Characteristics of Propagation and Attenuation for Different Stress Waves in Layered Rocks

Bing Sun, Jie-hui Xie, and Sheng Zeng
School of Civil Engineering, University of South China, Hengyang, China
School of Nuclear Resources Engineering, University of South China, Hengyang, China
Email: {sunbingnh, xiejiehuinh, usczengs}@126.com

***Abstract*—The rules of propagation for stress waves is researched in layered joints, which are the basis on studying the physical and mechanical properties as well as dynamic characteristics of rock mass. In order to research this rules for stress waves that pass through layered jointed rock mass after effect of transmission and reflection. Based on similar proportion methods of Froude, the experimental model was conducted under the effect instantaneous impact and blasting. The results showed, due to the superposition effect of transmitted and reflected waves in structural plane, the transient impact stress waves were strengthened, which made the peaks of time-history signals that passed the joint reached successively maximum during the time after jumping instead of the beginning of its jumping; Because of the barrier effect of joints, the main frequency and the maximum amplitude decreased in a nonlinear tendency of the signal before and after joints. The high frequency part of signal attenuation decreased rapidly and energy was absorbed gradually; As for the vertical or small angle of incidence stress wave, the attenuation was obvious and the amplitude was biggish in vertical and lengthways direction. However, the attenuation of stress waves was lower in lateral direction. As to stress waves of oblique incidence, there was no obvious change for its attenuation in the lateral and vertical direction, but the lengthways direction was contrary. It has vital meanings that the research on rules of propagation and attenuation for stress waves in layered joints to develop and apply in dynamic field and, damage field and underground chamber.**

***Index Terms*—layered and jointed rock mass, stress wave, attenuation, spectral analysis**

I. INTRODUCTION

There are masses of natural beddings, cracks, joints, faults and other defects in natural rock masses, which play a great effect on the mechanical properties of rock mass. In the numerous joint, the parallel structure of joint plays a leading role. In fact, the emphasis of research on propagation of stress wave was put on the parallel joint in several jointed rock masses at present [1]. Therefore, laws of propagation for stress waves is researched in bedding joint, which is the basis on knowing the physical and mechanical properties as well as dynamic characteristics of rock mass. In practical project of blasting, due to the existence of discontinue structural planes, the propagation and attenuation of blasting stress waves are affected highly [2]. It has an important meaning that the research on rules of propagation and attenuation for stress waves in bedding joints to develop and apply in dynamic stress field, damage field and underground chamber.

In 1950, the overseas scholar, Thomson W T [3] started to research the rules of propagation in the bedding rock mass. Meanwhile, based on the theory of elastic waves, the matrix formula was deduced. However, these aspects of research began late at home. In 1979, Wuhan institute of rock mass mechanics, Wang J T [4] applied the mechanical theory of compound materials to deduce the expression that could reflect geometry dispersion phenomena of axisymmetric cylindrical wave stress field. At present, there were a little achievement about the propagation and attenuation of stress waves. Based on the modified methods of equivalent viscoelastic medium, Li J C *et al*. [5], [6] researched the effect of stress waves' propagation though considering several characteristics such as the angle of incidence, thickness of joint, frequency of stress waves and so on. According to the recursive analysis of time domain, the question about oblique incidence of stress waves in the form of nonlinear joint was solved effectively at the same time. Based on the model of stratified medium, the study showed that the sticky joint could absorb more energy than elastic joint and the transmission coefficient decreased with increasing of number of jointed plies. Meanwhile, the transmission coefficient was acquired under the method of virtual waves [7]-[9]. Wang S *et al*. [10] adopted theories of waves and displacement discontinuity to reveal that transmission coefficient of displacement and jointed space had a greater effect on the propagation of one-dimension waves, but lower for number of joints. Yu J *et al*. [11] came up with the conception of nonlinear and elastic medium. According to the model of displacement discontinuity, half time-domain solution was put forward. The studies mainly analyse rules of propagation of stress waves in jointed rock mass in theory or in method of numerical modelling [12]. Of course, these studies are under the partly hypothesis, for example, the research only considered a single waveform. Therefore, there are some differences between theory and practical engineering. As for instantaneous impact or blasting stress waves in practical engineering, this aspect of research is relatively less. Considering above analysis, it was developed that the experimental study for the

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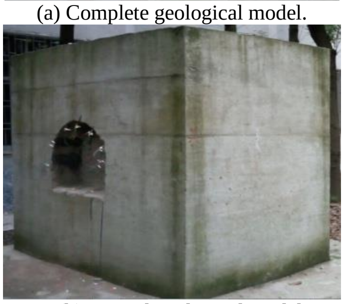
propagation rules of instantaneous impact or blasting stress waves in the bedding jointed rock mass by geo-mechanical model test, in which rules of energy attenuation for different stress waves before or after passing through the joint were acquired. This research will have vital theoretical guiding significance for design or construction of engineering blasting.

