Analysis of the dynamic stress path under obliquely incident P-waves and its influencing factors

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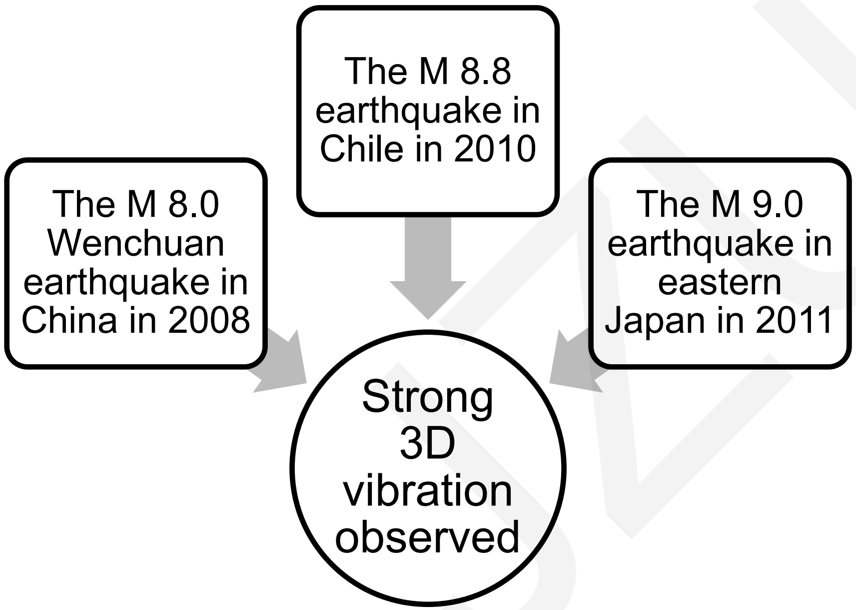
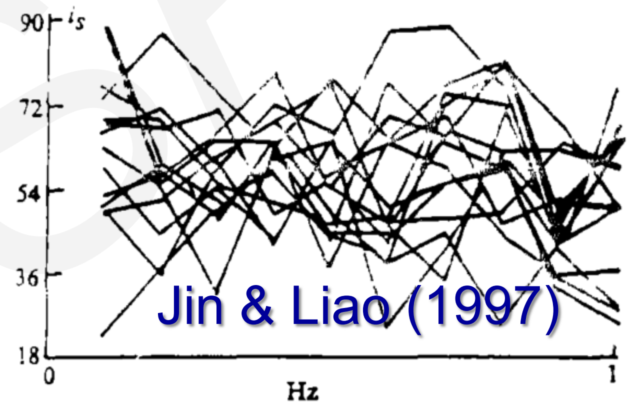
Strong 3D Vibration

- **Oblique incidence is a quite common seismic wave incident condition, particularly in near-field strong earthquake.**





Jin & Liao (1997)

Table 2: Propagation times and incident angles

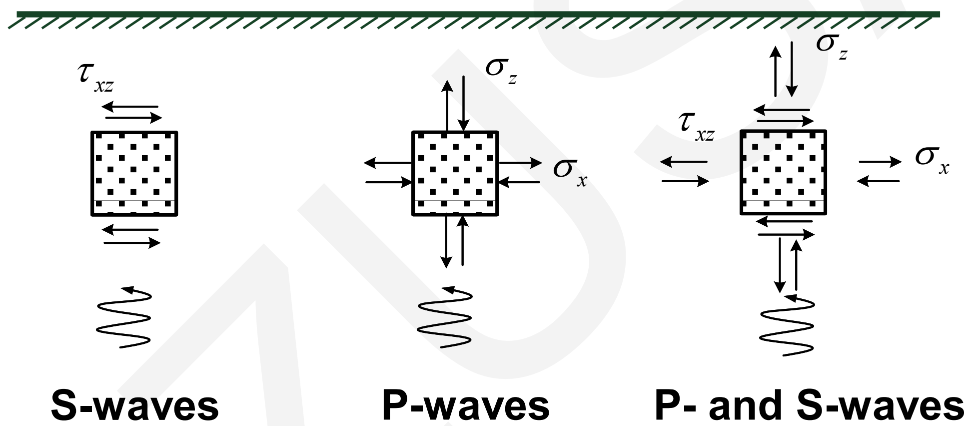
Date	Time (Japanese Time)	Propagation time from GL.-130m to GL.-70m (Δt (s))		Estimated incident angle (°)	
		X	Y	X-Z plane	Y-Z plane
3/26/1997*1	17:31	0.03125	0.02734	38.6	46.9
3/26/1997	18:05	0.02734	0.02734	46.9	46.9
3/26/1997	22:24	0.02734	0.02734	46.9	46.9
3/26/1997	22:48	0.02734	0.03125	46.9	38.6
3/31/1997	9:04	0.02344	0.02734	54.1	46.9
4/3/1997	4:33	0.03516	0.03516	28.5	28.5
4/3/1997	5:13	0.03516	0.03125	28.5	38.6
4/4/1997	2:33	0.03516	0.03125	28.5	38.6
4/5/1997	13:24	0.02734	0.03125	46.9	38.6
4/9/1997	23:20	0.03125	0.03125	38.6	38.6
4/9/1997	23:23	0.02734	0.02344	46.9	54.1
4/15/1997	9:33	0.03516	0.03125	28.5	38.6
5/3/1997	9:00	0.03125	0.03516	38.6	28.5
5/13/1997*1	14:38	0.02734	0.03125	46.9	38.6
5/14/1997	8:32	0.03125	0.02734	38.6	46.9
5/25/1997	6:11	0.00391	0.02734	84.4	46.9
6/27/1997	14:12	0.03125	0.03125	38.6	38.6
7/26/1997	18:36	0.05078	0.03125	*2	38.6
11/11/1997	21:41	0.03125	0.03125	38.6	38.6
12/14/1997	0:19	0.03516	0.03906	28.5	12.4
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1/10/1998	14:01	0.03516	0.03516	28.5	28.5
1/10/1998	14:02	0.03906	0.03125	12.4	38.6
			Mean	38.1	38.1

