Prediction of rockburst classification using Support Vector Machine

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Abstract. With the deepening of underground excavation, rockburst has become a serious geological disaster, which will always cause casualties, machine damage and delay of construction schedule. Therefore, many scholars at home and abroad have carried out researches on rockburst. Because the mechanism of rockburst is complex, and there is no unified understanding of its generation mechanism at present, thus it is hard to predict the rockburst happen or not and the intensity to guide for the underground engineering construction. Support Vector Machine (SVM) was used to classify the rockburst. Some main factors of rockburst, such as the maximum tangential stress $\sigma_\theta$, the compressive rock strength $\sigma_c$, the tensile strength $\sigma_t$, the stress coefficient $T_s$, the brittleness coefficient of rock $B$, and the elastic energy index $W_e$ were selected in the analysis. The factors were divided into two combinations: index I and II. SVM model and criterion were acquired through 36 training samples. Another 10 testing samples were used to evaluate the model. As a consequence, the evaluated results agree well with the measured record. No matter the training samples or the testing samples, the misjudgement ratio using the combination index I is smaller than that using the combination index II. It is suggested that using SVM model and the index I can classify the rockburst grade very well.

Keywords: underground excavation, rockburst, Support Vector Machine, rockburst prediction

1. Introduction

As the increasing demand for transportation construction. Lots of geotechnical engineering projects (e.g. underground laboratories and tunnels) were constructed in deep areas with complicated...
conditions (Jiang et al. 2010). There are many rockbursts in coal mines in China. The earliest rockburst occurred in Shengli Mine in Fushun in 1933. According to incomplete statistics, from 1949 to 1985, China has 32 coal mines have occurred 1842 times of rockburst, causing many casualties. Therefore, the research on rockburst in China’s coal system started earlier, and has been carried out in the mid-1980s. In the hydropower project, Rockburst first occurred in the construction of yuzixi and Yingxiuwan hydropower stations, and then appeared in the construction of Baihetan, Ertan, Tianshengqiao and Taipingyi hydropower stations. The research work started in the late 1970s with the study of drilling cake core, and gradually involved in the field of rockburst. In the railway tunnel project, the earliest rockburst occurred in Guancun Dam tunnel of Chengdu-Kunming railway in 1965.

The high stress and complex underground environment usually cause a series of geological hazard, such as large deformation, high ground temperature and rockburst (Ranjith et al. 2017; Shi et al. 2020). It is a dynamic rock failure phenomenon usually by abruptly ejection of rock blocks from underground opening. Most of the time, the ejection of the rock material is associated with a rapid release of energy.

According to the energy source mechanism, rockburst often can be classified into three types: strain burst, pillar burst, and fault-slip burst (Cai 2013). Usually the strain burst is the most common kind in the underground excavations (Zhang et al. 2012). Strain burst occurs because of the concentration of excavation-induced tangential stress and existence of a relatively “soft” loading environment in the rock mass surrounding the fractured rock. Pillar burst is drastic failure in the pillar core or a complete collapse of a pillar. This kind of failure usually occurs suddenly when the accumulated elastic strain energy reaches to a critical level, which means that the released energy is higher than the dissipated energy. As a result, a large volume of failed rocks is released. Moreover, the magnitude is larger than the strain burst (Ortlepp and Stacey 1994). Fault-slip burst is because of the slip along pre-existing faults or some newly generated shear ruptures. When the shear stress along a shear rupture or a fault exceeding, the shear strength, the shear rupture or a fault will slip suddenly and rapidly. As a consequence, a large amount of seismic energy will be released with high ground motions and vibrations, which may trigger other types of rockburst (Wang et al. 2021).

Rockburst can be classified into three types according to the mechanism and time: instant, intermittent, and time-delayed (Xiating et al. 2019). It was known that rock burst events have been reported in some mining countries since the first cases were recorded in India and South Africa in the 20th century.