(a) Complete geological model.



(b) Jointed geological model.

Figure 1. Geological mechanics model.

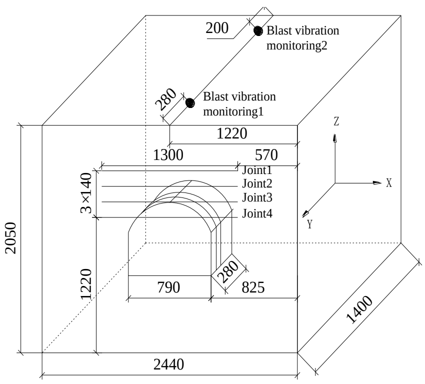


Figure 2. Model sizes and joint arrangement (mm).

II. Testing Experiment of Instantaneous Impact Waves in Bedding Joints

A Arrangement of Experimental Points

According to the similar theory of model, the proportion of Froude and geological mechanics parameter of a metal mine, the physical model of bedding joint was fabricated and improved. At first, the density similar ratio K0=1:1.2, geometry similar ratio KL=1:5, due to the similar theory of model, it could be known that the size of model is $2.44m\times1.40m\times2.05m$. Meanwhile, adopting the cement mortar to simulate the surrounding rock, its mix proportion is mc: ms: mw: mr =1:5.14:0.86:0.04 (c, s, w, r respectively represent cement, sand, water and retarder). In addition, the polycarbonate sheet in the thickness of 5 millimeters was acted as similar material and fabricated into several parallel joint. Therefore, the complete geological mechanic model was built as the Fig. 1. The equal interval joint of four floors was arranged in above parallel jointed model. Its distribution position was shown as Fig. 2.

In order to measure energy attenuation of instantaneous impact stress waves before and after passing through each floor of joint, five acceleration sensors was arranged in the top of model and the centre of each layer of joints. The monitoring point arrangement is shown as Fig. 3. The propagation waves' testing is based on the reflection methods of stress waves. This test system is made up of Hangzhou billion constant dynamic testing analyser (AVANT-10), acceleration sensors, force hammer, charge amplifier and computer processing system. The stress waves would be produced when force hammer was knocked on end region of top. And then, the charge amplifier and dynamic signal acquisition instrument were collected acceleration time-history signal of every position.

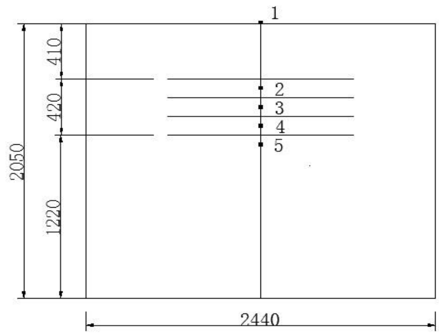


Figure 3. Monitoring point arrangement (mm).

B Propagation Characteristic of Instantaneous Impact Stress Waves in Joints

1) Original time-domain signal

A force was act on the end region of top and then measured five-position time-history signals. Due to the propagation and attenuation of instantaneous impact stress waves shocked in a less field, the corresponding residual energy is less. Therefore, here a period of time from 0 to 4ms was cut up as time-domain signal, which is shown as Fig. 4.

In Fig. 4, there are some time intervals on each measured points' signal of take-off point. Its top end of signal reached peak rapidly after 0.2ms, but during 1ms, the attenuation of signal decreased to half of peak. The speed of attenuation became slowly and showed a time of shock. When the time is 1.8ms, there was a new peak while it is lower than before. When the stress wave had passed to between the second and fifth measured point, its peak of stress still decreased. The peaks of time-history signals that passed the joint reached successively maximum during the time after jumping instead of the beginning of its jumping. Due to the barrier effect of joints, its energy was attenuating gradually and superposition was weakened. So, its residual energy gradually decreased to 0.

