*Research Article*

# An Evaluation Method of Rock Brittleness Based on the Prepeak Crack Initiation and Postpeak Stress Drop Characteristics

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Recent research shows that the brittleness of rock is closely related to the initiation and propagation of internal microcracks, but there are few brittleness evaluation indices considering the characteristics of rock initiation. Based on the theoretical analysis of brittleness and the characteristics of rock initiation, this study proposes an evaluation method of rock brittleness based on the prepeak crack initiation and postpeak stress drop characteristics. First, based on the description and definition of brittleness by George Tarasov and Potvin et al., the feasibility of an evaluation method based on the prepeak crack initiation and postpeak stress drop is theoretically analyzed. Second, the component $\mathbf{B_i}$ representing the prepeak brittleness of rock and component $\mathbf{B_{ii}}$ representing the prepeak brittleness of rock are constructed, and the product of the two is the brittleness index $\mathbf{B_I}$, representing the prepeak crack initiation and postpeak stress drop. Finally, experimental tests of granite and marble were conducted to evaluate the new index, and the brittleness indices of different methods are calculated and compared. The results show that, like other brittleness indices ($B_1 \sim B_5$), the brittleness index $\mathbf{B_I}$ can effectively reflect the effects of different confining pressures and loading modes on rock brittleness. The brittleness of marble decreases with increasing confining pressure from 5 MPa to 35 MPa. At a confining pressure of 5 MPa, the brittleness of granite during a triaxial unloading test is greater than that during a triaxial compression test. The calculated results are consistent with the experimental results. By tests and comparison results, the reliability of this evaluation method was verified, which provides a way to evaluate rock brittleness from the perspective of crack initiation and is helpful to enrich the analysis and evaluation of rock brittleness in the laboratory.

## 1. Introduction

Rock brittleness, as one of the basic properties of rock, is a key index to evaluate rock properties. Accurate evaluation of rock brittleness is of great significance for guiding the effective development and utilization of coal, oil, and gas resources, underground engineering, construction, and geological disaster prevention and mitigation [1–11]. Brittleness is the comprehensive performance of rock under different stress and different environments. Although an internationally accepted definition of brittleness has not yet been established [12], various researchers have defined rock brittleness to suit different purposes. From the perspective of strain, Morley and Hetenyi defined brittleness as the loss of

material plasticity. From the perspective of strength [13, 14], Ramsay argued that brittle failure occurred when the cohesion of rock was destroyed [15]. Obert and Duvall suggested that brittleness is a feature describing the failure behavior of rock materials when the yield strength of the rock is reached or exceeded [16]. From the perspective of energy, Tarasov and Potvin argued that rock brittleness is the ability to self-maintain macroscopic damage through the energy balance in the postpeak stage [17]. In addition, Li et al. believed that brittleness was a comprehensive property of rock materials: the ability to generate local damage and develop spatial fractures under an internal nonuniform stress distribution caused by the inherent heterogeneity of the rock [18].

Over the past 50 years, according to brittleness characteristics, many quantitative evaluation methods for rock brittleness have been proposed, and the influencing factors have been analyzed. These brittleness indices generally fall into three categories: brittleness index based on physical tests [4, 19, 20], brittleness index based on rock mechanical tests [3, 17, 21–23], and brittleness indices based on other methods [24, 25]. For example, Rickman et al. suggested that brittleness increases with the increase in quartz minerals, based on which they proposed a brittleness index to quantify rock brittleness as a function of the amounts of quartz, carbonate, and clay minerals in rocks [26]. However, this method fails to evaluate the same rock under different stress states [22]. Porosity also affects rock brittleness. Jin et al. claimed that there is a global correlation between mineralogy-derived brittle indices and neutron porosity [20]. Based on rock compression and splitting tests, various brittleness indices were built considering stress, strain, and energy, such as the ratio of the compressive strength to tensile strength [21], the ratio of the difference between the peak strength and residual strength to the peak strength, and the ratio of peak strength to the crack initiation stress [9]. Meanwhile, Coates determined the brittleness by the ratio of the recoverable strain to the total strain [27]. Hajiabdolmajid and Kaiser introduced a plastic strain-dependent brittleness index that considers cohesion weakening and frictional strengthening [28]. Tarasov and Potvin proposed a brittleness index based on the complete stress-strain curve of the energy balance [17]. However, for brittleness indices based on stress, many scholars criticized that those indices have yielded contradictory results to those calculated from the perspective of strain or energy; furthermore, the results are not monotonic and continuous. In addition to the above limitations, rock brittleness can be affected by the stress state, and rocks may be less brittle and more ductile under high confining pressure conditions, so those indices are not suitable for complex stress environments [22]. Indices based on strain do not consider the postpeak characteristic, which is critical to characterize the brittle features [28, 29]. Other indices were derived based on penetration testing [24], point load testing [25], and Mohr's circle analysis [30]. These approaches also have some limitations, such as the specific equipment required for the sampling and testing of rock via penetration testing, leading to its limited use. There is a lack of sufficient evidence that the point load testing method is reasonable for determining the values of $K_b$ for various rocks.

