subjected to Oblique incidence waves

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Presented by

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OUTLINE

- Introduction
- Equivalent Artificial Boundary Element and Its Seismic Input with Oblique Incidence
- Verification of the Procedure
- Application to a

Introductio n

- Oblique incidence waves play a vital role in the spatial variation of seismic ground motions.
- It has great effects on bridges with high piers, especially those with quite varied pier heights.
- The seismic wave propagation will be difficult to

Introduction

- The effect of oblique incidence waves on the bridge should be considered for complex topographic.
- The paper proposed a method for how to input the seismic waves considering its oblique incidence in finite element analysis.

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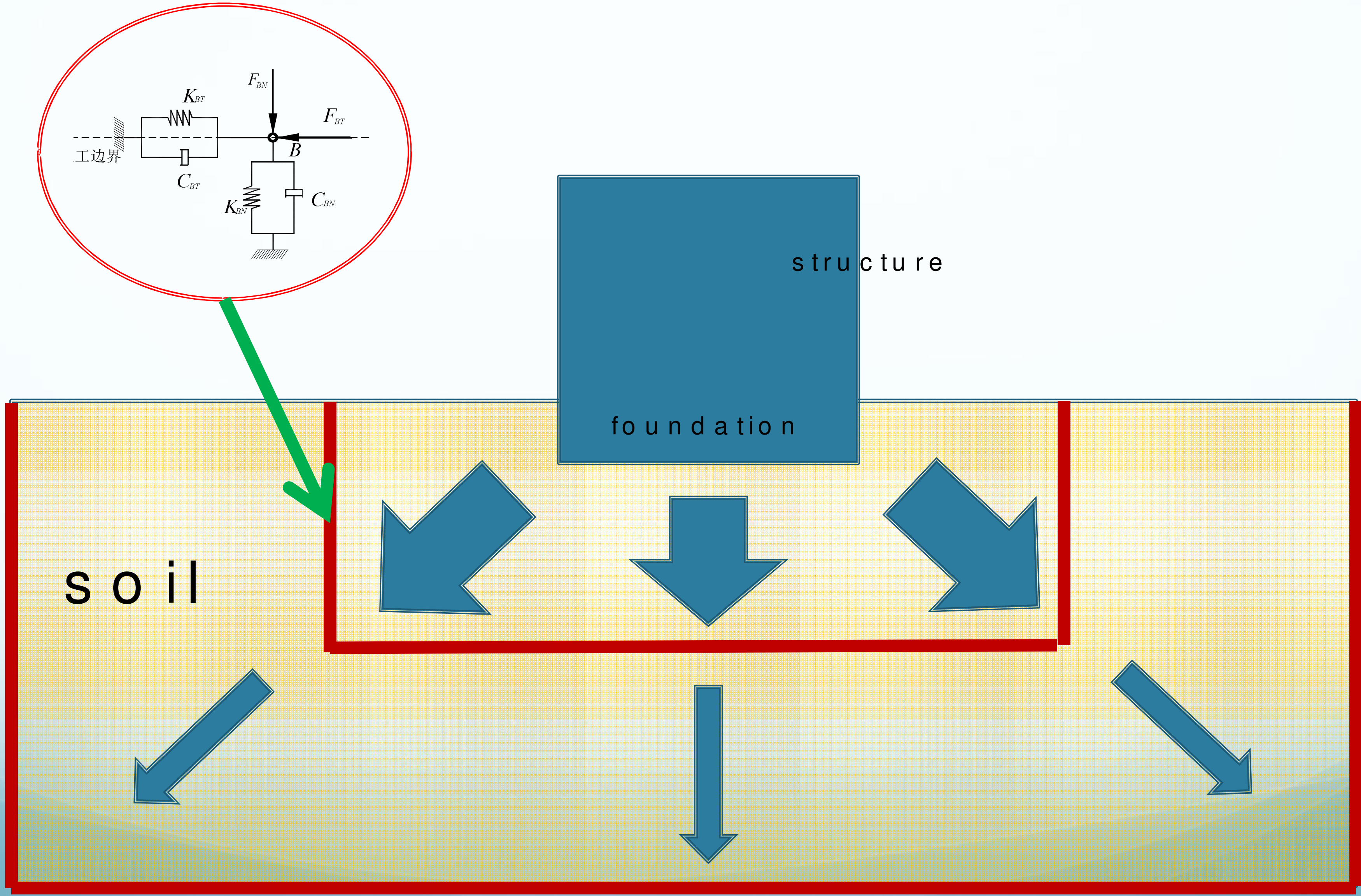
Artificial Boundary Element and Its Seismic Input