On May 31, 2015, there was a rockburst at the Neelum-Jhelum Hydropower Project in Pakistan, led to three deaths and TBM damage (Naji et al. 2018). On August 28, 2016, a serious one occurred in Qinling tunnel in Hanjiang-to-Weihe River Water Diversion Project in China, resulting in the destruction of a Tunnel Boring Machine (TBM) and several days of project delay. It is easily concluding that a large number of rock burst events are incontrovertible evidence.

To date, great efforts have been devoted to the investigation and research to it. Most studies were focus on the mechanisms, contributing factors, risk evaluation and prediction, the measures of prevention and mitigation. Over the last five decades, the main methodologies of research can be classified into five categories: empirical, analytical, experimental, numerical, and data-based. As it was so complex and often influenced by lots of factors, there is not yet an effective way to control
rock burst up to now (Manouchehrian and Cai 2018).

At present, many studies of the risk were conducted, yet in qualitatively. Usually it can be divided into four levels: No rockburst, Light rockburst, Medium rockburst, and Violent rockburst.

**Figure 1.** Examples of rockburst in Qinling tunnel in Hanjiang-to-Weihe River Water Diversion Project

A deep buried conveyance Qinling tunnel in Hanjiang-to-Weihe River Water Diversion Project occurred lots of rockbursts. The tunnel was constructed with TBM. Strain burst was one of the most common problems, as shown in Figure 1.

Due to the complexity of rockburst mechanism and prediction, explore on the mechanism, learning the knowledge from case history, use suitable rock indexes to predict rockburst and study on the prevention measurement are very important and needed.

At present, many scholars have suggested many prediction methods, such as random forest (RF), support vector machine (SVM), and artificial neural network (ANN). Support Vector Machine is considered as one of the most effective and reliable new artificial intelligence methods (Dong et al. 2013; Dong et al. 2011) for solving classification problems. In this work, according to the complicated problems of rockburst prediction, the SVM method is applied to predicting rockburst classification.

### 2. Criteria and indexes of rockburst

#### 2.1 Criteria of rockburst

The occurrence or not of rockburst is related to many factors, and the characteristics can be described from many angles, so there are many methods to judge it, such as strength theory, energy theory and comprehensive criteria. The strength theory is simple to distinguish and easy to use.

According to the modern strength theory gradually formed from 1950s to the present, rockburst is the failure phenomenon of surrounding rock when the stress of surrounding rock reaches or exceeds the strength of surrounding rock. Starting from the static limit equilibrium condition of surrounding rock, various strength criteria are taken as the criteria of rockburst. Table 1 lists some of the criterias of rockburst by representative scholars at home and abroad (Xiating et al. 2013).

In Table 1, $\sigma_0$ is the maximum tangential stress of cavity, $\sigma_c$ is the uniaxial compressive strength of rock, $\sigma_{T}$ is the maximum principal stress of surrounding rock, $\sigma_l$ is the axial pressure of the cavern.

From Table 1, it can be easily found that different scholars use different parameters as index to evaluate the criterion to rockburst. Furthermore, the classification of rockburst intensity is also different from each other. As a result, it is difficult to use these criteria directly to guide for the construction.
2.2 Indexes selected as input variables for SVM

According to previous studies on rockburst phenomenon and formation mechanism for many years, it is found that various scholars have proposed different criteria and classification methods. Table 1 summarizes the partial criteria and classification methods only considering stress in surrounding rock.

