Measurement of damaged area in permanent high rock slopes

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This paper presents the results of research concerning investigation of the effects of the presplitting and damaged area of permanent high rock slopes in limestone mining. There have been few reports on the results of investigations to evaluate the effects of presplitting. Thus we have not only investigated the extent of the damage in permanent high rock slopes using the VSP system but have also conducted an investigation into the effects of presplitting carried out experimentally. As result, it was confirmed that there are large differences (3. 0-10. 0m) in the damaged area of the permanent high rock slope depending on the site conditions. The damaged area caused by presplitting was not recognized in this measurement.

1. Introduction

In recent years there has been a growing need for ways to efficiently and precisely control the permanent high rock slope after excavation in open pits at limestone mines and quarries, and this need is expected to continue grow. Generally, in limestone mining the permanent high rock slope in limestone mine is formed by presplitting.

Plesplitting is generally adopted for the purpose of reducing the damaged area when a permanent high rock slope excavation surface.[1] The damaged area of the permanent high rock slope which is formed by presplitting is considered small, but it is very important to evaluate the effects of presplitting. However the method for evaluating the damaged area is generally a qualitative assessment (visual judgment) of the damaged area in the permanent high rock slope. Generally the damage caused by blasting, the condition of the base rock, and the stress relief due to excavation work are considered as casual factors for the damaged area in permanent high rock slopes. Some in-situ testing using VSP (Vertical Seismic Prospecting) were carried out to measure the damaged area arising from presplitting and production blasting, and the effect of the two type of blasting on the damaged area of the permanent high rock slope was investigated. The following is a report on what was learned from the in-situ testing and the study of the effect of blasting on the damaged area of the permanent high rock slope.

2. Measurement system

2. 1 The compact Vertical Seismic Prospecting system[2]

The compact vertical seismic prospecting system that was developed consists of probes attached to sensors to detect elastic waves in super-elastic alloy springs, an extendable probe rod made of carbon fiber, a cable, an A/D converter, a computer to record wave data, a trigger system to get a shot timing, and a percussion hammer to which a piezo-

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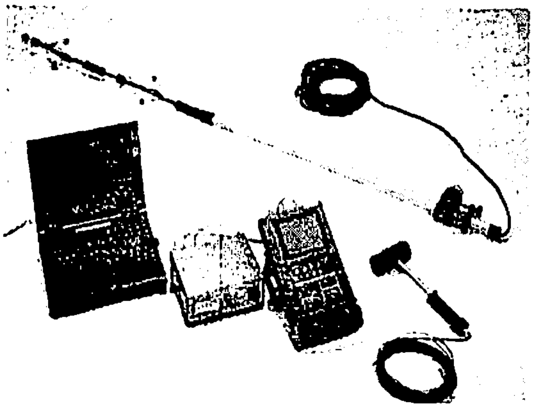

Fig. 1 Photograph of VSP system

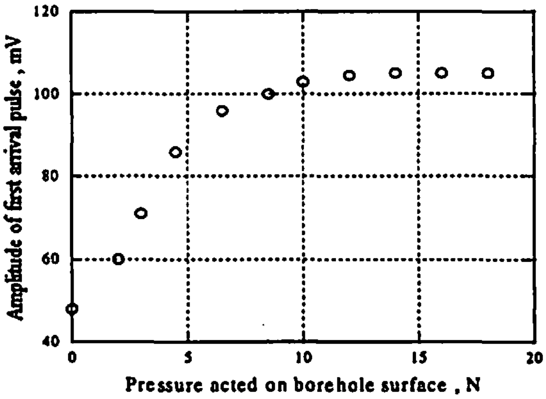

Fig. 2 Relationship between pressing force and output of sensing device

electric element is attached. Fig. 1 shows an overview of the measurement devices of the compact VSP system has been developed.

The structure is such that the vibration sensors are brought against the inner wall surface of the borehole by pulling the super-elastic alloy spring from outside the borehole. This structure of VSP system makes it easy to set the vibration sensors at any desired position. The vibration sensors have small acceleration sensors with an internal preamplifier. One accelerometer is set up at one side of the central part of the super elastic pipe in a four way split longitudinally, and another is set up in the opposite direction about a central rod to run the cable for the accelerometer. The pipe has no outside diameter of 10mm, a thickness of 0. 26mm, and a length, before heat treatment, of 30mm.

After VSP probes are set into arbitrary position within the borehole, measurements are made of the elastic waves and P waves produced by hitting the base rock near the borehole with the hammer. Elastic-wave measurements are taken repeatedly to the prescribed depth while varying the amplification conditions according to the base rock conditions and depth to be measured. The size of the damaged area is calculated from the relationship between the depth and the arrival time according to the measured wave data.

