Ground Shaking Characteristics of River Valleys and Seismic Response of Dams Considering Scattered Fields

Xinyu Yang, Zhiqiang Song*

Department of Water Resources and Hydropower Engineering, Xi'an University of Technology, Xi'an, Province, 710048, China

*Corresponding author's e-mail: zqsong@xaut.edu.cn

Abstract. For a river valley site with non-flat topography, the scattering effect will significantly change the distribution of the seismic field, and the role of the site scattering effect on ground shaking under oblique incidence of seismic waves is not clear for the time being. The scattering effect will change the ground vibration characteristics of the river valley, and then exert non-uniform excitation on the hydraulic structures located in the river valley. In this paper, the ground vibration characteristics of the valley features considering the scattered field are investigated based on the indirect boundary integration method (IBIEM), and the seismic responses of the dam under free-field and full-field viscoelastic boundary inputs are compared, and the results are as follows: the ground vibration features at the foot of the slope and the top of the slope on both sides of the valley are more affected by the angle of incidence, and the amplification effect of the feature facing the seismic wave is stronger; the peak acceleration of the dam is amplified by about 20% under the full-field input. The peak acceleration of the dam under full-field input is amplified by about 20%, which reveals the necessity of full-field input.

Keywords: river valley earthquake; scattered field; IBIEM; Dam Seismic Response; magnification effect;

1 Introduction

Seismic wave propagation process when encountered in the flat surface will occur when the regular reflection, but for the irregular surface similar to the river valley, the reflection and scattering of seismic waves is very complex, the scattered waves generated by the irregular terrain and the incident wave, the superposition of the reflected wave will be caused at different locations in the site of the seismic response of the amplification or attenuation of the phenomenon[1].

However, the current seismic calculations of hydraulic buildings are basically based on free-field inputs[2][3] without considering the scattering effect of river valley topography, and neglecting the influence of the scattered field will underestimate the peak value of ground shaking, which is not conducive to the safety of hydraulic

Z. Zhang et al. (eds.), *Proceedings of the 2024 6th International Conference on Structural Seismic and Civil Engineering Research (ICSSCER 2024)*, Advances in Engineering Research 246,
https://doi.org/10.2991/978-94-6463-556-0_4

buildings. Therefore it is significant to study the scattering effect of river valley site topography.

In addition, the seismic wave is often not a single wave incident, but a P-wave and SV-wave co-incidence, and the terrain scattering effect caused by the two is also different. And since there is a phase difference between the two waves, the displacement under combined incidence is not equal to the sum of the displacements at separate incidence, which reveals the necessity of studying the combined incidence. In the past, most of the scholars studied the single-wave incident case[4][5], but when the P and SV waves are jointly incident to the valley site, the ground vibration characteristics will be more complicated, which is also more in line with the actual working conditions. Therefore, all the analyses in this paper are based on the case of joint incidence of P and SV waves.

2 Calculation Methods and Valley Model

In this paper, the total site vibration input method based on IBIEM (Indirect Boundary Integration Method) considering the scattered field is used to study the impact of scattering effect of river valley topography while considering the impact of scattering effect. IBIEM (Indirect Boundary Integration Method) has a series of advantages such as reducing the solution dimension, satisfying the radiation conditions, high accuracy, and adapting to irregular river valleys, which is more convenient and time-saving than other methods in the solution process. Therefore, this paper adopts the IBIEM method to analyze the scattering effect of ground vibration in an asymmetric river valley site.

As shown in Fig. 1, the actual valley section is simplified as an asymmetric trapezoidal model: the width of the valley bottom W is 100 m, the height H is 100 m, the valley slope H/L is divided into two parts, H/L_1 on the left side, and H/L_2 on the right side, and the extension of the valley on each side of the valley is taken to be d=100 m, and the extension of the valley on each side of the valley is taken downward to be h=200 m. The feature points 5-11 are the feature points of the valley boundary; the feature points 2 and 14 are the foot of the valley on the right and left; the feature points 4 and 12 are the top of the valley on the right and left; the feature point 1 is the center of the valley bottom. Feature points 5-11 are valley boundary feature points; feature points 2 and 14 are the foot of the valley on the left and right sides; feature points 4 and 12 are the top of the valley on the left and right sides; and feature point 1 is the center of the valley bottom.

