Propagation Characteristics of Seismic Wave While Transiting Interlining in Soil Medium

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ABSTRACT

Based on the theory of wave and the Snell theorem, propagation characteristics of seismic wave, three kinds of elastic body waves, is studied when they pass through soil/elastic solid medium including elastic thin plan intercalation in half-space. The analytic solution of the amplitude rate is the rate of the amplitude of the wave behind the intercalation to that of the incident wave. Compared with the field data, the analytic results are beneficial, affected by soft clay stratum, at the Nankai District of Tianjin Municipality caused by the 1976 Tangshan earthquake (had a magnitude of 7.8). In this area, however, damage of the buildings was generally minor, about 50%, with the Heping District near Nankai.

INTRODUCTION

Macroscopic seismic damages survey that abnormal ground seismic damages is closely related to ground response of weak interlining in soil medium. For example, in some area of Tianjin, China, Seismic damages of the area with mucky silty clay interlining and Vs≈80m/s shear velocity at $0.12\lambda_R$ under the ground, is less than that of other vicinity areas without it in many earthquakes. In 1976, earthquake with a magnitude of 7.8 in Tang Shan, China, rate of building collapse in the area with weak interlining in soil medium is 6.4% while that of building collapse in other vicinity areas without it is 12%. In 1970, characteristic of seismic damage is similar to the above in Tong Hai in China. Zhou、Wang and Han, (1984) take direct dynamic method to study the theoretic explanation of the above phenomena. This paper, in according to theory of wave propagation in elastic medium and Snell theorem [Wu ShiMing, 1997], calculates amplitude of transmitted wave [Xu, Yang and Chen, 2001] and reflected wave of elastic plane P wave at plane interface and interlining 、provides the theory that ground seismic damages is reduced with the change of the interlining and put forward to theoretic explanation and contrast analysis for the sector of abnormal ground seismic damages in Tianjing .

MECHANICAL MODEL AND ANALYSIS

The propagation characteristics of plane P wave while transmitting in weak interlining.

Plane P wave can be considered as the question in plane and simplified as analysis of two-dimensional plane wave. Its boundary conditions can be determined by Fig.1. and Fig.2. According to the stack principle of wave, potential function in medium 1 is

$$j_1 = A_{11}e^{[ik(y+P_{11}x-ct)]} + A_{12}e^{[ik(y-P_{11}x-ct)]}, \quad x \leqslant 0$$

$$y_1 = B_{12}e^{[ik(y-P_{12}x-ct)]}, \quad x \leqslant 0 \qquad (1)$$

Same argument, according to the relationship of reflection with refraction at x=d interface, superimpose transmitted P wave on transmitted SV wave produced by P wave and SV wave at x=d interface and then conclude the potential function in medium 2 is

$$j_2 = A_{21}e^{[ik(y+P_{21}x-ct)]}, \quad d \leqslant x$$

$$y_2 = B_{21}e^{[ik(y+P_{22}x-ct)]}, \quad d \leqslant x \qquad (2)$$

According to Snell Theorem in medium 3, superimposed amplitude by refraction P wave and refraction SV wave at x=0 interface on its reflection P wave and reflection SV wave at x=d interface can be regarded as P wave along forward direction of the coordinate x and SV wave along backward direction of the coordinate x and then the potential function in medium 2 is