In recent years, with the further study of rock fractures, it has been found that the failure symptoms and fracture energy of brittle rock materials are closely related to internal crack initiation fractures [9, 21]. For example, George pointed out that rock brittleness refers to the ability of microcracks in rock to produce and cause nonpermanent deformation and continuous deformation [31]. The rock brittleness is related to microcracks, including the characteristics of stress and strain when the crack initiates. In addition, Tarasov and Potvin considered brittleness under compression as the ability of the rock to self-sustain macroscopic failure in the postpeak region due to the elastic

energy accumulated within the loaded material [17]. From this definition, it can be seen that the brittleness of rock is related to the accumulation of elastic energy. The whole process of rock failure can be regarded as the occurrence of the following processes: microcrack compaction, initiation, development, convergence and penetration, and energy accumulation and consumption. Before microcracks initiate or before the stress level is lower than the initiation stress level, the microcracks in the rock do not propagate, which correspond to the process of elastic accumulation. When the stress level is higher than the crack initiation, stress microcracks in the rock initiate and develop. After crack initiation, the work performed by the external load will be transformed into compression elastic energy and consumed energy to maintain crack propagation. The elastic energy of the rock will continue to increase, but the growth rate of the crack will decrease. When the stress level reaches the yield strength, the internal cracks of the rock propagate rapidly, and the work performed by the external load is mainly transformed into consumable energy. When the rock falls, the total energy of the external work performed is consumed by rock failure, and there is no excess elastic energy. It can be considered that before the microcrack initiates, the microcrack is closed and the external work is purely transformed into elastic energy; after that, the microcracks initiate and expand, and part of the loading work is converted into consumed energy until the final failure when the loading work is completely converted into consumed energy. Combining the definition of brittleness, following [17, 31], the microcrack development, and the energy conversion process during rock failure, it is considered that the rock brittleness can be evaluated from prepeak crack initiation and postpeak stress drop characteristics. For example, some scholars have established new indices from the perspective of crack initiation stress [9, 21]. However, it is rarely reported that an evaluation index of rock brittleness is established from the viewpoint of crack initiation strain. In this study, the evaluation of the prepeak brittleness of rock is established from the viewpoint of crack initiation strain, and then, the evaluation component of postpeak brittleness is established according to the postpeak stress drop characteristics. Then, the rock brittleness evaluation index based on prepeak crack initiation and postpeak stress drop characteristics are established by synthesizing the prepeak and postpeak brittleness evaluation components.

## 2. Methods

### 2.1. Analysis Method for the Characteristics of Prepeak Crack Initiation in Rock.
At present, the main analysis methods of rock crack initiation characteristics are the observation method, crack volumetric strain method, and acoustic emission method. Among them, the crack volumetric strain method is the most widely used. In this study, the crack initiation characteristics of rock will be determined by the crack volumetric strain method.

The crack volumetric strain method was first proposed by Martin in his doctoral thesis [32]. The key to determining the crack initiation stress by this method is that the crack

volumetric strain ($\varepsilon_{V\text{crack}}$) is subtracted from the volumetric strain ($\varepsilon_V$) by the elastic volumetric strain ($\varepsilon_{V\text{elastic}}$). Among them, the volumetric strain ($\varepsilon_V$) is calculated by the axial ($\varepsilon_{\text{axial}}$) and lateral strain ($\varepsilon_{\text{lateral}}$) measured in the test. The elastic volumetric strain is calculated by the stress state ($\sigma_1$, s $\sigma_3$) and elastic parameters ($E$, $\mu$) in the corresponding stage of the test, and the formulas for calculating each strain are as follows:

$$\varepsilon_V = \varepsilon_{axial} + 2\varepsilon_{lateral},$$
$$\varepsilon_{V\ elastic} = \frac{(1 - 2\mu)(\sigma_1 + \sigma_3)}{E}, \qquad (1)$$
$$\varepsilon_{V\ crack} = \varepsilon_V - \varepsilon_{V\ elastic}.$$

Figure 1 shows the volumetric strain characteristics of a crack. Under pressure, the internal microcracks and voids in the rock are continuously compressed. At the stage of linear elastic deformation, the crack volume is compressed to the limit state, and the rock is similar to an isotropic material, with only elastic volumetric strain and no crack volumetric strain. After that, with the increase in stress, when the loading stress reaches the crack initiation stress, the internal crack begins to initiate and propagate, and the crack volume increases gradually.

## 2.2. Proposed Method Based on Prepeak Crack Initiation and Postpeak Stress Drop Characteristics.

A reasonable brittleness index should fully consider the entire scope of rock behavior and as many of the effects of the mechanical parameters of the rock and external loading conditions as possible [6, 33]. For example, Xia et al. proposed a new brittleness definition based on the postpeak stress drop rate and the ratio of prepeak released elastic energy to total energy [33]. In this study, we propose a brittleness index considering prepeak crack initiation and postpeak stress drop characteristics.

