DEVELOPMENT OF A SLOPE FAILURE PREDICTION MODEL FOR SURFACE MINES

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Doctor of Philosophy

By

Mohd Maneeb Masood

DEPARTMENT OF MINING ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY
(BANARAS HINDU UNIVERSITY)
VARANASI– 221005
INDIA

Roll No. 17151002

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5. CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORK

The model is reliable, user-friendly, and meets study goals, accurately forecasting surface mine slope failures. The model assesses thresholds linked to slope movements and can be connected to alarms for timely action in early warning systems. It swiftly processes deformation data, enhancing radar monitoring and enabling proactive measures in surface mining operations. The research led to the following conclusions, which are discussed in the following paragraphs;

(i) Time of Failure Prediction: The core objective of this research revolves around prediction of the time at which slope failures are likely to occur in surface mines. Accurate prediction is critical for preventing accidents, optimizing operational efficiency, and minimizing losses. The methodology involves an intricate analysis of historical and real-time data pertaining to the slope's movement. For this model parameters related to deformation and its patterns are considered. Advanced predictive modeling techniques, such as machine learning algorithms and statistical analysis, are applied to discern patterns and trends in the data. These patterns are then used to predict the time at which a slope is most likely to fail. The accuracy of these predictions is essential for the effectiveness of early warning systems, which are pivotal for ensuring the safety of mine personnel and infrastructure. We run the model on failed and stable slope failure datasets. The results for these datasets returned high accuracy with the field observations.

Dataset 1 predicted a slope failure on 16th August at 10:53 AM, showcasing the model's predictive accuracy, as the slope failure occurred on 16th August at 11:03 AM. Dataset 2 where the model accurately identified the acceleration phase, aligning with existing literature, giving the failure date as 9th August whereas the actual failure occurred on the 10th August. Dataset 3 saw the model predict the acceleration onset on November 20th and the failure was predicted to happen on the 1st December. The failure in this case occurred early on the 2nd December. Dataset 4 The model accurately identified the onset of acceleration around March 4th, in line with existing research. Other datasets have been shown added in the appendix. These datasets are from the slope which did not show any signs of failure.

All these datasets predicted the OOA very close to the field observation. The failure was predicted within the range of 1 day.

(ii) Site-Specific Applicability Extensiveness: One of the remarkable strengths of the developed model is its versatility and adaptability across a wide spectrum of slope behaviours and geological features. Traditional slope failure prediction models often struggle with generalizability, relying heavily on specific site characteristics. However, this model has overcome this limitation by employing a sophisticated algorithm that can interpret and predict failure times across diverse terrains, materials, and geological compositions. The model utilizes a data-driven approach that doesn't rely on predefined rules but instead learns patterns from the provided data. This allows it to be applied to a broader range of scenarios, making it an invaluable tool for both mining researchers and practitioners. In the study, it was found that most of the slopes followed a similar deformation pattern, giving the outputs as per the field observation. Dataset 1 was from Kusmunda mines, SECL, Dataset 2 from Nara Prefecture, Dataset 3 was a slope collapse near Fukui City and Dataset 4 dealt with a rockslide in Tuckabianna West open pit mine. All these datasets showed similar deformation behaviours and the model predictions were accurate although these datasets correspond to different sites.

(iii) Device Flexibility: The model's design is agnostic to the type of slope monitoring device or method used. It can seamlessly integrate with a plethora of monitoring systems, such as Slope Stability Radar (SSR), extensometers, inclinometers, and more. This adaptability is achieved through a modular architecture that can interface with various data sources and formats. The model processes the data obtained from these devices, extracting relevant parameters related to slope displacement and deformation. The flexibility of this design is instrumental in real-world applications where different mining sites might employ different monitoring technologies based on their specific requirements and constraints. The dataset collected from the field was directly from SSR. But the dataset digitized from literature were mostly collected using conventional techniques. Thus, proving the flexibility of the model.

(iv) In-depth Analysis of Displacement Behaviours: Understanding the deformation behaviours of slopes is fundamental for predicting failures accurately. The model incorporates advanced mathematical and statistical techniques to analyse displacement behaviours meticulously. It considers the deformation of the slope and historical displacement rates to discern patterns. By doing so, it can identify critical trends that precede slope failures. The OOA/OOF identification using the algorithm can act as a major breakthrough in the development of this work forward. This could be seen from the results of the OOA identification using the model which match the onset of acceleration from the field. The OOA was identified as 15th August, 29th July, 20th November, and 4th March from the four datasets used for validation of the model.

(v) Threshold Value Determination for Slopes: A significant contribution of this research is the introduction of a generalized approach to determine critical threshold values associated with slope movements. Traditionally, determining these thresholds has been a complex task, involving a combination of empirical observations and domain expertise.

However, the developed model offers a systematic method to calculate these thresholds. It leverages historical data and statistical analysis to derive critical levels of displacement, velocity, or other relevant parameters. These thresholds are then used to trigger alarms in early warning systems. By setting these alarms appropriately, mine operators can take timely preventive actions, mitigating the risk of slope failure and ensuring the safety of personnel and assets.

(vi) Real-Time Application: Real-time application is a key focus area in this research, aiming to enhance the proactive capabilities of the model. By integrating the methodology into a self-learning system, the model can dynamically adjust its parameters and predictions in real time based on incoming data. It automates the determination of the onset of failure or acceleration, providing instantaneous alerts to stakeholders. This real-time application is made possible through a combination of efficient algorithms, advanced computational capabilities, and continuous data monitoring. It forms the foundation for proactive risk management, enabling timely decision-making and intervention strategies to minimize the impact of slope failures in surface mining operations. The algorithm can be followed and the codes can written for slope monitoring software like SSR for improved slope behaviour monitoring and analysis.

Each of these aspects has been meticulously addressed and validated in the research, contributing to a robust and comprehensive Slope Failure Prediction Model for Surface Mines (SFPMSM). The integration of these elements results in a powerful tool that has the potential to revolutionize slope failure prediction and risk management in the mining industry.

We had some limitations related to data. We recommend that this model can be further worked upon to integrate this with the existing slope failure prediction systems. The integration of the model with existing slope monitoring systems like GroundProbe Slope Stability Radar (SSR) and its software Slope Stability Radar Viewer (SSR Viewer) will increase the usability manifolds. This will not only increase the safety standards but also increase the efficiency of monitoring and prediction. The work does not incorporate the knowledge of the software used in the SSR Viewer and the SFPMSM is MATLAB based. The model can be made in different languages as the algorithm remains the same and thus the outputs will not differ. Thus, making it integration friendly.

Mining firms sometimes fail to adequately record or make use of the vast amounts of displacement data collected by radar. If possible, mine geotechnical staff working together to compile a comprehensive record of slope collapses from a variety of mines can get a huge dataset providing critical details into this field of research. This study demonstrates the potential of using surface displacement data to understand slope deformation behaviours and uses SSR data as field data inputs. The work does not take into account the electronics of RADAR based monitoring systems. We recommend further research into alternative approaches and models to study slope deformation behaviour in various different sets of conditions using different methodologies and platforms in co-operation of mining companies to develop the research further in the field of mine slope stability and failure prediction.