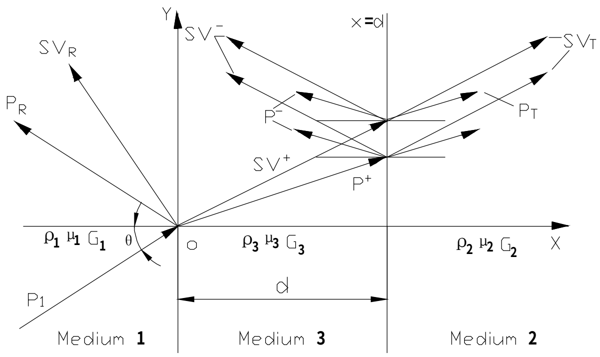

Fig.1. The propagation model of plane P wave in three mediums

$$j_3 = A_{31}e^{[ik(y+P_{31}x-ct)]} + A_{32}e^{[ik(y-P_{31}x-ct)]}, \quad 0\leqslant x\leqslant d$$

$$y_3 = B_{31}e^{[ik(y+P_{32}x-ct)]} + B_{32}e^{[ik(y-P_{32}x-ct)]}, \quad 0\leqslant x\leqslant d \qquad (3)$$

There are nine unknown constants in equation (1)、(2)、and (3), assume that amplitude A_{11} of incident P wave is given at x=0 interface. Other eight unknown constants can be obtained by eight equations produced by boundary condition at x=0 and x=d interfaces. Eight linear equations are gained by the boundary condition of continuous displacement and stress at x=0 and x=d interfaces and stress and displacement with the expression of potential functions. After complex derivation. amplitude ratio of transmitted P wave to incident wave is equation (4).

$$\frac{A_{21}}{A_{11}} = \frac{H_{wp}}{F_{wp}} e^{-ikP_{22}} \qquad (4)$$

Where:

H_{wp}、F_{wp}——lengthy explicit function that is related to medium 1、medium2、medium3、P wave and SV wave.

$$P_{j1}^2 = \frac{c^2}{V_{pj}^2} - 1, \quad P_{j2}^2 = \frac{c^2}{V_{sj}} - 1, \text{ (j=1, 2, 3)}$$

Where:

V_{pj}, V_{sj}: the velocity of P and SV wave in medium;

$c = \frac{w}{k}$:the propagation velocity at interface in medium.

The propagation characteristics of plane SH wave while transiting interlining in elastic medium.

According to propagation characteristics of wave in elastic medium and Snell law, general solution of displacement in medium 1、medium 2 and medium 3 is

$$u_{Z1} = A_1 e^{ik(y+P_1x-ct)} + B_1 e^{ik(y-P_1-ct)}, \quad x\leqslant 0$$

$$u_{Z2} = A_2 e^{ik(y+P_2x-ct)} + B_2 e^{ik(y-P_2-ct)}, \quad 0\leqslant x\leqslant d$$

$$u_{Z3} = A_3 e^{ik(y+P_3x-ct)}, \quad d\leqslant x \qquad (5)$$

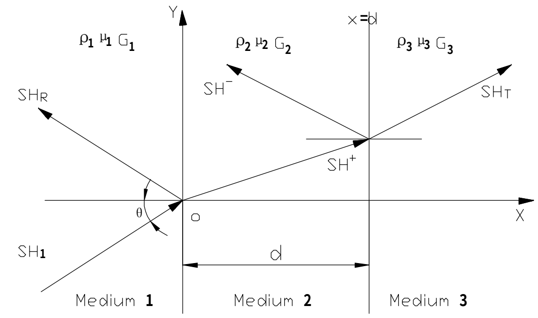

Fig.2. The propagation model of plane SH wave in three mediums

Where:

$P_j^2 = \frac{c^2}{V_{sj}^2} - 1$, V_{sj} (j=1,2 and 3) is SH wave velocity in the three mediums.

A_1 is amplitude of incident wave, B_1 is amplitude of reflected wave and A_3 is amplitude of transmitted wave. B_2 and A_2 is respectively amplitude of forward direction and backward direction wave in the interlining and A_2、A_3、B_1 and B_2 is superimposed final amplitude that considered by many times reflective and refractive separately.