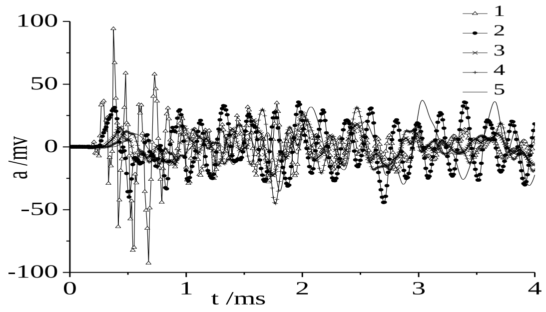


Figure 4. Original time-domain signal.

2) Spectral characteristics of signal

When the stress wave was propagating in jointed rock mass, its energy must be attenuated gradually. Meanwhile, its Spectral curves would present distortion. Therefore, there were some limitations for the analysis of time-domain signal. Through adopting method of Fast Fourier Transform, Spectral characteristics of acceleration on time-domain signal were analyzed. The Spectral curves of stress waves before and after passing through each layer of joint was shown as Fig. 5.

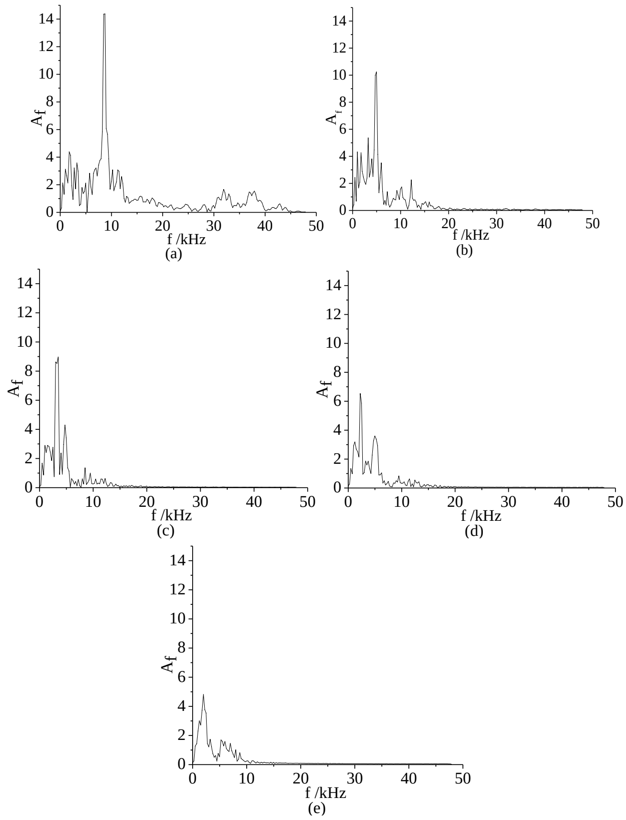


Figure 5. Stress wave spectrum of measured points.

Where, it is known from Fig. 5 that the Spectral curve had obvious change before and after passing through joints. The main frequency and the maximum amplitude decreased gradually with the increasing of jointed layers of passing through. The energy of stress waves attenuated gradually. Before passing through the joint, the main frequency of the first measured point was 8.727 KHz and the maximum amplitude reached 14.373. In addition, there were shock between 30 and 40 KHz. When it passing through the fourth layer of joint to the fifth measured point, the main frequency of stress wave was only 1.24 KHz and the amplitude reached 4.811. The frequency of signal mainly focused on 10 KHz and there were no high amplitude signal among this. It is known from the fifth measured points' Spectral curve that when the stress wave propagated in joints, there was some low-pass filtering action Because of the barrier effect of structural planes. Therefore, the high frequency was absorbed and the proportion of low frequency was greater in total composition. The main frequency tended to transfer to the low frequency. Finally, the distorted degree of Spectral curves also increased with it. With the layers of passing through increasing, the main frequency and the maximum amplitude signal decreased in a nonlinear tendency. The change trend of both was basically identical, which was shown as Fig. 6.

