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Characteristics of Blasting Vibration in Presence of Weak Interlayers

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Abstract A numerical model is proposed in this paper to consider the effect of thin weak layers within semi-infinite homogeneous elastic media when explosives are at different locations. Using this model, we have studied the different features of blasting vibrations generated by explosives placed at different locations and for different dimensions (different areas) of weak layers through LS_DYNA. The numerical results reveal that the longer the layer length is, the larger vibration amplitude is and the less the characteristic frequencies of vibration signals are. The amplitude of vibration signals has a maximum value when blasting source is in the weak layer, and will decrease when the blasting source go away from the weak layer. There is a significant shading effect when the dimension of weak layer is large and the relative stiffness of the weak layer compared to surrounding medium is low. These findings are helpful to identify underground weak interlayer. In-situ experiments also confirm above findings qualitatively.

Key words: Blasting vibration, weak layer, identification

INTRODUCTION

Detection of sliding surfaces is a crucial problem in geotechnical engineering. The sliding surface of a slope is usually a thin weak layer in the geo-material mass, and it is hardly detected by traditional seismic geophysical methods, as little contrasts could be identified from the blasting vibration signals whether the thin weak layer exists or not. Ding and Zheng [1] have recently developed a new source model for blasting vibration by combining cavity theory and moment tensor representation. This model is especially established for numerical purpose, and the numerical results have showed a good accordance with experimental data. The physical mechanism of this model is based on the assertion that propagated wave signal mainly comes from the natural vibration of geophysical structure after blasting. This assertion gives not only the physical laws governing the process in blasting vibration, but also the insight of some tentative applications of engineering geophysics, such as the identification of weak layers and cracks (Ding and Zheng [2]).

This paper presents a numerical model to study the effect of weak layer and explosive locations on the vibration signals on the ground surface. The numerical results reveal the contrasts of blasting vibration signals between existence of a weak layer and no weak layer. The result is in a good qualitative accordance with in-situ experimental data. The effect of layer dimensions on the vibrations is also studied.

PROPOSED METHOD FOR IDENTIFYING WEAK LAYERS

Because vibration signal retains the characteristics of the natural vibration of the geometrical structure modified by the explosion near the source, we can use explosives sources to identify the thin weak layers in engineering geostructures. Fig. 1 gives a schematic explanation of this method.

We have done some numerical experiments to confirm the feasibility of this method. The numerical simulation is for a thin weak layer placing under the ground surface in depth (some primary work has been done for embedded cracks, see Ding et al [3]). The blasting vibration source model introduced in Ding and Zheng [1] is used to perform the numerical experiments. The results reveal that when the explosive is placed in the position near ground surface, the existence of the weak layer does not affect the observed signal at the ground surface very much. However, when the explosive is placed near the weak layer, the characteristics of signal are totally different. The signals do reflect the information of the weak layer.

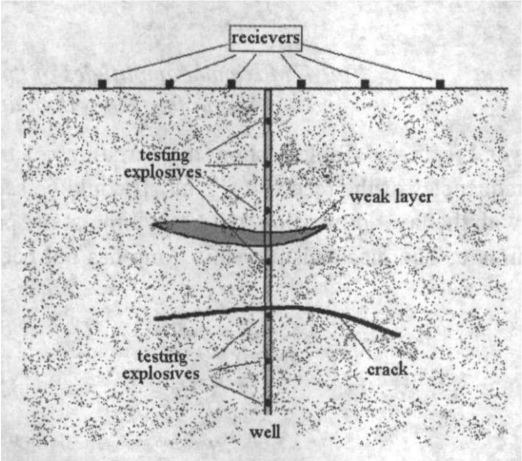

Fig. 1 Schematic explanations of the method to identify thin weak layers in engineering geostructures