According to boundary condition at x=0 and x=d interfaces, analytic solution expression of amplitude ratio of transmitted wave to incident wave at two sides of the elastic interlining is

$$\frac{A_3}{A_1} = \frac{4P_1G_1P_2G_2e^{-ik(P_2+P_3)d}}{a_2a_3e^{-2ikP_2d} + a_1a_4} \qquad (6)$$

Where:

$a_1=P_1G_1-P_2G_2$; $a_2=P_2G_2+P_3G_3$; $a_3=P_1G_1+P_2G_2$ $a_4=P_2G_2-P_3G_3$

NUMERICAL CALCULATION AND ANALYZE

Results of Numerical calculation.

The results of numerical analysis of equation (4) and equation (6) can be obtained by inserting calculation parameters in the equations and drawing variable curve. Because of the length limit of the paper, just analyze the effect of weak interlining on amplitude of the transmitted wave while changing incident angle of P wave and SH wave 、thickness of weak interlining and shear modular of weak interlining. Medium 1 and medium 3 are elastic soil. Their elastic modular is $G_{1=}G_3=2.52\times10^9$Pa and density is $\rho_1=\rho_3=1900kg/m^3$. Medium 2 is loose silty soil. Then the correlated curves for amplitude ratio of transmitted wave with the change of incident angle、thickness of interning and shear module of the interlining are obtained as Fig.3、Fig4 and Fig5. These figures show that the weak interning has obvious shielded function in some range and if out of the range, the shielded function will disappear.

Analysis of numerical results.

The thickness of interlining has largely effect on transmission of incident P wave. The less the thickness is, the more the energy of transmission. Incident angle θ has not obviously effect on the transmission. Fig.3. shows that the relationship of amplitude ratio of transmission wave to incident wave with angle while the thickness of interlining is $d=0.09\lambda_P$. Fig.3. also shows that not only the thickness of interlining but also incident angle θ has the effect on the transmission of incident SH wave and weak interlining have good shielded function on SH wave in the far field.

Fig. 4. shows the effect of the thickness of the interlining on incident SH wave with θ=45°. It is obvious that weak interlining has the clear shielded function on seismic wave

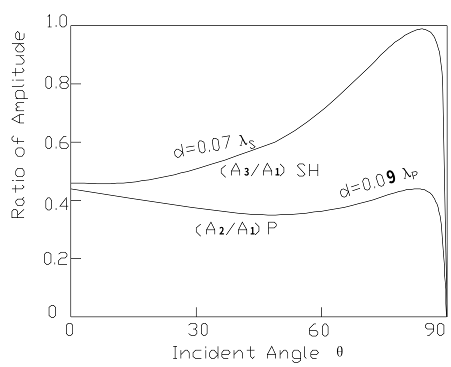

Fig.3. Pertinent curve of amplitude rate of transmission wave and incident wave with incident angle

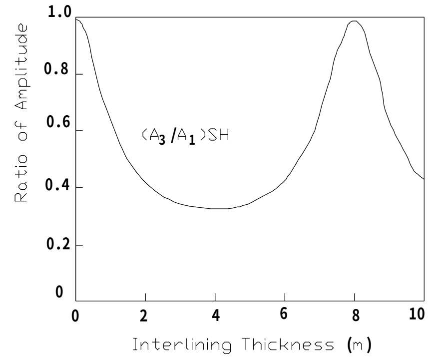

Fig.4. Pertinent curves of the amplitude rate of transmission wave and interlining medium thickness (incident angle θ=45°)

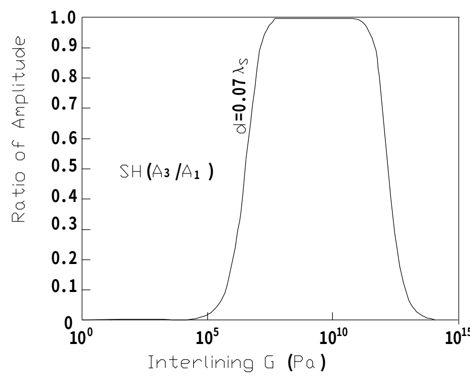

Fig.5. Pertinent curves of the amplitude rate of transmission wave and interlining medium shear modulus G (incident angle θ=45°)

while the thickness of interlining is $d=0.22\ \lambda_S$. However, with the increase of the interlining thickness, the shielded function will not continually be enhanced. The shielded function will disappear while the thickness of interlining is $d\approx0.67\lambda_S$.