### 2.2.1. Theoretical Analysis.
In the process of rock compression, the crack initiation stress is the boundary point of crack compression and propagation. If rock brittleness represents the ability of the rock to maintain the accumulation of elastic energy in the crack compaction state [32], the elastic energy growth rate reaches the peak when the crack initiates; then, the microcrack propagates, and the growth rate decreases. If the crack initiation strain $\varepsilon_{ci}$ (the strain corresponding to the crack initiation stress) is used to characterize the ability of a rock to be compacted and the difference ($\triangle \varepsilon = \varepsilon_c - \varepsilon_{ci}$) between the peak strain $\varepsilon_c$ (the strain corresponding to peak stress) and the crack initiation strain $\varepsilon_{ci}$ represents the ability of a crack in the rock to propagate, then the strain ratio ($\varepsilon_{ci}/\Delta\varepsilon$) can be used to characterize the ability of the rock to maintain the compaction state. The larger the initiation strain $\varepsilon_{ci}$ is, the more compression work consumed by the rock, the greater the elastic energy accumulation, and the stronger the compaction of the cracks. The smaller $\triangle \varepsilon$ is, the faster the crack growth. The larger the

$\varepsilon_{ci}/\Delta\varepsilon$ is, the greater the ability of the rock to maintain the crack compaction state. Then, the prepeak brittleness characteristics of rocks can be characterized by $\varepsilon_{ci}/\Delta\varepsilon$ (Figure 2).

In general, there are two failure forms (I and II, as shown in Figure 3(a)) for rocks due to compression testing [34]. Type II failure is commonly considered unstable and brittle, and brittle hard rock often follows this deformation and failure model. Therefore, combined with the postpeak characteristics of the stress-strain curve, the greater the brittleness of the rock is, the greater the stress drop after the peak. As shown in Figure 3(b), the steeper the drop in the postpeak curve, the larger the area $S$ is. The postpeak brittleness characteristics of the rock can be characterized by $S/S_\triangle$ ($S_\triangle$ is the red triangle area in Figure 3(b)). Points M and N represent the peak point and the beginning point of residual stress.

### 2.2.2. Brittleness Evaluation Method.
The brittleness evaluation method based on prepeak crack initiation and postpeak stress drop characteristics is as follows:

(a) According to the characteristics reflected by the stress-strain curve of rock, the brittleness characteristics of the rock can be judged qualitatively

(b) Considering the experimental data, it can be used to identify the crack initiation strain $\varepsilon_{ci}$

(c) Considering the peak strain $\varepsilon_c$, the prepeak brittleness component $\mathbf{B_i} = \varepsilon_{ci}/\Delta\varepsilon$ can be calculated

(d) Considering the postpeak characteristics, the areas of $\mathbf{S}$ and $\mathbf{S_\triangle}$ can be calculated, and then, the postpeak brittleness component $\mathbf{B_{ii}} = \mathbf{S}/\mathbf{S_\triangle}$ can be calculated; the value of $\mathbf{B_{ii}}$ is between 0 and 1.

(e) The brittleness index based on prepeak crack initiation and postpeak stress drop characteristics can be calculated as follows:

$$\mathbf{B_I} = \mathbf{B_i} \cdot \mathbf{B_{ii}}. \qquad (2)$$

$\mathbf{B_i}$ and $\mathbf{B_{ii}}$ characterize the prepeak and postpeak brittleness characteristics of rock, respectively. There may be many combination modes that can be used to characterize the brittleness characteristics of rock by using these two components, such as in a sum form ($\mathbf{B_a} + \mathbf{B_b}$), a product form ($\mathbf{B_a} \cdot \mathbf{B_b}$), or other forms. Some scholars, such as [18, 21], take the sum of the two components as the brittleness index. Some scholars, such as [22, 35], take the product of the two components as the brittleness index. In this study, the brittleness evaluation index in the form of a product is mainly considered based on the following factors. As the prepeak brittleness evaluation component of $\mathbf{B_i} = \varepsilon_{ci}/\Delta\varepsilon$ is based on its ability to maintain the crack in the compacted state, generally, after yielding, the stress of brittle rock falls rapidly under a small strain, resulting in $\triangle \varepsilon$ being smaller than the early crack initiation strain $\varepsilon_{ci}$; thus, the ratio $\mathbf{B_i}$ is usually greater than 1. The postpeak brittleness evaluation component of $\mathbf{B_{ii}}$ is less than 1. If taking the sum of the two
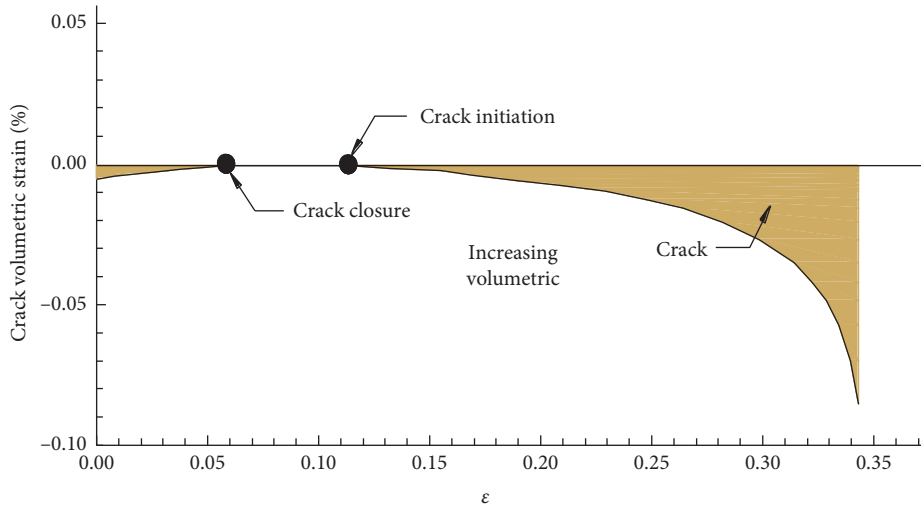
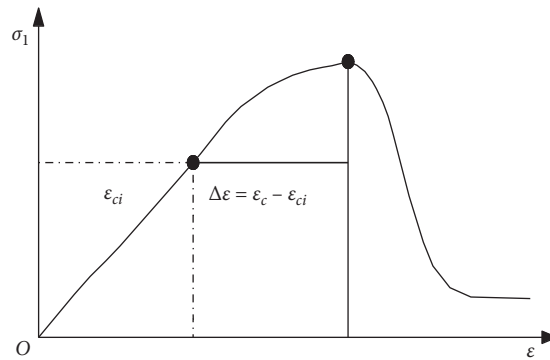FIGURE 1: Crack volumetric strain characteristics.
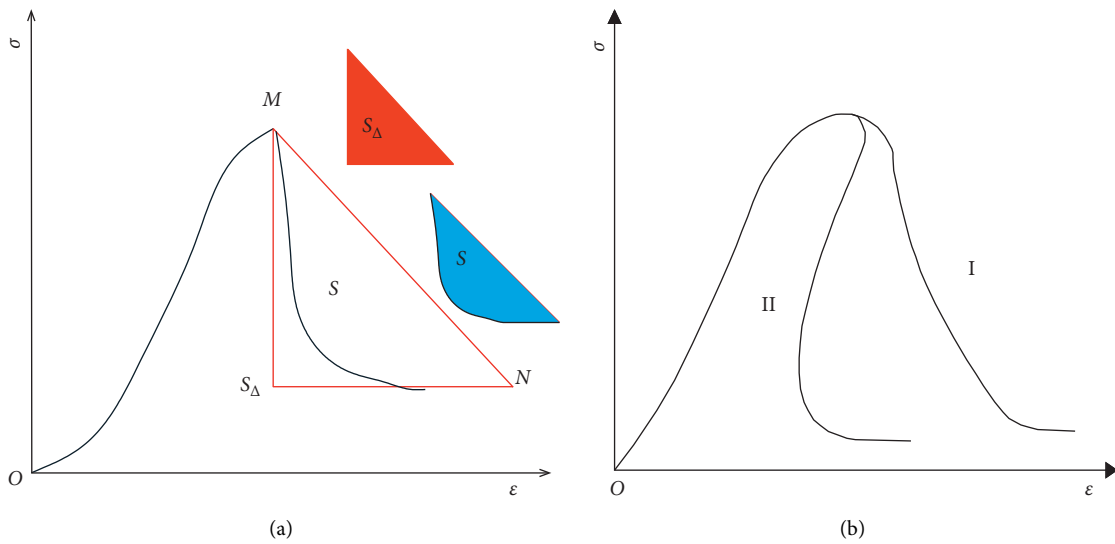


FIGURE 2: Schematic diagram of prepeak rock brittleness.



FIGURE 3: Schematic diagram of postpeak rock brittleness. (a) Rock failure mode [34]. (b) Postpeak brittleness characteristics.