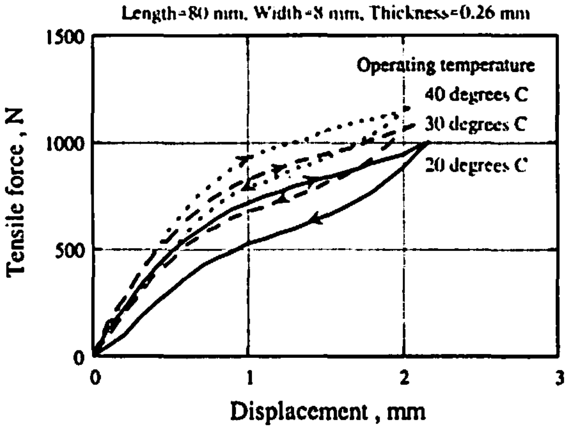

Fig. 3 Relationship between vertical displacement and the pressing force

2. 2 Super-elastic alloy spring[3)]

When measuring elastic waves by VSP system, the vibration sensors must actually be in contact with the inside wall of the borehole. It has been confirmed in laboratory experiments that elastic waves of sufficient amplitude cannot be measured unless the contact between the vibration sensor and the inside wall of the borehole is adequate. Ensuring adequate contact is important for eliminating measurement error. It has simultaneously been confirmed in laboratory experiments that the first arrival amplitude shows a roughly constant value if the vibration sensor makes contact with the borehole wall with force of 10N or more. Fig. 2 shows the relationship between the pressure and the first arrival amplitude.

For the layer probe, a mechanism was adopted in which the vibration sensor was kept in contact with the hole wall with a constant pressure, utilizing the super-elastic effect of a super-elastic alloy plate (made of 49% titanium and 51% nickel alloy). As shown in Fig. 3, the load-displacement curve of a super-elastic alloy plate shows non-linearity. This property is not plastic body since the super-elastic alloy plate returns to its pre-load state when the load is removed. With a steel spring, it is considered difficult to keep a vibration sensor in contact with the inner wall of the borehole with a constant pressure. By utilizing the super-elastic effect of a super-elastic alloy plate, the vibration sensor can be kept in contact with the inner wall of the borehole with a generally constant force by deforming it to a certain extent.

3. Permanent high rock slope

3. 1 General view of permanent high rock slope

3. 1. 1 Rock (limestone) condition

Typical rock physical properties of site A are shown in Table 1.

3. 1. 2 Presplitting conditions

The presplitting conditions are shown in Table 2. The half cast is observed on the front surface of the permanent high rock slope from end to end.

3. 2 Test methods and results

The horizontal measurement hole is drilled with a hole diameter of 65mm and a depth of 20. 0m at a height of 1m. Taking the collar of the horizontal measurement hole as the origin, measurements were made from collar in the depth direction at interval of 1. 0m. The damaged area was investigated at four boreholes at the same bench level. The permanent high rock slope measured this time had been formed five years previously. Fig. 4 outlines the method used for taking these measurements.

Typical wave data measured in permanent high rock slope is shown in Fig. 5, and the travel time curve calculated from the wave data of Fig. 5 is shown in Fig. 6. From the measurement results at the four locations, including the travel time curve

Table 1 Typical rock physical properties

Density	2. 72 g/cm^3
Uniaxial compressive strength	83. 8 MPa
Tensile strength by radical compression test	7. 1 MPa
P wave velocity	6080 m/sec

Table 2 Presplitting conditions

Bench hight	15. 0 m
Hole depth	16. 5 m
Angle of hole	70 degrees
Borehole diameter	65 mm
Spacing	1. 5 m
Charge quantity	SV400P, 3 kg/hole