Fig.5. shows shear module G of interlining or corresponding shear velocity V_S has the effect on incident SH wave with θ=45° and energy of transmission of SH wave reduces by half while shear velocity V_S of the interlining is 0.23 times as large as that of the medium 1 and medium 3. When shear modular is $G_2=1\times10^5\sim1\times10^7$Pa and $G_1=G_3=1\times10^{12}\sim1\times10^{14}$Pa, amplitude rate of transmission wave sharply declines from 0.9 to below 0.1. Therefore, shear wave velocity ratio of weak (or hard) interlining to elastic medium 1 and medium3 (i.e. impedance ratio) is important parameter for transmission ratio of SH wave.

For hard interlining, transmission ratio of incident P wave is closely related to incident angle. When incident angle θ>45°, transmission of P wave in hard interlining largely reduce, especially when the thickness of hard interlining is $d > 0.17\lambda_p$, transmission of P wave reduce more.(Yang Xianjian, Gao Guangyun and Xu Hongyu, 2002).

CASE HISTORY

Fig.6. shows that brief sketch on 7.8 level seismic damages for Heping (area A) and Nan Kai (area B) in Tianjing, China in Jul.28, 1976. characteristics of building structures and their foundation are not enough to incur dramatically different damages when earthquake arrives. However, in many earthquakes, the damages of Heping area(area A) is more serious than that of Nan Kai area (area B).(Zhou, Wang and Han, 1984). Table 1 provides typical survey results in the two areas. The clear difference between the two profiles of area A and area B is that there is a mucky silty clay weak interlining with 4.3 m thickness and V_S=80m/s shear wave velocity below 9.5m in area B, but there is not in area A. other parts of the two profile have no markedly difference.

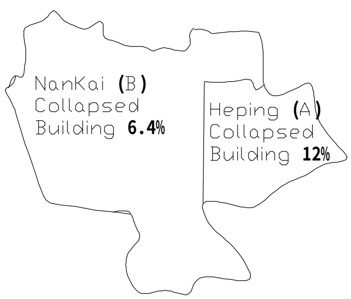

Fig.6. Brief sketch on earthquake damages for Heping (area A) and Nankai (area B) in Tianjin China

The shielded function of the weak interlining on the incident P wave and SH wave in elastic medium as this paper mentioned may explain, in many earthquakes, why the damage of area A is more serious than that of area B.

<u>Impedance ratio of weak interlining to elastic medium.</u>

Soil profile in table1 shows there is a weak interlining with 4.30m (i.e. $0.016\lambda_s$, where λ is seismic wavelength and λ_s=70.5m) thickness and V_S=80m/s shear wave velocity below 9.5m (i.e. $0.135\lambda_s$) and the impedance ratio of weak interlining to the elastic medium is about 0.23. Corresponding shear module of the impedance ratio is approximately equal to $G_2=6.88\times10^7$Pa in Fig.5. The amplitude ratio of incident SH wave A_1 to transmission wave A_2 is approximately 0.5. This

Table 1 Soil Profile of Area A and Area B

Area A: depth (m)	profile	type	thik. (m)	Vs (m/s)	dens. (ts^2/m^4)	SPT N (10 20 30 40)
1.0						
4.2		Pt	4.2	0.20	120	
6.5		OH	4.3	0.196	140	
8.5		SC				
13.0		OH	4.5	0.21	140	
17.8			4.8	0.21	440	
19.5		SC	6.5	0.21	380	
20.5		MH				
24.3		SC				
27.5		OH	3.2	0.21	140	
35.9		OH	5.0	0.21		
			3.4	0.21		
39.8		SC	3.9	0.21		
45.0		OH	5.2	0.21		
46.1		MH	4.0	0.21	250	
48.4		CL				
49.0						
		CL		0.21	700	