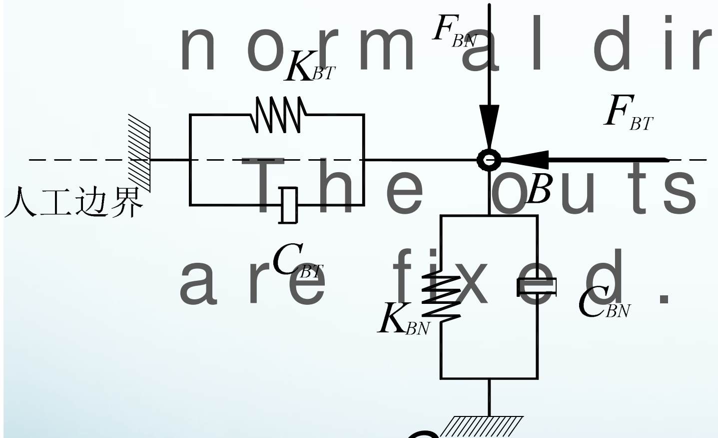
- The system including the structure and the surrounding soil is more accurate.
- Artificial boundary is added to the boundary to simulate the radial damping of continuous medium.

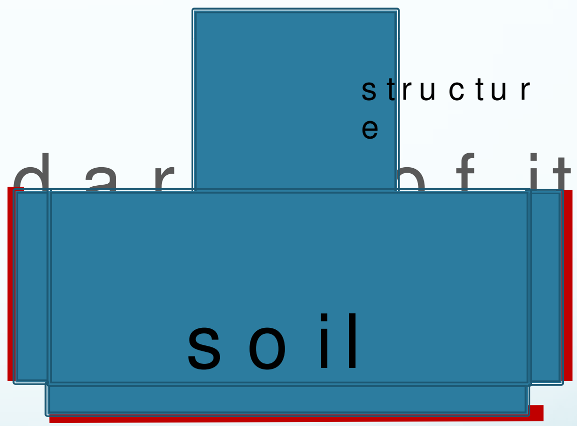
Viscoelastic artificial boundary element



Artificial boundary element

Extend a layer of elements with the same type of the inside elements along the normal direction.





The outside boundary of it are fixed.

$$G = hK_{BT} = \alpha_T h \frac{G}{R}$$

$$E = \frac{(1+\nu)(1-2\nu)}{(1-\nu)} hK_{BN} = \alpha h \frac{G}{R} \frac{(1+\nu)(1-2\nu)}{(1-\nu)}$$

$$\tilde{\eta} = \frac{\rho R}{2G}\left(\frac{c_s}{\alpha_T} + \frac{c_p}{\alpha_N}\right)$$

Seismic Input

- How to input the earthquake waves in soil-structure system.
- Consider the equivalent loading, which cause the same displacement, velocity and stress as the free wave field.

Seismic Input

- The equation of the equivalent load input at node point on the boundary of the artificial boundary element is

$$P_{BN}(t)=\left[\sigma_0(x_B,y_B,t)+\rho c_p\dot{u}_0(x_B,y_B,t)+\alpha_N\frac{G}{R}u_0(x_B,y_B,t)\right]\sum_i A_i$$

$$P_{BT}(t)=\left[\tau_0(x_B,y_B,t)+\rho c_s\dot{v}_0(x_B,y_B,t)+\alpha_T\frac{G}{R}v_0(x_B,y_B,t)\right]\sum_i A_i$$

earthquake → Force Loading

Input Seismic Waves with Oblique Incidence

- P wave and SV wave can be interchanged when they pass through the boundary of different medium.
- Waves of oblique incidence produce P and SV waves and their reflected waves.