| Scholar     | Criteria of rock burst | Rock burst level     |
|-------------|------------------------|----------------------|
| HOEK, et al.| $\sigma_b/\sigma_c < 0.34$ | Light stripping      |
|             | $0.34 \leq \sigma_b/\sigma_c < 0.42$ | Violent stripping   |
|             | $0.42 \leq \sigma_b/\sigma_c < 0.56$ | More lining         |
|             | $\sigma_b/\sigma_c \geq 0.7$ | Violent rockburst    |
|             | $\sigma_b/\sigma_c < 0.20$ | No rockburst         |
|             | $0.20 \leq \sigma_b/\sigma_c < 0.30$ | Light rockburst      |
|             | $0.30 \leq \sigma_b/\sigma_c < 0.55$ | Medium rockburst    |
| RUSSENES    | $\sigma_b/\sigma_c \geq 0.55$ | Violent rockburst    |
|             | $\sigma_b/\sigma_c < 0.30$ | No rockburst         |
|             | $0.30 \leq \sigma_b/\sigma_c < 0.50$ | Light rockburst      |
| XU, et al.  | $0.50 \leq \sigma_b/\sigma_c < 0.70$ | Medium rockburst    |
|             | $\sigma_b/\sigma_c \geq 0.70$ | Violent rockburst    |
| BARTON      | $2.5 \leq \sigma_c/\sigma_1 < 5.0$ | Medium rockburst    |
|             | $\sigma_c/\sigma_1 < 2.5$ | Violent rockburst    |
| TAO         | $\sigma_c/\sigma_1 > 14.5$ | No rockburst         |
|             | $5.5 \leq \sigma_c/\sigma_1 \leq 14.5$ | Light rockburst, with light sound |
|             | $2.5 \leq \sigma_c/\sigma_1 < 5.5$ | Medium rockburst, with crack sound |
|             | $\sigma_c/\sigma_1 < 5.5$ | Violent rockburst, with strong crack sound |
| TURCHANINOV | $(\sigma_b+\sigma_L)/\sigma_c \leq 0.3$ | No rockburst         |
|             | $0.3 < (\sigma_b+\sigma_L)/\sigma_c \leq 0.5$ | Rockburst probably  |
|             | $0.5 < (\sigma_b+\sigma_L)/\sigma_c \leq 0.8$ | Rockburst surely    |
|             | $(\sigma_b+\sigma_L)/\sigma_c > 0.8$ | Violent rockburst    |
is generally believed that there are many reasons cause rockburst, and the influencing factors are complex, such as stratigraphic lithology, in-situ stress state in deep underground, buried depth of the cave, terrain, stress state of surrounding rock after tunnel excavation, excavation section shape, excavation mode and so on (As shown in Figure 2). But in these factors, the formation lithology and in-situ stress conditions are the decisive factors to produce rockburst, only with these two conditions, it is possible to occur rockburst, is indispensable.

3. Support Vector Machine (SVM)
Support Vector Machine (SVM) can be used to solve the classification problem. Its learning strategy is to maximize the interval, which can be transformed into the solution of a programming problem.

In the case of linear inseparability, SVM first completes the calculation in the low-dimensional space, then maps the input space to the high-dimensional feature space by kernel function (As shown in Figure 3), and finally constructs the optimal separation hyperplane in the high-dimensional feature space, so as to separate the nonlinear data in the plane which is not separable by itself.

4. Case study
Referring to relevant literature (He et al. 2015; Keneti and Sainsbury 2018; Li et al. 2012), 46 sets of rockburst samples at home and abroad were chosen to test the rationality of the SVM model (As
shown in Table 2). The first 36 sets data were used as training samples, another 10 sets data were used as testing samples. SVM model and criterion were acquired through 36 sets of rockburst training samples.

Four levels of rockburst, including no rockburst, light rockburst, medium rockburst, violent rockburst, are indicated by 1, 2, 3, 4, respectively. They are considered as the output variables in the SVM model. The real level of rockburst were wrote as the measured record (MR).

A SVM model with Radial Basis Function (RBF) of kernel function type was established. The RBF kernel is also referred to as the Gaussian kernel (As shown in Figure 4). The RBF kernel of two samples $x$ and $x'$ can be expressed as the eigenvector of an output space, which is defined as Equation (1).

$$K(x, x') = \exp\left(-\frac{\|x - x'\|^2}{2\sigma^2}\right)$$

The calculated results of SVM model were also listed in Table 2.

The misjudgement ratio of two combinations I and II are listed in Table 3. The predicted results of both training and testing samples show that the index I is more appropriate than index II to be used in SVM model for rockburst prediction. In other words, the stress coefficient $T_s$ and the brittleness coefficient of rock $B$ play more important role than $\sigma_0$ and $\sigma_c$.