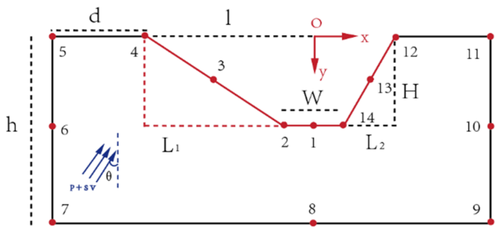


Fig. 1. Trapezoidal asymmetric model

3 Calculations and Discussion

3.1 The Effect of Angle of Incidence On Ground Shaking at River Valley Feature Points

In the study of the effect of changes in the angle of incidence on the ground vibration of the characteristic point, other factors remain unchanged, H/L_1 =1/2.5, H/L_2 =1; H=100m; W =100m; shear wave speed 500m/s, compression wave speed 1000m/s. P-wave angle of incidence is taken to be 0, 15, 30, 45, 60°, and the SV-wave angle of incidence is taken to be 0 , 10, 15, 20° , all of which are from the left side of the river valley. In this paper, the angle of incidence is the angle with the vertical direction. The foot of the slope on the left and right sides of the valley and the top of the slope on the left and right sides of the valley are selected as the feature points, i.e., feature points No. 2, No. 14, No. 4 and No. 12. The amplification factors D_h and D_v are defined as the ratio of the peak total field displacement D_{max} in the presence of valley topography to the peak displacement $D_{max,free}$ when only the free field is considered. If Dh and D_v are greater than 1, it is an amplification effect and vice versa. The waveforms are shown in Fig. 2 using the Rick sub-wave as a seismic wave with a time duration of 4 s and a superior frequency of 1 Hz.

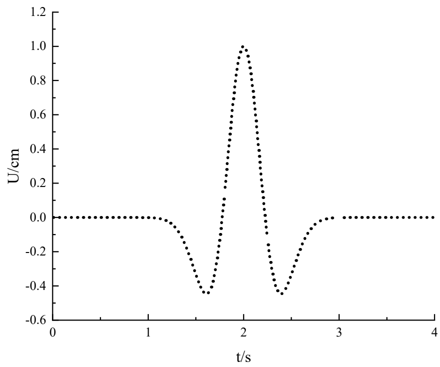
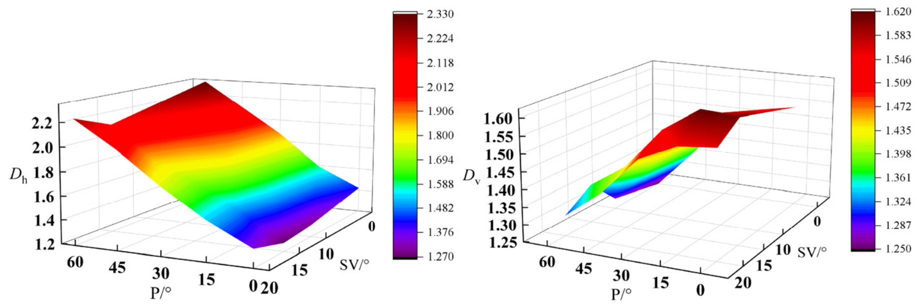
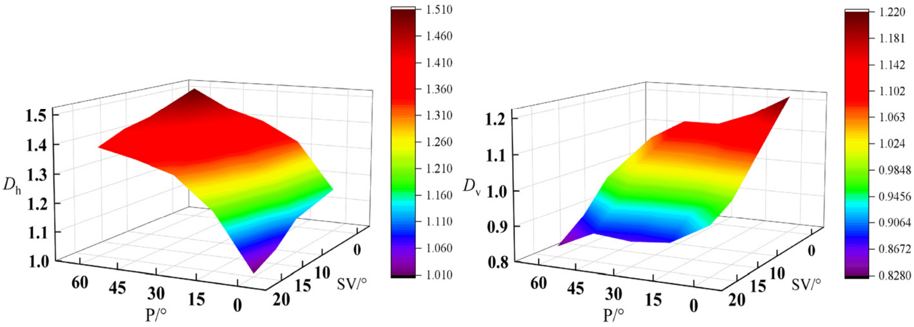