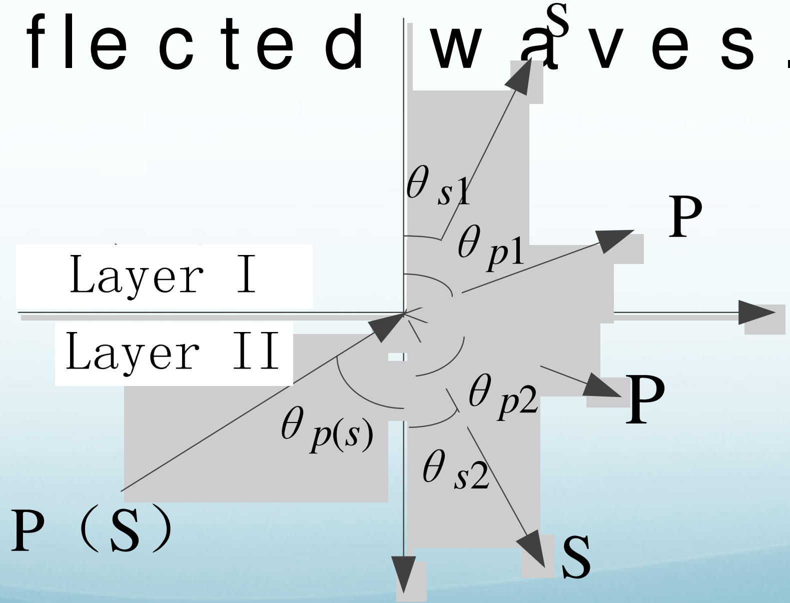


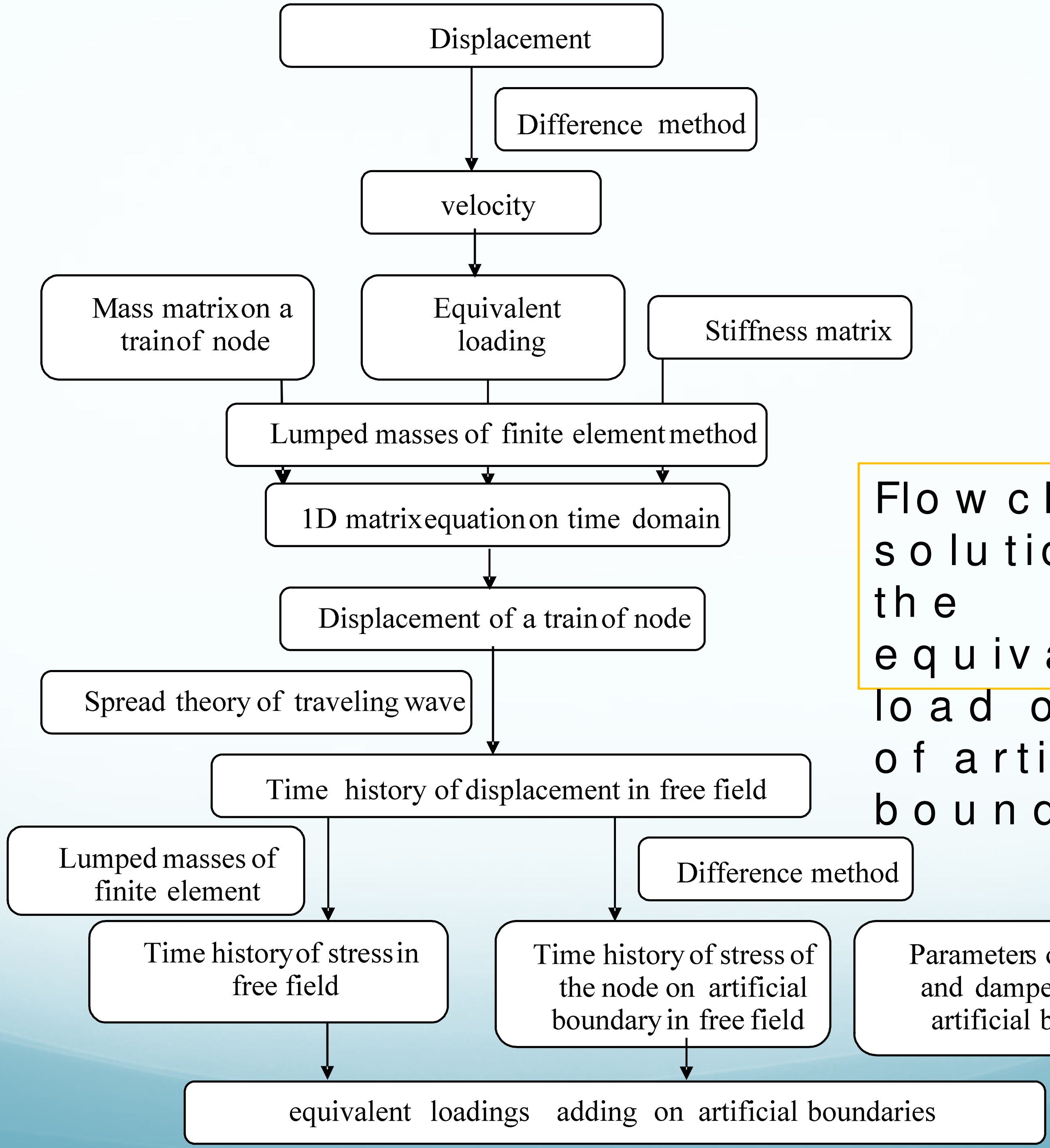
Fig.1. Sketch of oblique incidence prop

Traveling Wave Velocity

- The traveling wave's velocity c_x,
- along horizontal direction is shown in

$$c_x = \frac{c_{p1}}{\sin\theta_{pi}}$$

$$c_x = \frac{c_{s1}}{\sin\theta_{s1}} = \frac{c_{p1}}{\sin