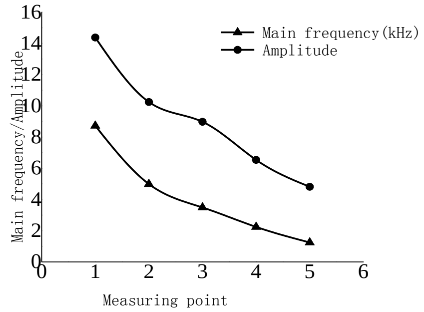
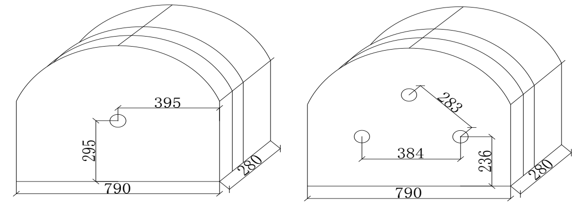


Figure 6. Frequency and amplitude of measured point.

III. The Experimental Test of Blasting Stress Waves

A. Testing of Blasting Stress Wave

In order to shape a blasting working plane, complete and jointed model was excavated by hand respectively. Its size of section is respectively as follow: the width is 790 mm; the height of wall is 390 mm; the height of arch is 270 mm; the excavation footage is 300 mm. And then, way of blasting was adopted to test the propagation characteristics of blasting stress waves. The measured machine is TC-4850 type blasting seismograph from Zhongke measure- ment and Control Company in Chengdu. In the first excavation, one blast hole was arranged and charged 50grams. In the second excavation, three blast holes were arranged and charged 40 grams each. The arrangement of blast hole is shown as Fig. 7. Two measured points was arranged during this testing. The first one was arranged in vertical direction of blasting source. The second one was arranged in the top of inclination. The measured point was shown as Fig. 7.

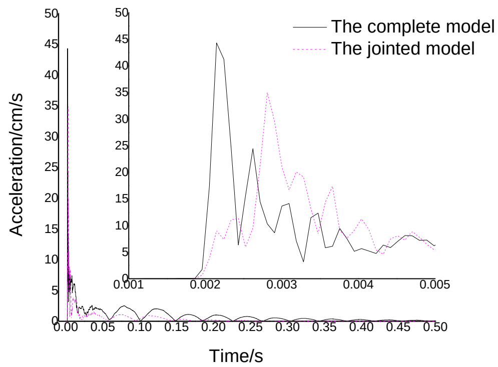


(a) The first blasting. (b) The second blasting.

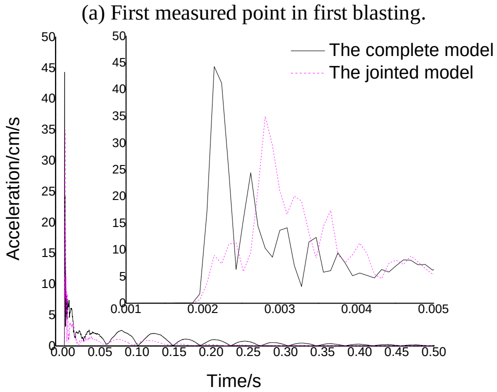
Figure 7. Blast-hole arrangement.

B. The Propagation Characteristics of Blasting in Joints

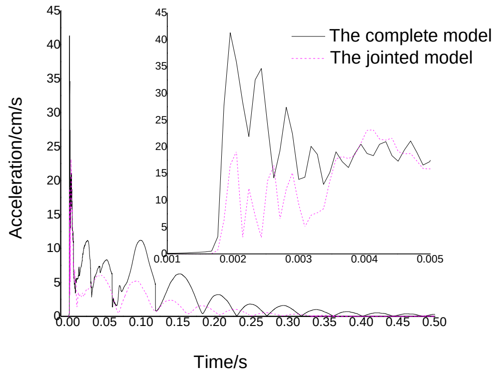
Through the blasting testing of tunnel excavation for complete geology model and jointed geology model, which got the first and second measured points' velocity time-history curves. In several researches on propagation rules of blasting waves, generally speaking, single-direction propagation of stress wave merely was taken into consideration. So, it is highly important to consider attenuation rules for three-direction stress waves. In Fig. 8, each point's time-history curve had three directions (x, y, z). Therefore, they could be compound as a pair of speed time-history curve. Among the Fig. 8, (a) denotes the first point's compound speed time-history curve in the first blasting; (b) denotes the second point's compound speed time-history curve in the first blasting; (c) denotes the first point's compound speed time-history curve in the second blasting; (d) denotes the second point's compound speed time-history curve in the second blasting; It is obvious from Fig. 8 that the complete model's peak velocity is greater than the jointed model. The first point's peak velocity in the second blasting is slightly lower than in the first one and amplitude of attenuation is higher. It is analyzed that due to the space of third blast hole is greater in the second blasting and the top of blast hole is close to the first measured point, experimental peak is also the stress wave in a blasting every hole. The second measured point's peak velocity in the second blasting is greater than in the first one. This is the reason why the distance between three blast hole and the second measured point is slightly close. That is to say, the second point's peak velocity in the second blasting is the velocity that the blasting payload produced.