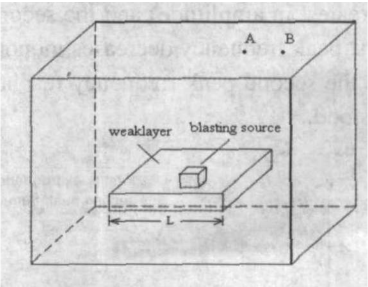

Fig. 2 Numerical model for horizontal weak layers

NUMERICAL RESULTS

Numerical simulations have been done for a model as shown in Fig. 2. The block has a dimension of 51mx51mx51m. The horizontal weak layers are under the ground surface at depth of 25m, and with the thickness of 1m and different dimensions (5m, 7m, 9m ...etc.). Blasting sources are placed along the vertical central line of this block with different depths. LS_DYNA with the source model of blasting vibration proposed by Ding and Zheng [1] is used for computations. All media are supposed to be isotropic and elastic:

For solid above and below weak layers: $E = 2.4\times10^{10}, \nu = 0.3$, $\rho = 2400$;

For weak layers and broken region: $E = 2.4\times10^{8}, \nu = 0.3$, $\rho = 2400$.

Each face is imposed transmitting boundary conditions but the upper face (ground surface) is stress free. Sensors are installed at points such as A or B in the experiment to pick up blasting vibration signals.

1. Results for different positions of blasting source For a weak layer of dimension 31mx31m, computations are performed with different positions of blasting sources. Fig. 3 compares the amplitudes of the Fourier transformations of vibration signals received at point A when the positions of blasting source are different (in, above and below the weak layer). As the blasting source approaches to the weak layer the main frequency of signals decreases and the amplitude increases in both direction: below and above.

Fig. 4 shows the maximum amplitudes in frequency domain (Eposz represents the position of explosive: the distance from ground surface with unity m). The weak layer is in the position between 25m and 26m from ground surface. The variation of the amplitudes versus source position gives a strong characteristic feature of the blasting vibrations when a weak layer exists.

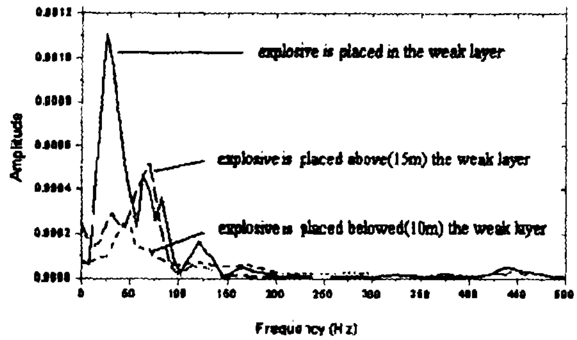

Fig. 3 Signals in frequency domain for different position of blasting source

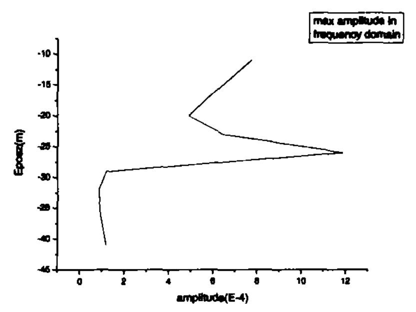

Fig. 4 Maximum amplitudes of the signals in frequency domain

2. Results for different dimensions of weak layer Fig. 5 and Table 1 show the variations of the first (the greatest in amplitude) and the second peak frequencies of the received signals. It could be seen that the first peak frequency decreases monotonically with the layer dimension, but has a jump at the position where the second peak frequency reaches its minimum. The mechanism of this jump has not been well understood.