\theta_{p1}} = \frac{c_{s2}}{\sin\theta_{s2}} = \frac{c_{p2}}{\sin\theta_{p2}}$$



Flow chart of solution for the equivalent load on node of artificial boundary

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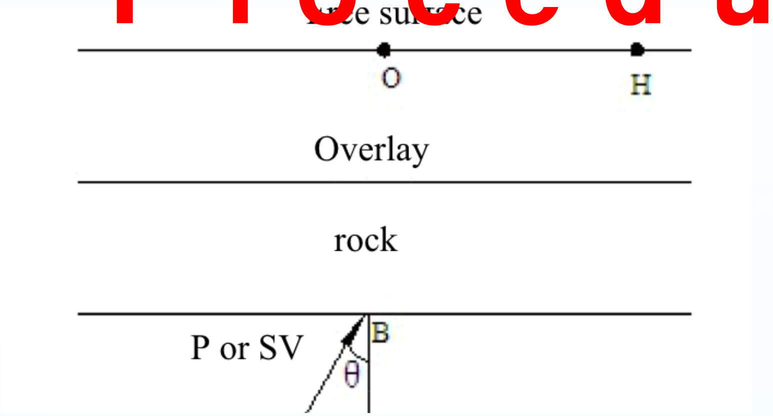
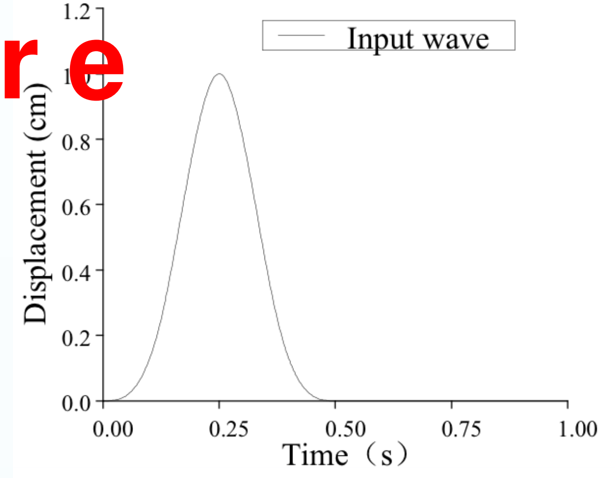
Verification of the Procedure