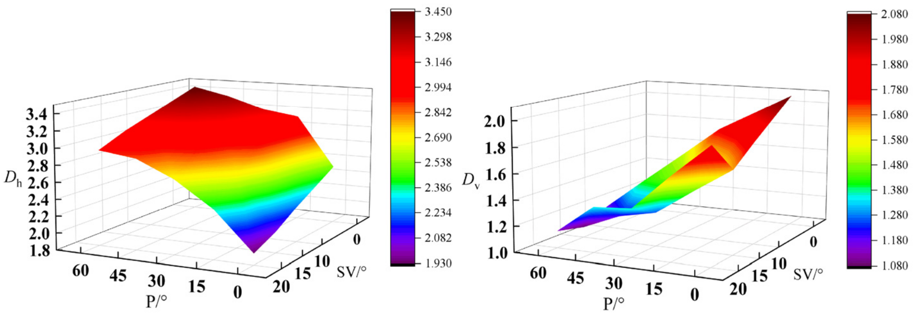
Fig. 2. Ricker wavelet history



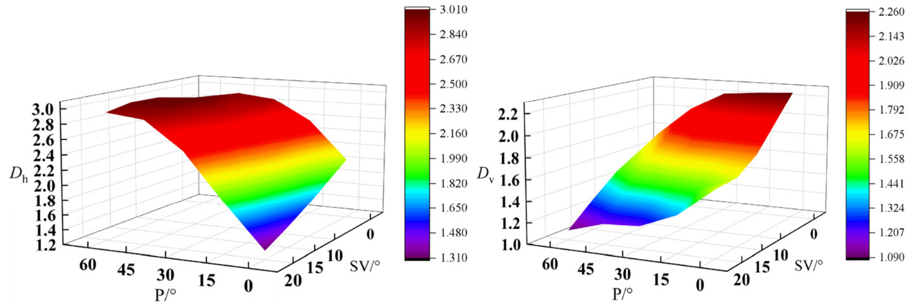
(a) No.2 point



(b) No.14 point



(c) No.4 point



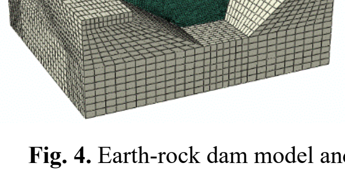
(d) No.12 point

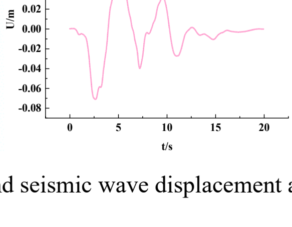
Fig. 3. Effect of incidence Angle on D_h and D_v

As can be seen from Fig. 3, at the foot of the river valley on the left side, D_h takes the maximum value when the SV wave is incident vertically and the P wave is incident at 60°, and when the incident angle of the P wave is constant, D_h decreases gradually with the increase of the incident angle of the SV wave, but then increases when *the* SV wave is incident at 20° compared with that of 15°, which is due to the fact that there is less vertical component of the SV wave incident at a near-critical angle. When the P wave is incident vertically and the SV wave is incident at 15°, D_v takes the maximum value, also because the vertical component converted by the SV wave incident at an angle close to the critical angle is less; at the foot of the river valley on the right side, when the SV wave is incident vertically and the P wave is incident at 60°, D_h takes the maximum value, but D_h does not increase when the SV wave is incident at 20° compared to that at 15°, which is because the horizontal component of the wave is weakened by the multiple reflections that occur when the wave enters into the river valley site. This is because the seismic wave enters the valley site and is reflected many times, weakening the horizontal component. D_v is maximized when both P and SV waves are incident vertically; at the apex of the left side of the valley, D_h is maximized when SV waves are incident vertically and P waves are incident at 60°, and D_h decreases gradually with the gradual increase of the incident angle of SV waves because the top of the slope is not directly facing the seismic wave, and the horizontal component is weakened by reflections in the valley when SV waves are incident at an angle close to the critical angle; D_v is maximized when P and SV waves are incident vertically. D_v takes the maximum value when the P wave and SV wave are both incident vertically, and the change of D_v at this point is more complicated because it is affected by the reflected wave from the right slope at the same time; at the top point of the right valley, D_h takes the maximum value when the SV wave is incident at 10° and the P wave is incident at 45°, and D_v takes the maximum value when the SV wave is incident at 0° and the P wave is incident at 15° because it is affected by the reflected wave from the left slope at the same time at this point. In addition, the maximum values of D_h and D_v at the left feature point are larger than those at the right feature point, which indicates that the topography of the valley on the wave-facing side has the effect of converging the seismic wave energy, forming a "barrier" effect.