*1:Mainshock *2:Not calculated by Equation (8) because observed Δt is beyond maximum propagation time

Takahiro *et al.* (2000)

Effect of P-waves

- **The great effect of P-waves should not be overlooked in strong near-field earthquakes, particularly in unsaturated soil foundation.**



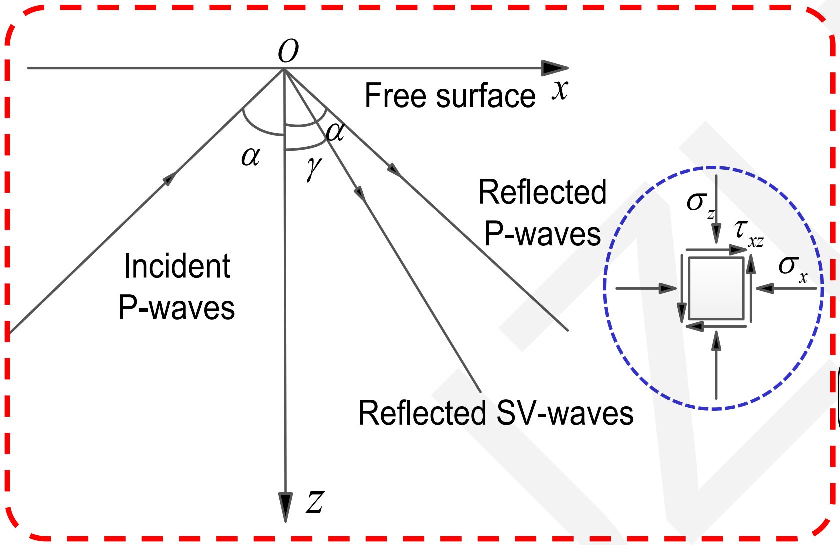
Strong near-field earthquake → **Inconspicuous attenuation of P-waves**

Unsaturated soil foundation → **Deviatoric stress level rises sharply**

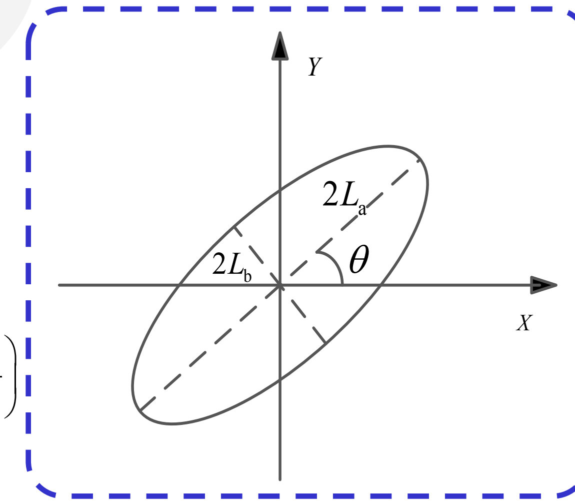
Rather common situation

Dynamic Stress Path

■ **The stress path under incident P-waves is proved mathematically to be an oblique ellipse in the plane of normal stress difference and horizontal shear stress herein.**



$$\left(X=\frac{\sigma_z-\sigma_x}{2A\_\rho\omega^2},\ Y=\frac{\tau_{xz}}{A\_\rho\omega^2}\right)$$



$$\frac{N_1^2+N_2^2}{(M_2N_1-M_1N_2)^2}X^2+\frac{M_1^2+M_2^2}{(M_2N_1-M_1N_2)^2}Y^2+\frac{-2(M_1N_1+M_2N_2)}{(M_2N_1-M_1N_2)^2}XY=1$$

$$\frac{1}{L_a^2}\left[\left(\cos^2\theta+\frac{\sin^2\theta}{\delta^2}\right)X^2+\left(\sin^2\theta+\frac{\cos^2\theta}{\delta^2}\right)Y^2+2\left(\cos\theta\sin\theta-\frac{\cos\theta\sin\theta}{\delta^2}\right)XY\right]=1$$