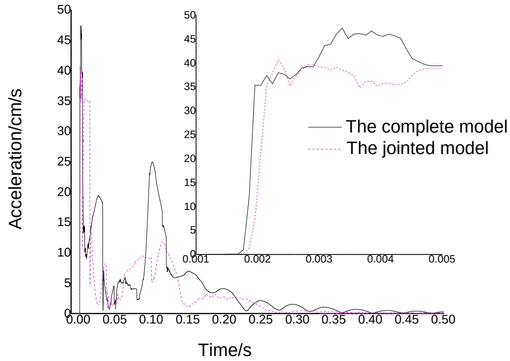
(a) First measured point in first blasting.



(b) Second measured point in first blasting.



(c) First measured point in second blasting.



(d) Second measured point in second blasting.

Figure 8. Synthesis of velocity time-dependent curves.

IV. Conclusions

(1) For instantaneous impact stress waves, the top end of time-domain signal presents several peak during the propagation. However, its peak decreases gradually than before and energy is attenuating until its value of attenuation is 0.

(2) It has obvious change before and after instantaneous impact wave passes through joints for the signals' spectral curves. Its main frequency decreases from 8.727 KHz to 1.247 KHz and its maximum amplitude decreases also from 14.373 to 4.811. Among this, the higher frequency is absorbed partly. The main frequency and maximum amplitude decreases gradually. Both present the nonlinear tendency.

(3) There is anisotropy in the propagation attenuation for the instantaneous impact waves and the rules of attenuation are different in each direction. When instantaneous impact waves pass through joints vertically, little attenuation in lateral direction, there is obvious attenuation and amplitude in vertical and lengthways direction. The moment instantaneous impact waves pass through joints obliquely, little attenuation in lateral and vertical direction, the attenuation and amplitude is greater in lengthways direction.

(4) In jointed model, its velocity time-history curve is deviating to right than complete model. That is to say, the existence of joints prevents the propagation of stress waves, which leads to delay for its peak velocity. The peak velocity of instantaneous impact waves depends on the intensive degree of charge. Moreover, when the distance of cartridge bags is over a constant, its practical

peak velocity is the stress waves that the closest cartridge bag produces, but no super composition of all stress waves in total payload.

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Bing Sun, her hometown is Pingdingshan in Henan province and was birth in December 1979. She got her Ph.D. in Safety Technology and Engineering, Central South China. She is an associate professor in College of Civil Engineering, University of South China. Meanwhile, she is a national certified supervision engineer, an intermediate blasting engineering and technical personnel, member of the institute of rock mechanics and engineering of Hunan province as well as hold the head of platform of her school's "twelfth five-year" civil engineering disaster prevention and mitigation innovation team. Her major researches take aim at rock mass dynamics, geotechnical engineering protecting, measuring and testing technique, etc. Moreover, she got a second prize of scientific and technological progress.

Jie-hui Xie, his hometown is Loudi in Hunan province and was birth in January 1989. He got his bachelor in College of Civil Engineering, Hunan University of Science and Engineering. Now, he is studying the master in University of South China. He got several national encouragement scholarships at his undergraduate level and his academic results are outstanding now.

Sheng Zeng, his hometown is Changde in Hunan province and was birth in February 1977. He got the Ph.D. in mining engineering, University of South China. Now, he is an associate professor in School of Nuclear Resources Engineering, University of South China. Meanwhile, he is a national security evaluation, a senior blasting engineering and technical personnel, member of the institute of rock mechanics and engineering of Hunan province. His major researches refer to mining rock mass mechanics and numerical simulation technology in geotechnical engineering, etc. He got respectively a second prize for Natural Science of Hunan Province and the Architectural Society of China Science and Technology Progress.