$(\mathbf{B_i} + \mathbf{B_{ii}})$ as the brittleness evaluation index, it mainly reflects the prepeak brittleness characteristic because the value of the prepeak brittleness component $\mathbf{B_i}$ may be much larger than that of the postpeak brittle component $\mathbf{B_{ii}}$, which is unreasonable. If taking the product of the two $(\mathbf{B_i} \cdot \mathbf{B_{ii}})$ as the brittleness evaluation index, according to the theoretical
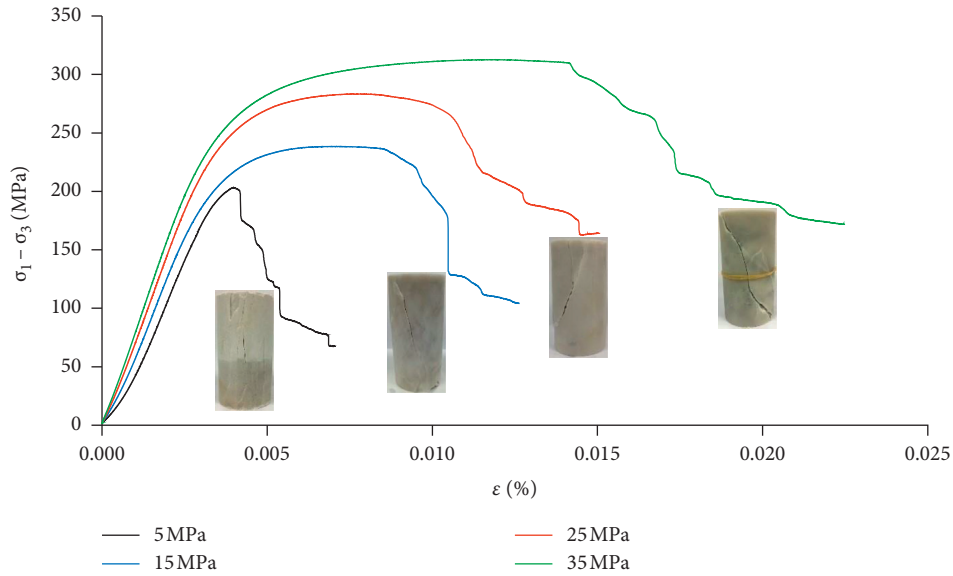
FIGURE 4: Marble test curves under different confining pressures.

analysis, the greater the brittleness of the rock is, the greater the $B_i$ and $B_{ii}$ values, and the greater the product of the two, which can eliminate the adverse effects of the obvious difference between the two components ($B_i$ and $B_{ii}$). For example, if $B_i = 3$ and $B_{ii} = 0.1$ or 1, their sum is 3.1 or 4, but their product is 0.3 or 3. From the example, we can see that taking the product of the two components as the brittleness evaluation index has the advantage of clearly categorizing the brittleness.

## 3. Verification of the Proposed Method

*3.1. Verification of $B_I$ under Different Confining Pressures.* The triaxial compression test data of marble under different confining pressures were selected to verify the feasibility of this method. The test was carried out at Rock Mechanics Laboratory, State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology. According to Figure 4, with increasing confining pressure, the plasticity of marble increases. At 5 MPa, the stress drops after the peak: first quickly and then more slowly, showing brittle failure. From 15 MPa to 35 MPa, with increasing confining pressure, the plastic deformation interval increases, and the plasticity increases. From a qualitative perspective, with increasing confining pressure, the plasticity of marble increases, which is consistent with previous research results [21, 22, 33, 35]. The calculation results of the brittleness index $B_I$ under the corresponding conditions are given in Table 1. The values of the brittleness index $B_I$ are 0.152, 0.110, 0.082, and 0.078 under 5~35 MPa. The calculated results are in good agreement with the experimental curve, which effectively reflects the variation in the brittleness index with confining pressure.

*3.2. Verification of $B_I$ under Different Loading Modes.* In general, it is considered that rock brittleness is more obvious under unloading conditions than that under conventional compressive loading conditions. Therefore, comparison analyses were conducted on the granite samples from the triaxial unloading test (5 MPa) and compressive test (5 MPa). According to Figure 5, for the unloading test under 5 MPa, the stress of the blue curve drops considerably after the peak point, indicating that the brittleness characteristic is prominent. For the compression test under 5 MPa, the stress of the green curve drops gradually after the peak point, showing strain-softening characteristics. The test results show that the brittleness of these granite samples under unloading conditions is larger than that under compressive loading conditions. The calculation results of the brittleness index $B_I$ under different loading modes are given in Table 2. The $B_I$ values are 0.94 and 0.40 for the unloading and compression tests, respectively. The calculated results are in good agreement with the experimental results. These results also effectively reflect the fact that the brittleness of rock under unloading conditions is stronger than that under loading conditions.

## 4. Discussion

At present, there are various rock brittleness indices. In this section, a comparison was made between the proposed brittleness index ($B_I$) and 5 commonly used brittleness indices. Because of the heterogeneity and anisotropy of rock materials, it is advisable to select the brittleness indices established based on the same sample or stress-strain curve as the object for comparative discussion and analysis. The formulas of the selected brittleness indices are given in Table 3. Figure 6 shows schematic diagrams for brittleness indices $B_1$, $B_2$, and $B_5$.

In addition, a classification of rock brittleness has been established based on the research of brittleness index $B_1$. There are 6 grades for rock brittleness, as given in Table 4.

TABLE 1: Calculation results of the brittleness index for marble under different confining pressures.