Analysis Method

$$\frac{1}{L_a^2}\left[\left(\cos^2\theta+\frac{\sin^2\theta}{\delta^2}\right)X^2+\left(\sin^2\theta+\frac{\cos^2\theta}{\delta^2}\right)Y^2+2\left(\cos\theta\sin\theta-\frac{\cos\theta\sin\theta}{\delta^2}\right)XY\right]=1$$

$$\frac{N_1^2+N_2^2}{\left(M_2N_1-M_1N_2\right)^2}X^2+\frac{M_1^2+M_2^2}{\left(M_2N_1-M_1N_2\right)^2}Y^2+\frac{-2\left(M_1N_1+M_2N_2\right)}{\left(M_2N_1-M_1N_2\right)^2}XY=1$$

The characteristic parameters are derived

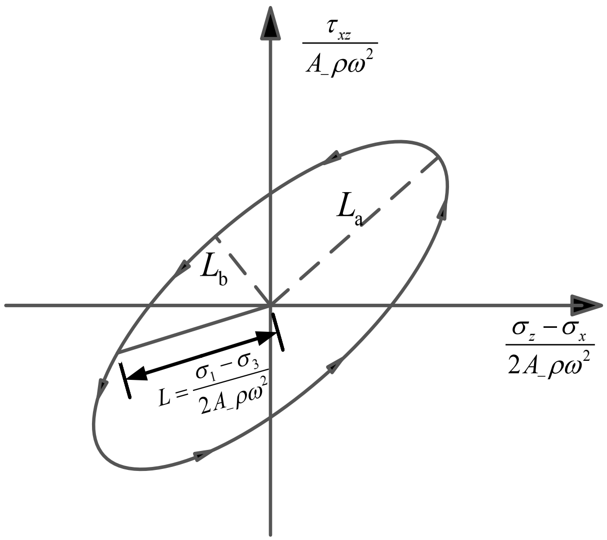
The 3 characteristic parameters of any elliptic stress path are θ, $\delta(=L_b/L_a)$, and L_a.

3 independent factors affecting elliptic stress path

incident angle α, Poisson's ratio μ, the depth corresponding to unit wavelength zf/v_s

Control Variables Method

Magnitudes of Dynamic Stresses



Nearly vertical incidence
1°, 5°, 10°

Oblique incidence
30°, 45°, 60°

The most dangerous situation

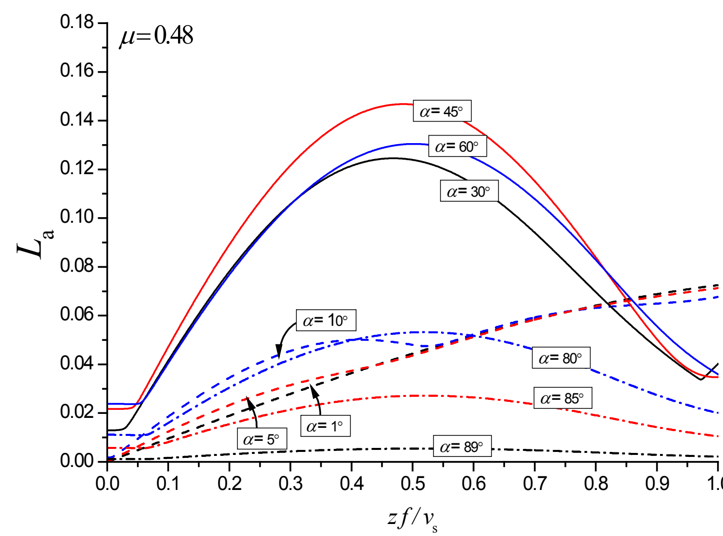
Nearly horizontal incidence
80°, 85°, 89°

Poisson's ratio
μ = 0.3

Poisson's ratio
μ = 0.4

Poisson's ratio
μ = 0.48

The greatest difference among different incident angles



Conclusions

- We reveal the fundamental characteristics of a dynamic stress path under obliquely incident P-waves as an oblique ellipse in the plane of normal stress difference and horizontal shear stress.
- We identify factors affecting the stress path, including the incident angle, Poisson's ratio, and depth corresponding to unit wavelength.
- The most dangerous incident angle of P-wave is within the range 30° ~60° , the induced dynamic deviatoric stresses will reach their maximum value.
- In particular, when Poisson's ratio is 0.48, the stress amplitudes are more than twice those under other incident angles.