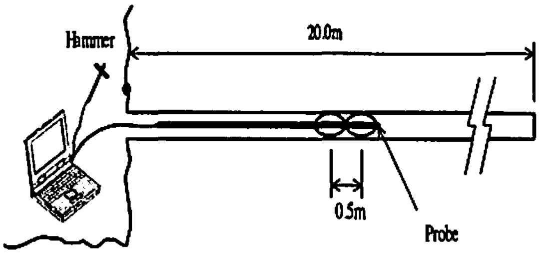

Fig. 4 General principle of use a compact VSP probe system

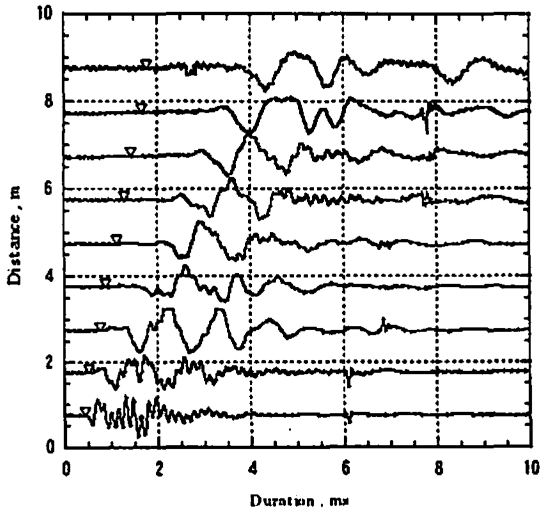

Fig. 5 Typical waveform data

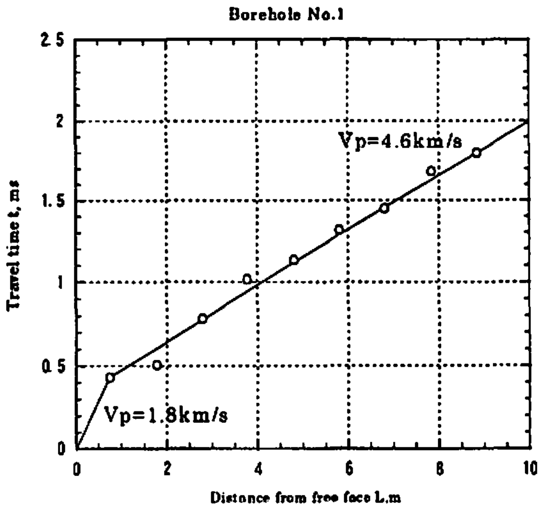

Fig. 6 Typical travel time curve

shown in Fig. 6, the damaged area of the permanent high rock slope at site A was about 1. 0 to 3. 0m. The stability of the permanent high rock slope at site A is considered adequately secured. The velocity of elastic wave (P wave) in the damaged area was 1. 8km/s, and the velocity of the P wave in areas unaffected by damage was 4. 6km/s. The following is inferred to explain why the damaged area of the permanent high rock slope can be kept to a minimum.

-The rock conditions are relatively good.

-A presplitting method that matches the rock conditins has been established.

-So as not to damage the permanent high rock slope, controlled blasting in which the charging hole diameter is made small is always carried out within 5 to 30m from the presplitting line, and within 5m, excavation work is done using machinery.

From similar measurements taken at site B (another limestone mine), it was confirmed that the damaged area of the permanent high rock slope is 10 - 15m, and there is a big difference in the damaged area of the permanent high rock slope due to differences in the rock conditions.

4. Effects of presplitting

4. 1 Survey of the presplitting zone

As stated above, measuring the damaged are resulting from presplitting is important for evaluating how presplitting affects the permanent high rock slope. In order to ascertain and investigate the damaged area caused by presplitting, on-situ experiments were carried out at the bench of site A. The distance from the free face (the borehole position) to the presplitting hole is as shown in Table 3. A borehole was drilled midway between presplitting holes, and as with the measurement conditions for the damaged area in permanent high rock slope, the horizontal measurement holes were drilled with a hole diameter of 65mm and a depth of 20m. The prespliting line was set obliquely for the following reason.

-Investigation of the damaged area produced by production blasting and by presplitting.

As in the measurement of the damaged area in the permanent high rock slope, elastic waves were measured at 1m intervals.

Table 3 Distance from free face

Hole No.	Distance (m)
PS-1	8. 75
PS-2	9. 65
PS-3	10. 25
PS-4	11. 05
PS-5	11. 75
PS-6	12. 55
PS-7	13. 45
PS-8	14. 05
PS-9	14. 65
PS-10	15. 35
PS-11	16. 15
PS-12	16. 85
PS-13	17. 85

4. 2 Blasting conditions

4. 2. 1 Presplitting

The condition for test presplitting are shown in Table 2.

4. 2. 2 Production blasting

The production blasting at site A are listed in Table 4.

4. 2. 3 Controlled blasting

As stated above, controlled blasting with a small charging hole was done within 5 - 30m of the presplitting line. The controlled blasting conditions are listed in Table 5.

4. 3 Test results

Typical wave measurement data measured in this testing is shown in Fig. 7, and the travel time curve

Table 4 Conditions for production blasting

Bench hight	15. 0 m
Hole depth	18. 0 m
Angle of hole	70 degrees
Borehole diameter	165 mm
Burden	6. 2 m
Spacing	7. 5 m
Charge quantity	ANFO, 187. 5 kg/hole
Powder factor	100 g/t

Table 5 Conditions for controlled blasting

Bench hight	15. 0 m
Hole depth	16. 5 m
Angle of hole	70 degrees
Borehole diameter	90 mm
Burden	3. 0 m
Spacing	3. 0 m
Charge quantity	ANFO, 64 kg/hole
Powder factor	176 g/t