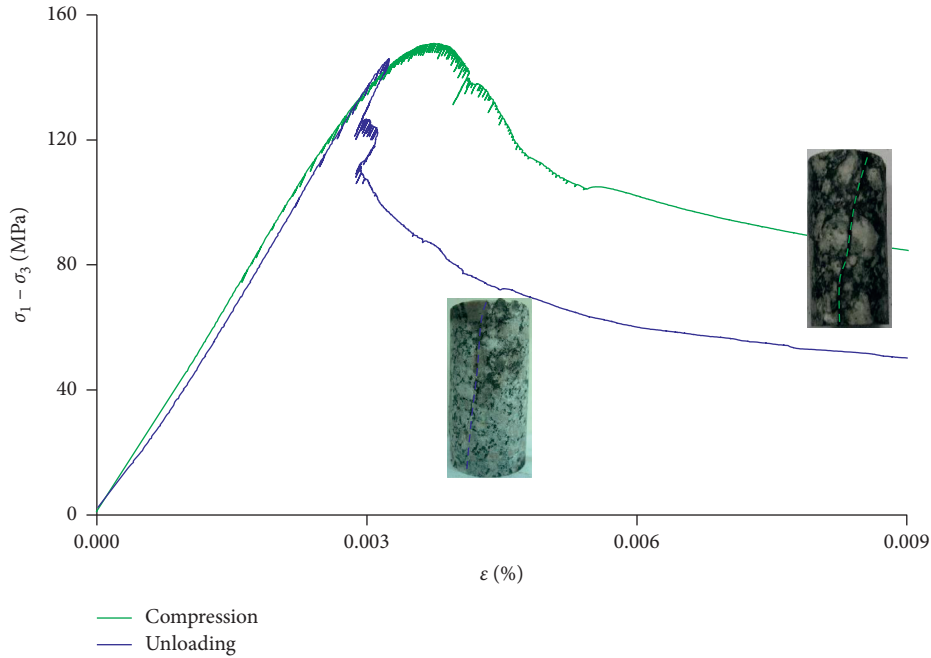| Confining pressure (MPa) | Peak strain $\varepsilon_c/\%$ | Crack initiation strain $\varepsilon_{ci}/\%$ | Strain difference $\triangle\varepsilon = \varepsilon_c - \varepsilon_{ci}$ | $B_i$ $\varepsilon_{ci}/\triangle\varepsilon$ | $B_{ii}$ $S/S_{\triangle}$ | $B_I$ $B_i \cdot B_{ii}$ | Qualitative analysis of the test curve |
|---|---|---|---|---|---|---|---|
| 5 | 0.003980 | 0.001250 | 0.00273 | 0.46 | 0.33 | 0.152 | Brittleness |
| 15 | 0.007170 | 0.002170 | 0.00500 | 0.43 | 0.25 | 0.110 | Elasticity-plasticity |
| 25 | 0.007570 | 0.002440 | 0.00513 | 0.48 | 0.17 | 0.082 | Elasticity-plasticity |
| 35 | 0.011820 | 0.002730 | 0.00909 | 0.30 | 0.26 | 0.078 | Elasticity-plasticity |



FIGURE 5: Granite test curves under different loading modes.

TABLE 2: Calculation results of the brittleness index of granite under different loading modes.

| Loading modes | Peak strain $\varepsilon_c/\%$ | Crack initiation strain $\varepsilon_{ci}/\%$ | Strain difference $\triangle\varepsilon = \varepsilon_c - \varepsilon_{ci}$ | $B_i$ $\varepsilon_{ci}/\triangle\varepsilon$ | $B_{ii}$ $S/S_{\triangle}$ | $B_I$ $B_i \cdot B_{ii}$ | Qualitative analysis of the test curve |
|---|---|---|---|---|---|---|---|
| Unloading | 0.003249 | 0.001828 | 0.001421 | 1.29 | 0.73 | 0.94 | Brittleness |
| Compression | 0.003746 | 0.001810 | 0.001936 | 0.93 | 0.43 | 0.40 | Strain softening |

TABLE 3: Brittleness indices for comparative analysis.

| Brittleness | Calculation formula | Parameter specification |
|---|---|---|
| $B_1$ | $B_1 = 1 - \exp(M/E)$ [36] | $E$ is the prepeak elasticity modulus; $M$ is the postpeak elasticity modulus |
| $B_2$ | $B_2 = (\tau_p - \tau_r/\tau_p)(\lg|k_{ac(AC)}|/10)$ [35] | $\tau_P$ is the peak compressive strength; $\tau_r$ is the residual compressive strength; $k_{ac(AC)}$ is the slope of ac (AC). |
| $B_3$ | $B_3 = (\tau_p - \tau_r)/\tau_p$ [12] | $\tau_P$ is the peak compressive strength; $\tau_r$ is the residual compressive strength. |
| $B_4$ | $B_4 = (\varepsilon_p - \varepsilon_r)/\varepsilon_p$ [12] | $\varepsilon_p$ is peak strain; $\varepsilon_r$ is the residual strain |
| $B_5$ | $B_5 = (\varepsilon_B - \varepsilon_P)/(\varepsilon_P - \varepsilon_M)$ [37] | $\varepsilon_p$ is peak strain; $\varepsilon_B$ is the residual strain; $\varepsilon_M$ is the prepeak strain when the stress reaches the residual stress. |

The brittleness evaluation results of $B_I$ and $B_1 \sim B_5$ are compared and analyzed for different confining pressure loading modes.

