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Collapse process and impact effect of viaduct demolition based on centrifugal model

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ABSTRACT

It is well known that prototype and model behave differently under the conventional gravity field when the influence of gravity cannot be ignored such as the collapse of viaducts. In this paper, we derived a similarity relations that takes gravity effects into account and simulated the viaduct collapse process and the impact effect on underground tunnel under collapsing vibration through a prototype and a scaled model. The results show that when the gravity expands n times in the model which scaled ration is 1/n, the prototype and model are similar. This study provides a theoretical basis for research on viaduct collapse vibration based on the centrifugal model.

1. Introduction

With the rapid development of urban construction, many city viaducts need to be rebuilt because they cannot meet requirements for wider use. In terms of time limit, safety, and environmental limit, the blasting demolition of viaducts is superior to traditional methods such as mechanical crushing, cutting, and dismounting. Engineers successfully applied blasting demolition to demolish four viaducts with a total length of 2078 m in Nanjing in 2012, and the Dunyang Bridge with a total length of 3.476 km in Wuhan in 2013. However, the complex urban environment is a problem during blasting demolition of urban viaducts. Viaduct demolition through blasting should ensure that other surrounding buildings are not affected. Shallowly buried underground pipelines and subway tunnels are two structures that need to be protected.

A study on the response of buried pipelines and tunnel effect under the impact of viaduct collapse has important guiding significance to the protection of surroundings and scheme design. Numerical simulation is a commonly used research method, and a series of research on the dynamic responses of blast and impact loads have been carried out by many authors [1–9]. Through numerical simulation, Zhao Hua-bin et al. [1] analyzed the influence of protective measures on shallowly buried underground pipelines during blasting demolition of viaducts. Ji Shan et al. [3] used LS-DYNA to simulate the blasting and subsiding process of viaducts, and the ground vibration response was analyzed in combination with engineering practice. Hartmann et al. [4] calculated the collapse process of a building under controlled blasting on the basis of the finite element model. Uenishi et al. [5] established a fully three-dimensional finite difference program to study the basic blasting process of reinforced concrete. Ohtsu et al. [6] studied the dynamic failure of fiber reinforced concrete due to blasting by applying boundary element method. Elsanadedy et al. [10] and Feng Fu [11] studied the collapse and dynamic response of buildings by finite element method.

In addition to the numerical method on the collapse and dynamic of buildings, the experimental study is also important. However, conducting a prototype test with large buildings is difficult and the model test is the main approach in this case, so the similarity relation of prototype and model should be derived first. Baylot [12] and Chen [13] conducted the model tests for the response of concrete structure under blast load, but the gravity wasn't considered in the similarity relations. Obviously the effect of gravity on the collapse of buildings cannot be ignored. Murphy [14] pointed out that size scaling tests cannot reasonably simulate gravity loading in the general gravity field. Considering the effect of gravity field, the scaling model test should meet not only size similarity but also gravity similarity. Therefore, model tests with similar gravity considerations need to be performed with a centrifuge. Most studies on centrifuge model test were based on quasi-static and elastic-plastic dynamic responses [15,16]. And there are some studies on centrifuge model for responses to explosion or impact loading. Kutter et al. [17] performed a centrifuge model test of an underground tunnel explosion. The tests under different acceleration conditions verified the similarity of the centrifuge model scale. Anirban et al. [18] conducted centrifugal model tests of underground structures such as pipelines and tunnels under surface blasting. The effect of different protection measures on the impact of explosion was studied. The current paper mainly studies the similarity relation between centrifugal

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Table 1
Similarity relation.

Classification	Parameter	Prototype	Model	Scaled ratio
Length	Characteristic length	l	λl	λ
	Height	h	λh	λ
Gravity	Gravitational acceleration	g	g/λ	$1/\lambda$
collapse	Collapse velocity	v	v	1
	Collapse time	t	λt	λ
	Impulse	I	λI	λ
Impact	Stress wave	σ	σ	1
	Vibration acceleration	a	a/λ	$1/\lambda$
	Vibration velocity	μ	μ	1

and real models of a shallowly buried underground pipeline under the impact load of viaduct collapse, thereby providing a theoretical basis for the structure collapse impact of the centrifugal model test.