3.2 Ground Vibration Response of Dams

The 3D finite element model of the earth-rock dam and the seismic waves selected in this section are shown in Fig. 4. The river valley H=100m, W=100m, H/L_1=1/1.5, H/L_2=1. The height of the earth and rock dam is 100m, and the upstream and downstream of the foundation, the left and right banks, and the bottom of the river valley all extend downstream for 100m. the elasticity mode of the foundation is taken as 5 GPa, the Poisson's ratio is taken as 0.3, and the density of the foundation is taken as 2.7 g/cm3. the relevant calculation parameters are as follows table 1 and 2.





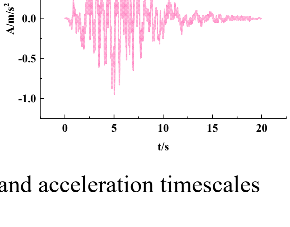


Fig. 4. Earth-rock dam model and seismic wave displacement and acceleration timescales

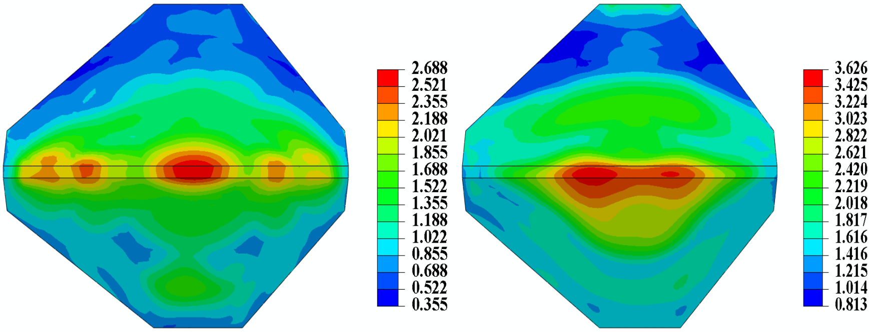
Table 1. Static parameter

parameters	ρ(g/cm^3)	K	n	R_f	$c(KPa)$	φ(°)	P_a	K_b	m	K_{ur}/K
rubble	2.15	950	0.56	0.89	40	36	100	600	-0.076	2

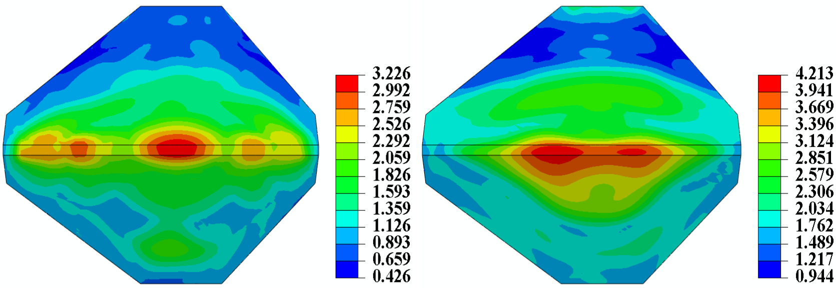
Table 2. Dynamic parameter

parameters	k_1	k_2	n	ν	λ_{max}
rubble area	17.1	1655	0.57	0.35	0.21

The following calculations take two working conditions: condition I is the free-field input at the viscoelastic boundary, and condition II is the total-field input at the viscoelastic boundary. The incident wave is incident from the left bank, the P-wave is incident obliquely at 30° and the SV-wave is incident obliquely at 15°. As show in figure 5.



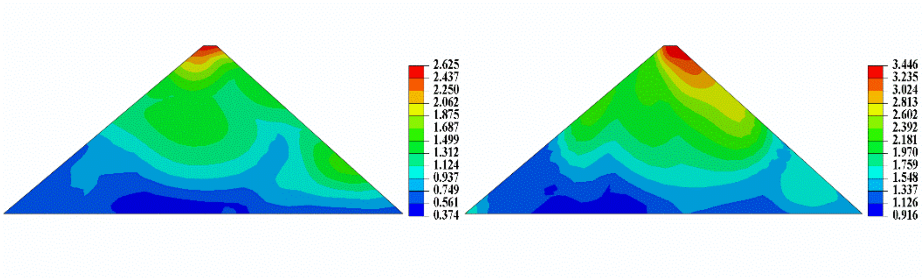
(a) Condition 1 is horizontal (b) Condition 1 vertical direction