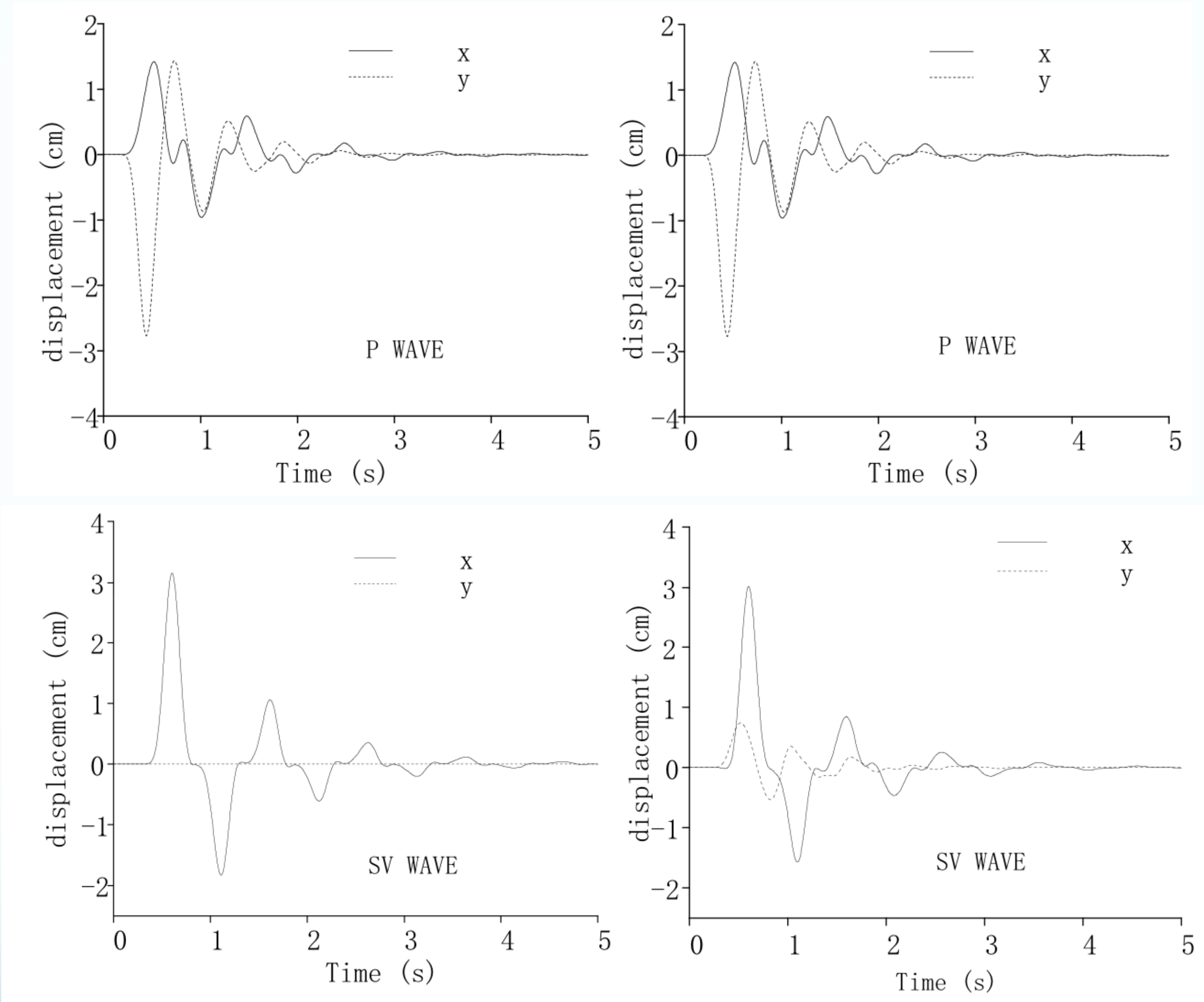




Sketch of the overlay model and the input

Table 1 Parameters of the soil

Type	**Thickness （m）**	**density （Kg/m³）**	**V_s（m/s）**	**V_p（m/s）**
Overlay	50	1000	200	346
Rock	50	1500	500	866



Time history curves of displacement with different angles: (a)θ=0.001° P wave (b) θ=30° P wave (c) θ=0.001° SV wave (b) θ=30° SV wave