Area B: depth (m)	profile	type	thik. (m)	Vs (m/s)	dens. (ts^2/m^4)	SPT N (10 20 30 40)
1.1						
3.8		Pt	3.8	0.19	180	
5.6		OH	5.7	0.196	350	
9.5		SC				
13.8		Pt	4.3	0.20	80	
16.9		OH	3.1	0.204	150	
21.0		SC	7.1	0.196	500	
24.0		OH				
29.2			5.2	0.21	340	
30.7		CL	3.9	0.21	330	
37.1		OH	4.0	0.21	320	
38.3		OH	6.7	0.20	200	
43.8		SC				
45.9		CL	2.8	0.20	200	
46.6		OH				
50.3		OH	3.7	0.20	200	
		CL		0.21	700	

means that area B with impedance ratio of weak interlining shields 50% of acceleration in earthquake. The result is nearly identical with the damage ratio of area B to area A.

<u>The thickness of weak interlining in area B and shield function of seismic wave.</u>

Table 1 shows that the thickness of weak interlining in area B is 4.3m and its corresponding calculation expression is $d=0.061\lambda_s$ which is similar to the calculating expression (that is $d=0.07\lambda_s$) for the thickness weak interlining in Fig.3. and Fig.5. under the condition, the amplitude ratio of transmitted wave to incident wave is also 50% and the result is consist with the damage ratio of area A and area B.

<u>Compared with ground acceleration response spectra.</u>

The relationship of the shield function of the interlining on seismic wave transmitting in elastic medium with ground acceleration response spectra can be obtained by calculating results (Zhou, Wang and Han, 1984). In Fig.7. the response spectra takes seismic wave calculation of EI Centro (1940) and area A and area B is the same to those of table 1. B′(broken line) is response calculation of area B without V_S=80m/s musk silty clay for the same seismic source. The comparison of area A with area B can conclude that the shield function of weak interlining make ground acceleration of area B be less 50% than that of area A, which is identical with calculating result of transmission theory in this paper.

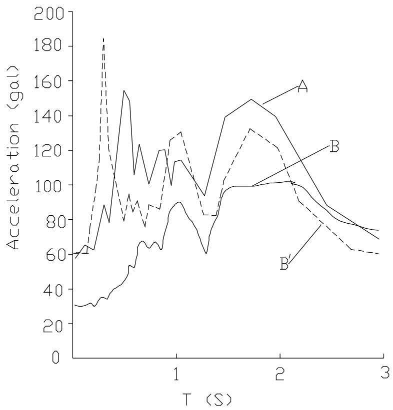

Fig.7. Acceleration response spectra for area A and area B in Tianjin, China [after Zhou, Wang and Han, 1984]

Conclusion

According to transmission theory of plane P wave and plane SH wave, this paper offers the corresponding shield function of weak interlining under different incident angle、different thickness of interlining and different impedance ration of interlining. The theoretic result is consist with the mitigation of damage in Nan Kai district with weak interlining.

Theoretical calculation shows that while the thickness of the weak interlining is d=0.05～0.35λ_s, weak interlining has better shield function but while it is d≥0.67λ_s, the function disappear. The function is the best while the thickness of weak interlining is d=0.20λ_s. however, in theory, while the thickness d＞0.9λ_s, the shield function still exist, but not enough survey of seismic damage to study.

The more the difference of impedance ratio of interlining and elastic medium is, the more effective the shield function of interlining. Hard interlining has better shield function while incident angle of seismic wave (θ>45°) is larger.
While interlining is (0.20~0.30)λ_s below ground, the shield function arrives the best. While interlining is 0.67λ_s below ground, its shield function almost loses.

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