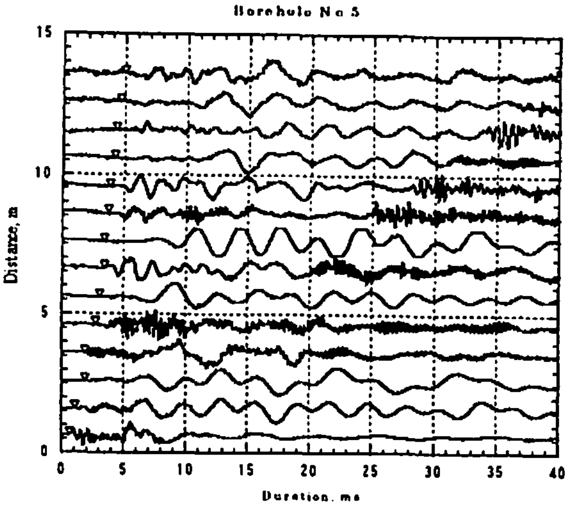

Fig. 7 Typical waveform data

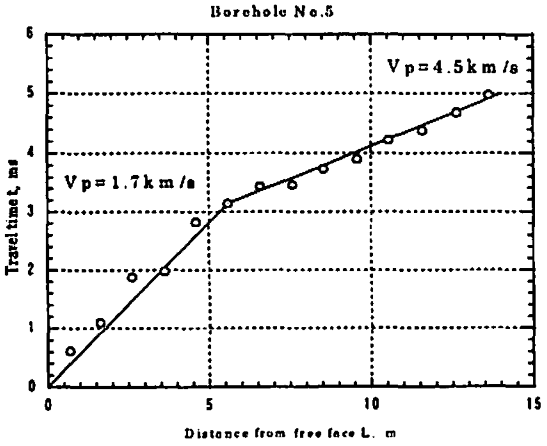

Fig. 8 Typical travel time curve

calculated from the measured waveforms of Fig. 7 is shown in Fig. 8. From the travel time curve shown in Fig. 8, it was confirmed that the damaged area caused by production blasting about 5m, and the velocity of P wave in this area is 1. 7km/s. It was confirmed that the velocity of P wave in this area unaffected is about 4. 5km/s, and the velocity of P wave measured in the permanent high rock slope is roughly the same. Fig. 8 shows the measurement results of borehole No. 5, and the near by presplitting hole is positioned at a depth of 11-12m. In Fig. 8, the travel time curve has a straight line at a depth of 5m or more, and discontinuity showing non-linearity at a depth of 11 - 12m has not been confirmed.

4. 4 Discussion

As stated above, from the travel time curve obtained from measurements of the velocity of P wave using the VSP system, discontinuity of the travel time curve at position near the presplitting hole has not been confirmed. This means that the damaged area caused by presplitting is only a very limited area around the presplitting hole. Considering the fact that this time the measurements were taken at 1m intervals, the damaged area thought to be caused by presplitting is inferred to be no greater than 1m. Of course, it can easily be inferred that the size of the damaged area will vary depending on the charging conditions and the rock conditions.

There are difference in the charging conditions and presplitting conditions, and it is difficult to make a general evaluation, but the damaged area of the permanent high rock slope was 1-3m at site A and 10-15m site B. Assuming that the damaged area with presplitting alone at site B is a size locally limited to about 1m as at site A, it is difficult to say that damaged area at the permanent high rock slope occurred only because of the blasting, and the appropriate conclusion is to think that other factors were also involved.

5. Conclusion

By field tests using the newly developed VSP system, a quantitative evaluation and investigation was made concerning presplitting and the damaged area that occurs in permanent high rock slopes.

The results of these field tests suggest that it is not just blasting that causes the damaged area that occurs on the permanent high rock slope, but the rock conditions and other factors are also involved in complex way. It cannot be denied that thus far no measurement methods have been proposed for evaluating the damaged area on the permanent high rock slope, and evaluations have been made qualitatively based on such evidence as borehole marks remaining on the free face. Thought the use of the newly developed VSP system, it is possible to quantitatively evalute the damaged area on the permanent high rock slope, and it has been confirmed that such damage is caused not just by presplitting and other blasting. This suggests the importance in the future of design methods, maintenance control, and elucidation mechanism by which damaged areas occur in permanent high rock slopes.

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永久残壁における損傷領域測定方法

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一般的に，石灰石鉱山では，残壁の力学的な安定性を考慮し，プレスプリット工法により，永久残壁が形成される。プレスプリット工法を採用することにより，損傷領域は装薬孔近傍に限定されるのではないかと考えられている。著者らは，VSPシステムを用いて，実験的に実施したプレスプリット工法により発生した損傷領域の定量的調査，ならびに永久残壁における損傷領域の調査を実施した。その結果，プレスプリット工法により生じる損傷領域は，装薬孔周辺の極めて限定された領域であることが確認された。また永久残壁における損傷領域は，現場条件，岩盤条件により約3.0m～15.0mと大きく異なり，永久残壁における損傷領域発生原因がプレスプリット工法のみに起因するのでなく，岩盤条件等複合的要因によることが示唆された。

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