The results for marble from the different brittleness evaluation methods are given in Table 5 for each confining pressure. According to Table 5, $B_I$ and $B_1$ decrease with
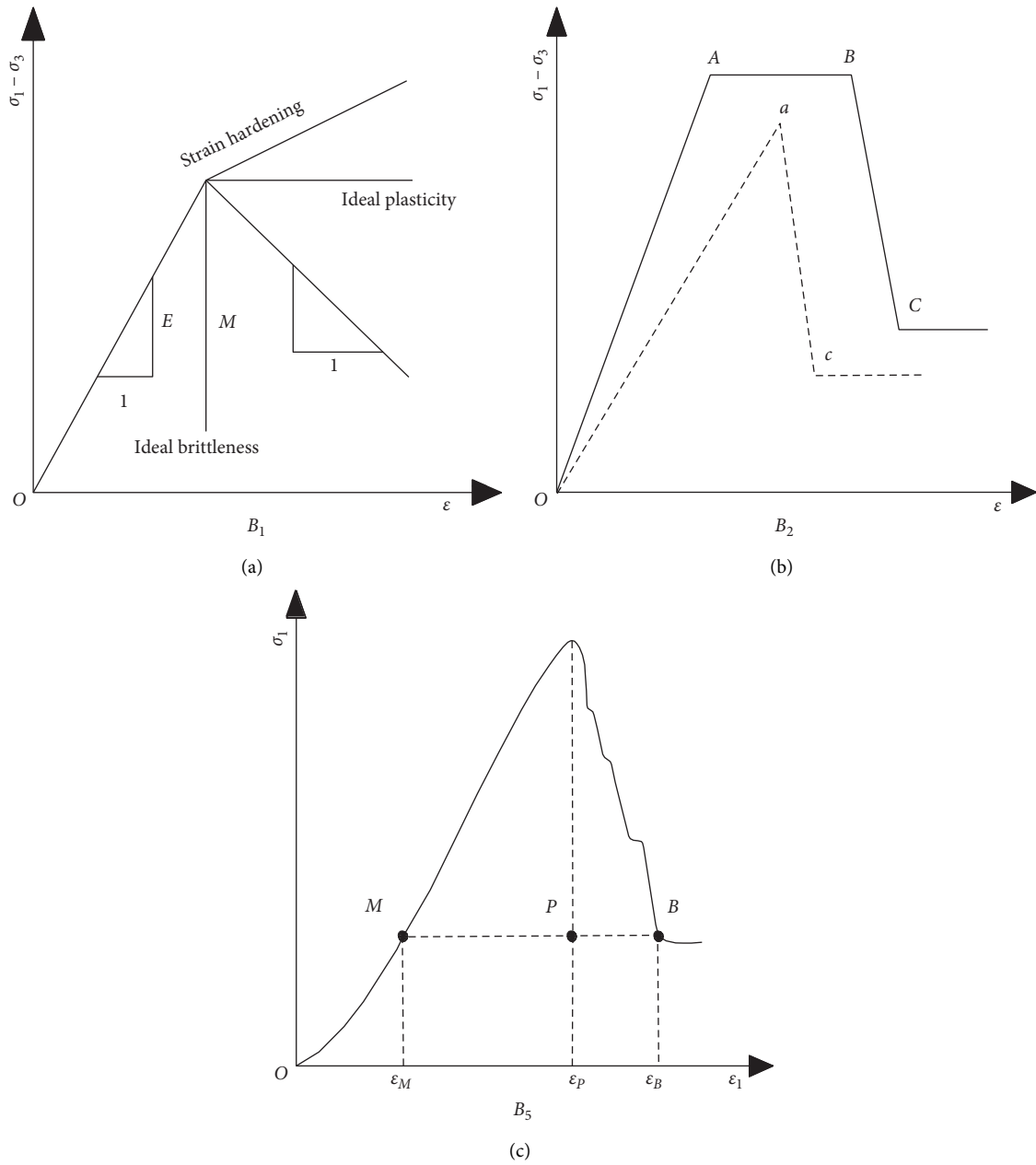
(a)

(b)

(c)

Figure 6: Schematic diagram of the calculation model of the partial brittleness evaluation index.