2. Centrifugal similitude law of viaduct collapse process and effect of impact on ground

When studying the collapse process and vibration impact effect during viaduct demolition through blasting, assuming that the concrete is the material of the bridge body and the ground medium is a continuous homogeneous solid medium, the influence of the following bridge parameters are considered: density ρ_1, elastic modulus E_1, Poisson's ratio μ_1, failure strength f_1, characteristic length l; ground medium parameters: density ρ_2, elastic modulus E_2, Poisson's ratio μ_2, failure strength f_2; other parameters: gravitational acceleration g. The measured parameters are bridge collapse speed v; time t; height h; acceleration of ground medium particle a, and stress wave σ.

Then, the density ρ_1, elastic modulus E_1, bridge height h are selected as the basic dimensionless terms.

And other variables can be expressed as following dimensionless π terms:

$$\underbrace{[\mu_1]}_{\pi_1},\ \underbrace{\left[\frac{f_1}{E_1}\right]}_{\pi_2},\ \underbrace{\left[\frac{l}{h}\right]}_{\pi_3},\ \underbrace{\left[\frac{\rho_1}{\rho_2}\right]}_{\pi_4},\ \underbrace{\left[\frac{E_2}{E_1}\right]}_{\pi_5},\ \underbrace{[\mu_2]}_{\pi_6},\ \underbrace{\left[\frac{f_2}{E_1}\right]}_{\pi_7},\ \underbrace{\left[\frac{\rho_1 gh}{E_1}\right]}_{\pi_8},\ \underbrace{\left[\frac{v\rho_1^{1/2}}{E_1^{1/2}}\right]}_{\pi_9},\ \underbrace{\left[\frac{tE_1^{1/2}}{h\rho_1^{1/2}}\right]}_{\pi_{10}},\ \underbrace{\left[\frac{\rho_1 ah}{E_1}\right]}_{\pi_{11}},\ \underbrace{\left[\frac{\sigma}{E_1}\right]}_{\pi_{12}} \tag{1}$$

The relations of a model and prototype can be derived from these dimensionless terms. In a study of size scaling models, the material is usually the same, which means the mechanical parameters of the bridge and the ground are determined. Thus, ρ_1 , E_1 , μ_1 , f_1 , ρ_2 , E_2 , μ_2 , f_2 are constants. Therefore, the π_i terms(i = 1,2,4,5,6,7) are constant. The dimensionless number π_3 and π_8 leads to the conditions of similarity as,

$$\frac{\pi_{3m}}{\pi_{3p}} = \frac{l_m/h_m}{l_p/h_p} = \frac{\lambda_l}{\lambda_h} = 1 \tag{2}$$

$$\frac{\pi_{8m}}{\pi_{8p}} = \frac{g_m h_m}{g_p g_p} = \lambda_g \lambda_h = 1 \tag{3}$$

Then the gravity acceleration scale shall be

$$\lambda_g = \frac{g_m}{g_p} = \frac{1}{\lambda_l} \tag{4}$$

And the similarity relation of these measured parameters can be derived through π_i (i = 9, 10, 11, 12) that

$$\lambda_v = \lambda_\sigma = 1;\ \lambda_t = \lambda_l;\ \lambda_a = \frac{1}{\lambda_l} \tag{5}$$

According to the above analysis, the bridge collapse and impact effect of the ground should not only meet a simple geometric similarity but also accord with the centrifugal similarity, namely, gravity similarity. Such model tests need to be studied through centrifuge technology. The model and prototype accord with the centrifugal similarity relation. If the scaled ratio of the length from the prototype to model is λ and the scaled acceleration of gravity is $1/\lambda$, then the similarity relations are as shown in Table 1.

3. Project overview

The blasting demolition of a viaduct is an important part of the rapid development and renewal of urban arterial roads. The Nanjing Hanzhong gate viaduct located on the west main road of Nanjing City is given as an example. Most structures along the street on both sides of the bridge and under the bridge are shops and office buildings. Fig. 1 shows the abovementioned viaduct.

The main structure of the viaduct is a wide wing continuous girder bridge with equal section, and two-way prestressed rebars are arranged in the longitudinal and the horizontal directions. The span combinations are 4 × (24 + 3 × 26 + 24) m (total of 504 m). From north to south, the columns are numbered 1# to 19#, in which 5#, 10#, and 15# are the transition piers. To reduce the impact effect on the tunnel underground near pier 14#, piecewise delay initiation was adopted from pier 14# to both ends as shown in Fig. 2.

4. Numerical simulation of blasting demolition of viaduct

4.1. Finite element model

LS-DYNA is a general explicit nonlinear dynamic analysis program. To simulate the collapse process of the viaduct, we established a model of the bridge piers and the ground [24]. To reduce the computation

Fig. 1. Viaduct and its surrounding environment.