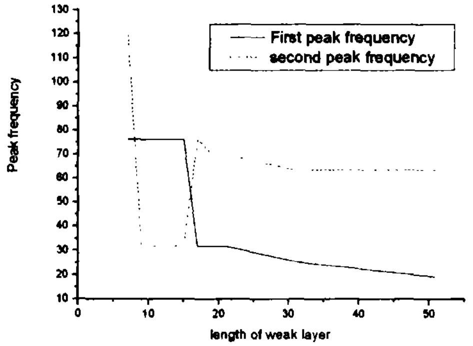

Fig. 5 Peak frequencies for different dimensions of weak layer

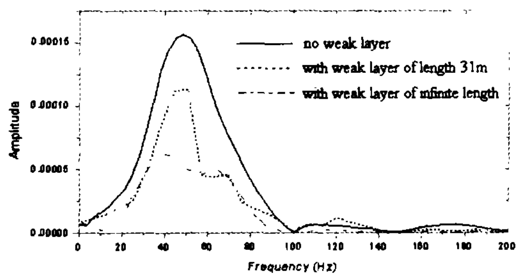

Fig. 6 Spectrum of signals with different lengths of weak layer

Table 1. Peak frequencies for different layer length

Length of weak layer (m)	First peak frequency (Hz)	Second peak frequency (Hz)
5		120.546
7	76.139	120.553
9	76.140	31.726
11	76.144	31.726
13	76.145	31.727
15	76.145	31.727
17	31.727	76.145
19	31.727	69.800
21	31.728	69.801
31	25.382	63.455
51	19.036	63.455

Fig. 6 shows the spectrum of signals when blasting source is below the weak layer. Three cases are analyzed: no weak layer, a weak layer of length 31m, and a weak layer of infinite length. A shading effect is observed when the weak layer exists, and the length of weak layer has great influence on the amplitude of signal.

3. Shading effect versus relative stiffness of weak layer Fig. 7 and Table 2 show the shading effect with relative stiffness. Only Young's modulus of the weak layer is changed and all other parameters remain the same. The relative stiffness is defined as the ratio of Young's modulus in surrounding material to that of weak layer. It can be seen that the shading effect becomes more and more significant when relative stiffness increases.

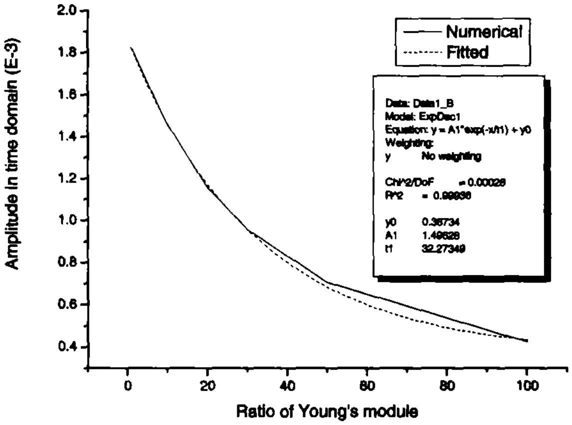

Fig. 7 Shading effect corresponding to different young's module of the weak layer

Table 2. Shading effect of weak layer

Relative stiffness （$E/E_{weaklayer}$）	Amplitude in time domain (×10^{-3})
1	1.825
10	1.461
20	1.158
30	0.9573
50	0.7067
100	0.4254

The curve in Fig. 7 can be well fitted by an exponential decay function. This makes it believable that when the stiffness of the weak layer decrease the shading effect will approach the effect of a thick layer. This can be explained by taking the relative thickness of the layer: $w = \alpha H/h$

where α is the ratio of the wave speed of the surrounding material to that of the weak layer (it is the square root of the ratio of Young's modulus when other parameters of material property remain the same), h is the characteristic length of blasting source, and H is the thickness of the weak layer. $w >> 1$ means that the H is much greater than the wavelength generated by the blasting source. In this case, refraction law can approximately estimate the transmitting wave from the source below weak layer. When $w << 1$, the shading effect could be neglected.

EXPERIMENTAL RESULTS

In-situ test has been carried out to verify the findings in numerical computations. Fig. 8 is test site picture where a weak layer is 0.4m thick and embedded in rock mass. This site is at Baiyi'an in Fengjie, Chongqing, China. Fig. 9 and 10 are the signals for two different tests.

Fig. 8 Picture of a weak layer embedded in rock mass at the site of Baiyi'an in Fengjie, Chongqing, China.