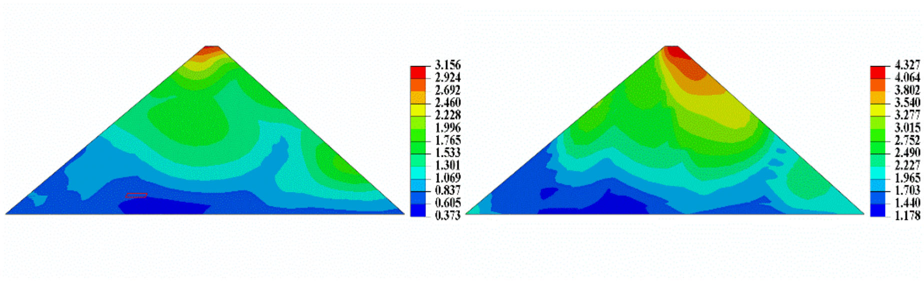
(c) Condition 2 is horizontal (d) Condition 2 vertical direction

Fig. 5. Peak surface acceleration of earth-rock dam

Comparing the two conditions, it can be seen that the peak accelerations in the horizontal and vertical directions are 2.625m/s^2 and 3.566m/s^2 respectively when the free field is input from the viscoelastic boundary, and 3.192m/s^2 and 4.168m/s^2 respectively when the total field is input from the viscoelastic boundary, so it can be seen that the maximum acceleration in the horizontal and vertical directions are amplified by 21.6% and 16.88%, respectively, when the total field is input from the consideration of the effect of terrain scattering. It can be seen that with the input of total field considering the topographic scattering effect, the maximum acceleration in horizontal and vertical directions are amplified by 21.6% in horizontal direction and 16.88% in vertical direction, which is detrimental to the seismic design of the structure because of the significant underestimation of the ground vibration response if only the free field is taken into account. As show in figure 6.



(a) Condition 1 is horizontal (b) Condition 1 vertical direction



(c) Condition 2 is horizontal (d) Condition 2 vertical direction

Fig. 6. Peak acceleration of typical profile of earth-rock dam

Comparing the viscoelastic boundary free-field input and total-field input, with the viscoelastic boundary free-field input, the maximum values of horizontal and vertical peak accelerations are 2.594 m/s^2 and 3.366 m/s^2, respectively, and with the viscoelastic boundary total-field input, the maximum values of horizontal and vertical peak accelerations are 3.142 m/s^2 and 4.256 m/s^2, respectively, which is basically the same as that of the surface pattern of the earth and stone dam. Both show the total field amplification effect. It can be seen that if only the free-field viscoelastic boundary input is considered, it will cause an error of about 20% from the typical profile, underestimating the peak ground vibration response.

4 Conclusions

The D_h and D_v at the foot of the slope and the top of the slope on both sides of the valley are affected by the combined incidence angle of P and SV in a complicated way. The maximum value of D_h is not necessarily taken when the SV wave is incident vertically and the P wave is incident at 60° and the maximum value of D_v is not necessarily taken when the SV wave is incident at 20° and the P wave is incident vertically, and the maximum values of D_h and D_v are larger than that at the right-side feature, which indicates the "barrier" effect of the wave-facing side. The maximum values of D_h and D_v are larger than those of the right eigenpoints on the wavefront side, indicating the "barrier" effect on the wavefront side.

Comparative analysis of the seismic response of three-dimensional earth and rock dams with viscoelastic boundary free-field input and viscoelastic boundary total-field input, the conclusion of the calculations shows that, comparing the total-field and free-field inputs with the viscoelastic boundary, the seismic response is similar to the basic law, and there is a certain difference in peak acceleration, which is generally enlarged by 20% after the total-field input, and the peak acceleration will be underestimated if the free-field input is used, therefore, it is more accurate and effective to use the total-field input. Therefore, the total field input is more accurate and more effective.

In summary, this paper provides a basis for adopting the combined incidence of P-SV seismic waves and the total field input in the ground vibration study, and suggests that multiple seismic wave combinations should be used in the subsequent related studies and the topographic scattering effect should be taken into account.

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