Table 2. Collected samples of rockburst cases and calculation results by SVM.

| No. | $\sigma_0$/MPa | $\sigma_c$/MPa | $\sigma_r$/MPa | $T_s$ | B | $W_{et}$ | MR | SVM I | SVM II |
|-----|----------------|----------------|----------------|-------|---|---------|-----|-------|-------|
| 1   | 89.56          | 190.30         | 17.13          | 0.47  | 11.11 | 3.97    | 3   | 3     | 3     |
| 2   | 89.56          | 170.28         | 12.07          | 0.53  | 14.11 | 5.76    | 3   | 3     | 3     |
| 3   | 89.56          | 187.17         | 19.17          | 0.48  | 9.76  | 7.27    | 3   | 4     | 2     |
| 4   | 56.10          | 131.99         | 9.44           | 0.43  | 13.98 | 7.44    | 3   | 3     | 3     |
| 5   | 54.20          | 133.99         | 9.09           | 0.40  | 14.74 | 7.08    | 3   | 3     | 3     |
| 6   | 70.30          | 128.52         | 8.73           | 0.55  | 14.72 | 6.43    | 3   | 3     | 3     |
| 7   | 48.75          | 180.00         | 8.30           | 0.27  | 21.69 | 5.00    | 3   | 3     | 3     |
| 8   | 62.50          | 175.00         | 7.25           | 0.36  | 24.14 | 5.00    | 3   | 3     | 3     |
| 9   | 75.00          | 180.00         | 8.30           | 0.42  | 21.69 | 5.00    | 3   | 3     | 3     |
| 10  | 57.00          | 180.00         | 8.30           | 0.32  | 21.69 | 5.00    | 3   | 3     | 3     |
| 11  | 89.00          | 236.00         | 8.30           | 0.38  | 28.43 | 5.00    | 3   | 3     | 3     |
| 12  | 50.00          | 130.00         | 6.00           | 0.38  | 21.67 | 5.00    | 3   | 3     | 2     |
| 13  | 108.00         | 140.00         | 8.00           | 0.77  | 17.50 | 5.50    | 4   | 4     | 4     |
| 14  | 18.80          | 178.00         | 5.70           | 0.11  | 31.23 | 7.40    | 1   | 1     | 1     |
| 15  | 11.00          | 115.00         | 5.00           | 0.10  | 23.00 | 5.70    | 1   | 1     | 1     |
| 16  | 55.40          | 176.00         | 7.30           | 0.31  | 24.11 | 9.30    | 3   | 3     | 3     |
| 17  | 48.00          | 120.00         | 1.50           | 0.40  | 80.00 | 5.80    | 3   | 3     | 3     |
| 18  | 63.00          | 115.00         | 1.50           | 0.55  | 76.67 | 5.70    | 3   | 3     | 3     |
| 19  | 49.50          | 110.00         | 1.50           | 0.45  | 73.33 | 5.70    | 3   | 3     | 3     |
Table 3. Misjudgement ratio of different sample type by SVM model.

| Sample type | SVM          |
|-------------|--------------|
|             | I            | II           |
| Training samples | 11.11% | 16.67% |
| Testing samples | 10%    | 20%      |

5. Conclusions
The following main conclusions are drawn from this study:

(1) Rockburst often can be classified into three types: strain burst, pillar burst, and fault-slip burst. Strain burst is more popular in the underground construction. Different scholars have different standards to classify the rockburst grade, but most of them agree to classify the
rockburst grade into four levels: no rockburst, light rockburst, medium rockburst and violent rockburst.

(2) Misjudgement ratio of training samples using index I and II are 11.11%, 16.67%, respectively. Misjudgement ratio of testing samples using index I and II are 10%, 20%, respectively.

(3) It is appropriate to choose the index including the maximum tangential stress $\sigma_0$, the stress coefficient $T_s$, the brittleness coefficient of rock B, and the elastic energy index $W_{el}$ to predict rockburst.

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