blasting activity and significant rainfall. As it appears, there are starred numbers for each of the reference coherence value (scale 0.8 – 0.5). These are the smallest number of contiguous pixels in two scans and assumed that these numbers appertain in both scans in each of the reference coherence value.

Figure 5 reveals the post-rain effect on post-blast reference value. The result is that the coherence scale reduction simulation of 0.8 with 34 contiguous pixels, there are four rainy periods that have a higher contiguous pixel. If this value is applied, it will cause frequent false alarms during pluvial conditions. The similar result appears using the coherence scale reduction simulation of 0.7 with 21 contiguous pixels. There are two rainy periods that have a higher contiguous pixel and might also lead to frequent false alarm due to rain event and diminish the alarm sensitivity.

The coherence scale reduction simulation of 0.6 and 0.5 show that there are no contiguous pixels equal to or more than the post-blasting reference value. This indicates that the coherence value of 0.6 or 0.5, will reduce the possibility of frequent false alarms triggered by rain events. However, to maintain the sensitivity of alarm, coherence value of 0.6 with 12 contiguous pixels will be applied.

Table 2. Contiguous pixels on post-blast effect area

Contiguous Pixels							
0.8		0.7		0.6		0.5	
1st Scan	2nd Scan	1st Scan	2nd Scan	1st Scan	2nd Scan	1st Scan	2nd Scan
34	29*	31	21*	23	12*	18	11*

Table 3. Contiguous pixels on post-blast effect area

Contiguous Pixels							
0.8		0.7		0.6		0.5	
1st Scan	2nd Scan	1st Scan	2nd Scan	1st Scan	2nd Scan	1st Scan	2nd Scan
30	**5***	18	**3***	5	**0***	3	**0***
55	**20***	20	**13***	12	**11***	7	**3***
47	**2***	18	**1***	15	**0***	8	**0***
75	**14***	17	**10***	4	**3***	3	**2***
21	**4***	8	**3***	6	**2***	3	**1***
44	**38***	**17***	25	**6***	13	**5***	11
80	**50***	**21***	48	12	**10***	**8***	8
16*	33	**10***	15	**4***	8	**2***	3
50*	75	**40***	68	**11***	37	**6***	16
2*	7	**2***	4	**1***	4	**1***	4
19*	24	13	**8***	6	**5***	**3***	4
39	**11***	25	**5***	11	**5***	6	**2***
31	**25***	12	**9***	10	**6***	5	**3***

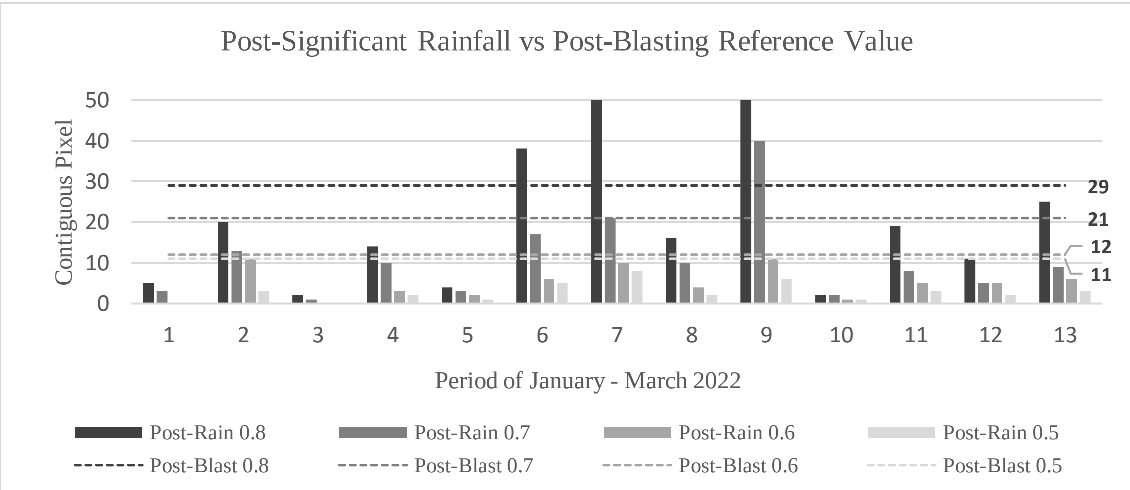

Figure 5. Post-rain coherence contamination upon coherence alarm threshold value (post-blasting).

5.3 Alarm Implementation

The implementation of the alarm as an early warning system is then applied by using several parameters that have been analyzed. Those parameters are 12 contiguous pixels, 2 scans, and coherence value below 0.6. In addition, the alarm calculation also uses of the alarm mask feature should also be maximized to reduce contamination due to vegetation, machinery activity, and riling materials. Figure 6 shows the general alarm settings have been optimized by applying the analyzed parameters.