Table 4: Classification and description of brittleness index B1.

| Grade | $B_1$ | Description |
|---|---|---|
| 1 | 1 | $M \longrightarrow -\infty$, ideal brittleness |
| 2 | 0.6321~1 | $-\infty < M < -E$, high brittleness |
| 3 | 0.6321 | $M = -E$ |
| 4 | 0~0.6321 | $-E < M < 0$, low brittleness |
| 5 | 0 | $M = 0$, ideal plasticity |
| 6 | <0 | $M > 0$, strain hardening |

increasing confining pressure, and from 5 MPa to 15 MPa, they decrease considerably more than they do from 25 MPa to 35 MPa. For $B_2$ and $B_3$ tend to decrease with increasing confining pressure, while their values increase at 35 MPa. $B_4$ increases with the confining pressure except at 35 MPa. $B_5$ decreases with confining pressure except at 25 MPa, and there are only small differences among the three decreasing values, which are not advantageous for the quantitative identification of rock brittleness. Above all, by comparative analysis, it is considered that $\mathbf{B_I}$ and $B_2 \sim B_5$ can all be used to evaluate the change in rock brittleness with confining pressure, and the results of $\mathbf{B_I}$ and $B_1$ are good, while there are small differences in the results of $B_2 \sim B_5$.

The evaluation results of granite samples under 5 MPa with different loading modes are listed in Table 6. According to Table 6, $\mathbf{B_I}$ and $B_1 \sim B_5$ all decrease during the compression tests. For $\mathbf{B_I}$ and $B_2 \sim B_4$, their values during the unloading test are nearly 2 times those during the

TABLE 5: Calculation results of each index for marble under different confining pressures.

| Confining pressure (MPa) | $\mathbf{B_I}$ $\mathbf{B_i \cdot B_{ii}}$ | Comparison of brittleness indices | | | | | Qualitative analysis of the test curve |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | |
| 5 | 0.152 | 0.76 | 0.26 | 1.13 | 0.36 | 0.66 | Brittleness |
| 15 | 0.110 | 0.39 | 0.21 | 0.83 | 0.47 | 0.65 | Elasticity-plasticity |
| 25 | 0.082 | 0.20 | 0.10 | 0.31 | 0.52 | 0.88 | Elasticity-plasticity |
| 35 | 0.078 | 0.19 | 0.13 | 0.45 | 0.48 | 0.63 | Elasticity-plasticity |

TABLE 6: Calculation results of each index of granite under different loading modes.

| Loading mode | $\mathbf{B_I}$ $\mathbf{B_i \cdot B_{ii}}$ | Comparison of brittleness indices | | | | | Qualitative analysis of the test curve |
| --- | --- | --- | --- | --- | --- | --- | --- |
| | | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | |
| Unloading | 0.94 | 0.57 | 0.26 | 1.28 | 0.67 | 1.22 | Brittleness |
| Compression | 0.40 | 0.44 | 0.13 | 0.43 | 0.43 | 1.08 | Strain softening |

compression test, while there is only a small difference in $B_1$ and $B_5$ under the two loading modes. Based on the above analysis, $\boldsymbol{B_I}$ and $B_1 \sim B_5$ all reflect the change in rock brittleness with the loading mode.

## 5. Conclusions

(1) Taking the crack initiation strain $\varepsilon_{ci}$ to characterize the ability of the rock to be compacted and the difference between the peak strain $\varepsilon_c$ and crack initiation strain $\varepsilon_{ci}$ ($\triangle \varepsilon = \varepsilon_c - \varepsilon_{ci}$) to characterize the ability of crack propagation, the prepeak brittleness component ($\mathbf{B_i} = \varepsilon_{ci}/\triangle \varepsilon$) considering the crack initiation is established. If $\varepsilon_{ci}/\triangle \varepsilon$ is larger, the ability of the rock to maintain the crack compaction state is greater, and the prepeak brittleness is greater.

(2) Based on the postpeak characteristic of a greater stress drop, the postpeak brittleness of rock is greater, and the postpeak brittleness component ($\mathbf{B_{ii}}$) is established by the ratio of $S/S_\triangle$. If $S/S_\triangle$ is larger, the stress drops faster after the peak, and the postpeak brittleness is greater.

(3) A brittleness evaluation index based on the prepeak crack initiation and postpeak stress drop characteristics of the rock is established, and its expression is $\mathbf{B_I} = \mathbf{B_i \cdot B_{ii}}$.

(4) The brittleness index $\mathbf{B_I}$ can effectively reflect the effects of different confining pressures and loading modes on rock brittleness. Under the same conditions, the brittleness of rock during an unloading test is greater than that during a compressive loading test, and the brittleness of rock under low confining pressure is greater than that under a high confining pressure.

## Data Availability

The data used to support the findings of this study are included within this article and are from Rock Mechanics Laboratory, State Key Laboratory of Geohazard Prevention and Geoenvironment Protection, Chengdu University of Technology.

## Conflicts of Interest

The authors declare that they have no conflicts of interest.

## Authors' Contributions

Meiben Gao conceptualized, visualized, and wrote the article. Lubo Meng developed methodology. Tianbin Li supervised and collected fund. All authors have read and agreed to the published version of the manuscript.

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