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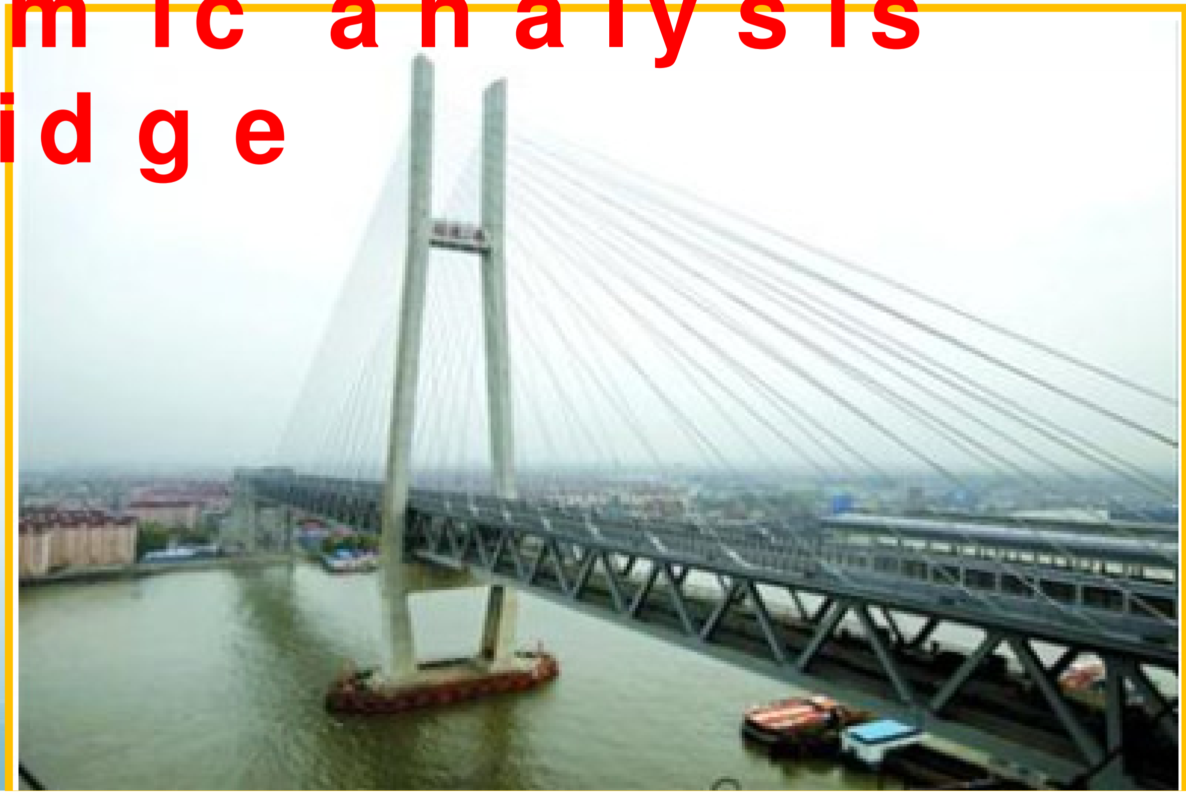
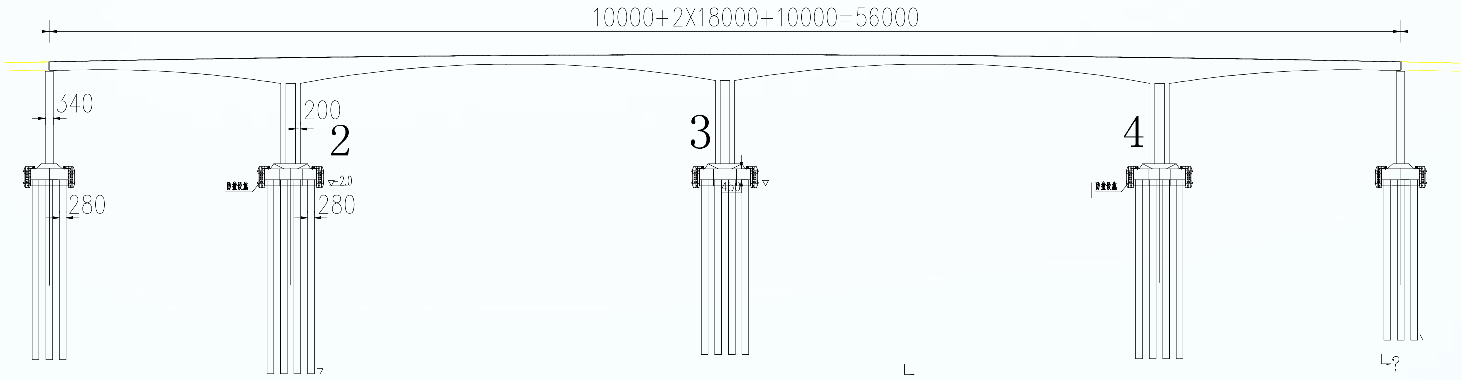
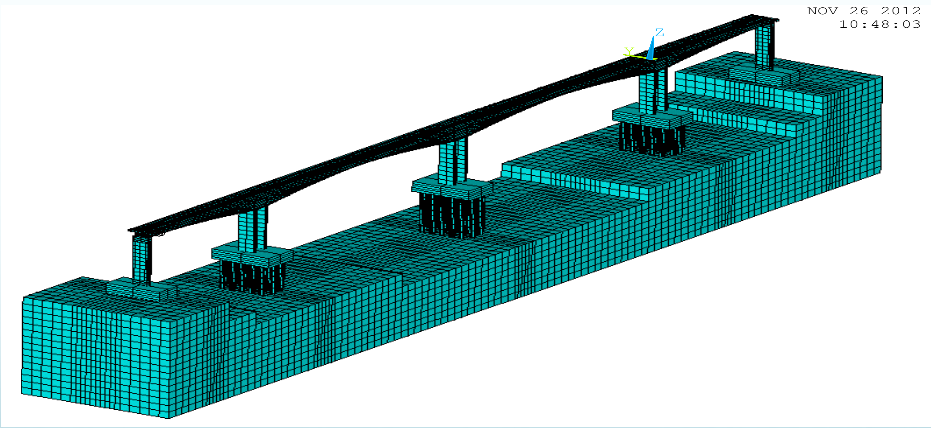
Seismic analysis of bridge