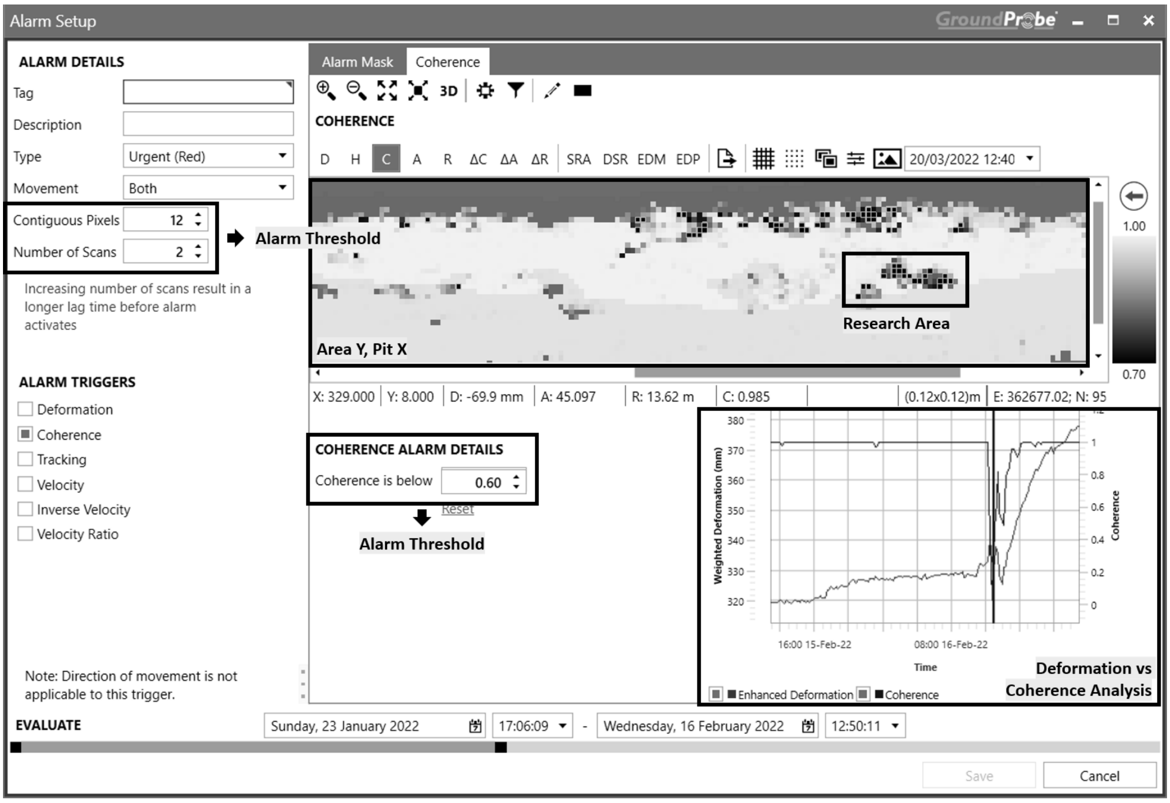

Figure 6. Simulation of coherence alarm implementation settings.

6 CONCLUSION

Blasting activity recorded by SSR's coherence data at 12:31, February 16, 2022 triggered slope instability, resulting in material detachment around Area Y. Thereafter, the data was analyzed to implement a coherence alarm as a warning system around Area Y. This is to provide immediate response and periodic notifications in case of similar case happening in the future. The alarm threshold considers post-rain effect in regard to the accumulation of contiguous pixels, the number of scans, and the decrease in coherence values. The result shows that 12 contiguous pixels in 2 scans with coherence value below 0.6 is optimal as the alarm threshold parameters. It is recommended to configure the coherence alarm system periodically due to dynamic mining condition. The paramount thing is to acquire adequate measurements to determine the alarm of coherence and the role of the person in charge of SSR to have comprehensive understanding of the concept of coherence and its implementation on site.

ACKNOWLEDGMENTS

The authors thank PT Pamapersada Nusantara in providing the data presented herein and to GroundProbe for the support during the submission of this paper.

REFERENCES

Arif, I., 2016. *Geoteknik Tambang Mewujudkan Produksi Tambang yang Berkelanjutan dengan Menjaga Kestabilan Lereng*. Jakarta: PT Gramedia Pustaka Utama.

Cahyo, F. A., Dwitya, R., and Musa, R. H., 2020. New Approach to Detect Imminent Slope Failure by Utilising Coherence Attribute Measurement on Ground-Based Slope Radar. *Proceedings of the 2020 International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, pp. 1401-1412.

Dick, G. J., Eberhardt, E., Cabrejo-Liévano, A. G., Stead, D., and Rose, N. D., 2015. Development of an Early-Warning Time-of-Failure Analysis Methodology for Open-Pit Mine Slopes Utilizing

Ground-Based Slope Stability Radar Monitoring Data. *Canadian Geotechnical Journal*, 52(4), pp. 515-529.

Indriastuty, D., Fajar, F., Tappang, G., and Irsyad, A., 2021. Pemantauan Deformasi Lereng Tambang Terbuka paska Peledakan dengan Slope Stability Radar. *Indonesian Mining Professionals Journal,* 3(2), pp. 71-82.

Internal Document GroundProbe Support Services, 2017. *SSR Geotechnical Training Module*, Brisbane: GroundProbe Pty Ltd.

Reeves, B., Noon, D. A., Stickley, G. F., and Longstaff, D., 2001, Slope Stability Radar for Monitoring Mine Walls. In *Subsurface and Surface Sensing Technologies and Applications III,* 4491, pp. 57-67.

Sannang, M. A., Musa, R. H., and Manaf, A., 2017. Analisa Balik dan Penentuan Ambang Batas Alarm Menggunakan Slope Stability Radar (SSR) Studi Kasus Longsor pada Batuan Keras. *Prosiding TPT XXVI PERHAPI,* pp. 294-308.

Saunders, P., Nicoll, S., and Christensen, C., 2016. Slope Stability Radar Alarm Threshold Validation and Back Analysis at Telfer Gold Mine. *Proceedings of the First Asia Pacific Slope Stability in Mining Conference,* pp. 367-378.

Saunders, P., Kabuya, J., Torres, A., and Simon, R., 2020. Post-Blast Slope Stability Monitoring with Slope Stability Radar. *International Symposium on Slope Stability in Open Pit Mining and Civil Engineering*, pp. 507-522.

Sharon, R. & Eberhardt, E. eds., 2020. *Guidelines for slope Performance Monitoring*. CSIRO Publishing.