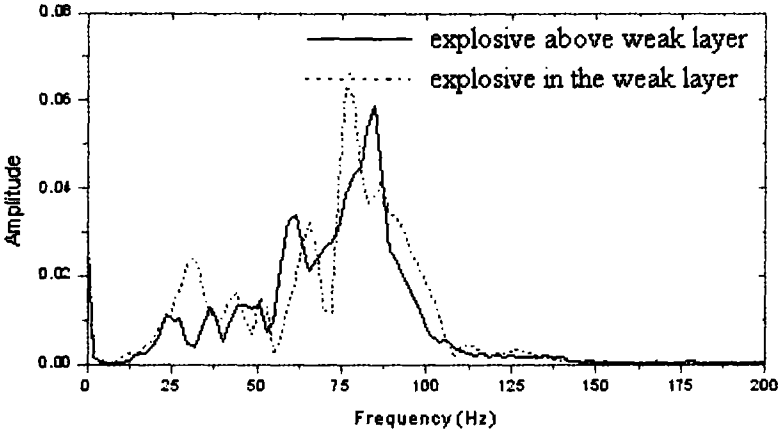

Fig. 9 Amplitude of signal at test 1

Fig.9 and Fig.10 confirmed the fact that when the blasting source is near the weak layer, the main frequency of the signal picked up at the ground surface is lower than the main frequency when the blasting source is far away from the weak layer. From the results it can be reasoned as follows: the stiffness of the material above the weak layer is a little higher than the stiffness of the weak layer, and the material below the weak layer is much harder than the weak layer. This is coincided with the site observation.

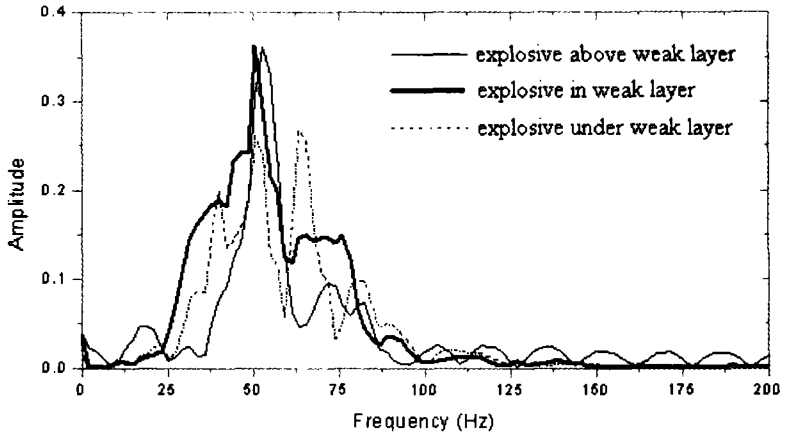

Fig. 10 Amplitude of signal at test 2

CONCLUSION

In conclusion, the longer the layer length is, the larger vibration amplitude will be and the less the characteristic frequencies of the vibration signals will be. The amplitude of signals has a maximum value when the blasting source is placed in the weak layer, and will decrease when the position of the blasting source go away from the weak layer. Furthermore, there is a significant shading effect when the dimension of weak layer is large and the relative stiffness is low. With these results combined with experimental calibrations, it is possible to extract the characteristic parameters of underground weak layers from blasting vibration signals induced by a blasting source near the position of the layer.

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REFERENCES

[1] H. Ding, Z. M. Zheng, *Source model of blasting vibration*, Science in China, Series E, 45(4), (2002).
[2] H. Ding, Z. M. Zheng, *Source model for blasting vibration and tentative application to engineering geophysics*, Proceeding of The 9th International Congress on Sound and Vibration, Orlando, Florida, USA, 8-11 July, (2002).
[3] Hua DING, Lipin Long, Yanfeng Wu, Zhemin Zheng, *Detection of cracks using blasting vibration, part 1: numerical results*, International Conference on Slope Engineering, Hong Kong, 8-10 December, (2003).