Case Study


10000+2X18000+10000=56000
340
200
2
3
4
280
280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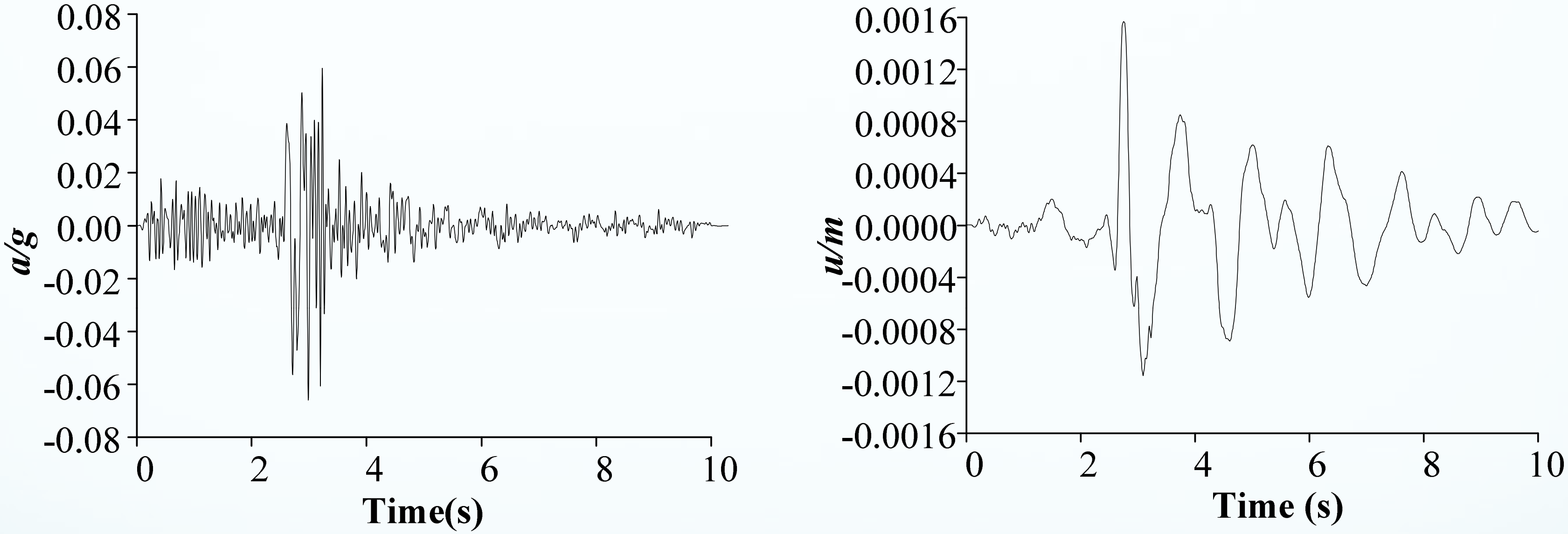
Case Study - Input seismic wave



(a) (b)

Fig.6. Input earthquake wave: (a) Acceleration (b) Displacem

Case Study - Results

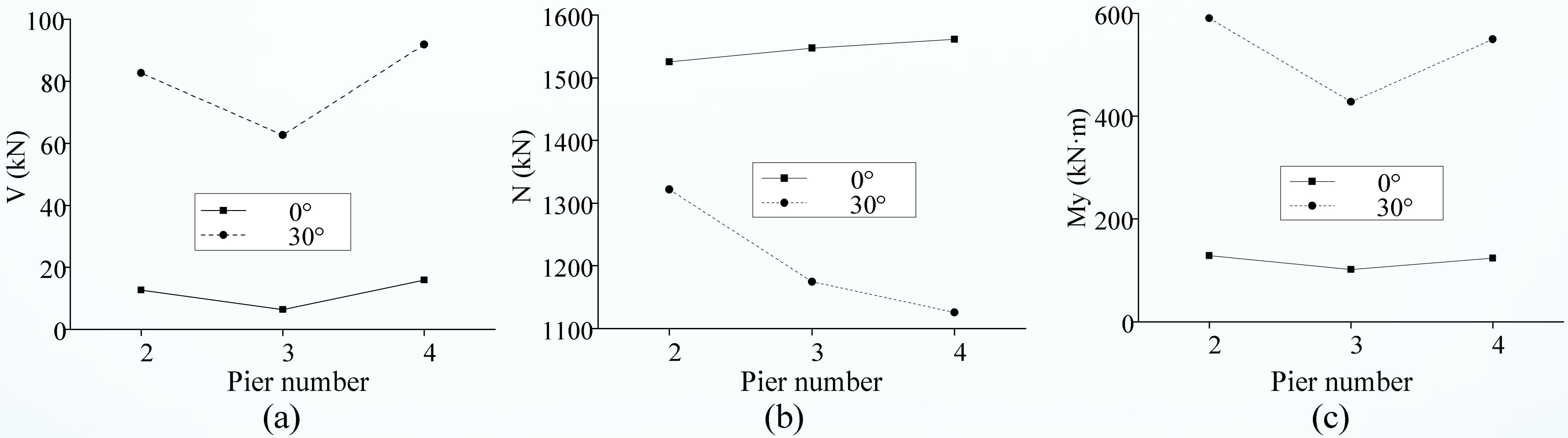


Fig.7. Maximum amplitude of internal forces at bottom of piers under oblique incidence P waves: (a) Shear force V (b) Axial force N(c) Moment My

Case Study - Results

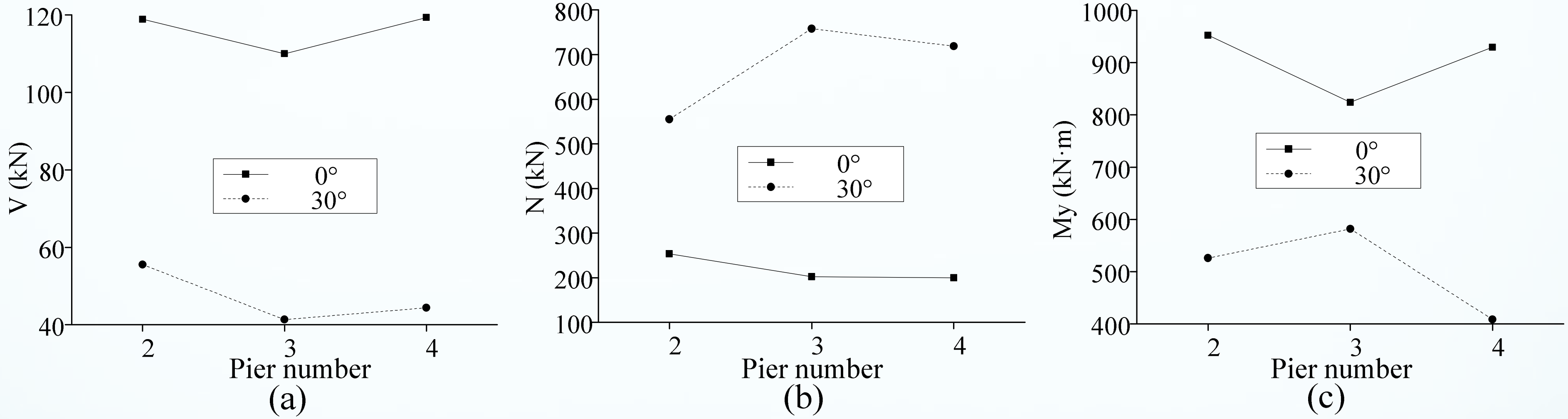


Fig.8. Maximum amplitude of internal forces at bottom of piers under oblique incidence SV waves: (a) Shear force V (b) Axial force N (c) Moment My

Case Study - Results

- Ratio of the values computed from vertical and oblique incidence input

$$\eta = \frac{\max|F| - \max|F_0|}{\max|F_0|}$$

Internal forces	η_P			η_{SV}		
	Pier 2	Pier 3	Pier 4	Pier 2	Pier 3	Pier 4
V	552%	8 74 %	4 77%	-53.28 %	-62.39%	-62.8 0%
N	13%	24 %	27%	118 .8 6 %	274 .26 %	259.4 1 %
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	-56.02%

It is shown that the oblique incidence has great effects on the piers of the bridges in

Thank you!

Q & A