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# Dynamic Response of Underground Structure Subjected to Collapse-touchdown Impact Loading

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**Abstract.** As the urbanization and urban planning in China make progress, many buildings are facing demolition. These buildings to be demolished are often located close to various underground structures built in many cities. Therefore, the impact loading due to the touchdown of these buildings will inevitably affect the underground structures. In this paper, field tests were used to analyze the response of underground structure subjected to the impact loading due to the collapse touchdown of superstructure. The dynamic response of underground pipeline to the collapse of a single-span viaduct was analyzed. The results showed that the vibration responses of both the soil and structure are mainly vertical, which generally attenuate rapidly with the distance away from the collapse touchdown area, and also the impact effect has little influence on small pipes.

## 1. Introduction

The average service life of Chinese buildings is only 30 years or so, which means that many buildings are facing demolition soon after they are built. Many demolition projects are concentrated in the downtown area, where both the surrounding buildings (superstructures) and underground structures (e.g. subway tunnels and pipelines) are densely distributed. The collapse touchdown of these buildings when they are demolished will inevitably have a large impact on the surrounding buildings and underground structures. Most of the previous studies on the impact effect of the collapse touchdown focused on superstructure aspect [1-4]. However, the relevant studies concerning the impact effect of collapse touchdown on the underground structures such as the subway tunnels are much fewer. Recently, the development of underground structures such as urban subways in China has been rapid, and the distribution of underground pipelines such as natural gas pipelines, oil pipelines, wires and cables has been extensive. When the demolition work is carried out in the downtown area of a city, the ground vibration induced by the falling structural components may cause damage to the adjacent underground facilities such as subway stations. Therefore, it is necessary to carry out such studies to investigate the influence of the collapse touchdown vibration on the underground structure.

Many studies have been performed to investigate the influence of underground structures under the impact loading of collapse touchdown. For example, Fourie [5] studied the stability of underground tunnels and the safety of pillars subjected to blasting vibration. The results showed that the vibration velocities of particles were generally less than 10 m/s. Besides, the size of the gravel would become smaller, and the amount of gravel was related to the energy of surface blasting. Stevens [6, 7] suggested a hybrid numerical approach to simulate the dynamic response of buried RC arch under blasting load, and its validity was verified by experimental data. Kawahara [8] has done a series of



laboratory experiments for a decomposed granite soil in the combination of the mass and drop height of the weight to investigate the effects of the dry density and thickness of a sand cushion on an impact response due to a falling weight likened to a rockfall. It showed that the transmissibility of the impact pressure decreases rapidly with the thickness of the soil. Yang [9] studied the responses of contact force, displacement, and damage and energy distribution of the shack tunnel under the impact of falling rock. Jiang [10] used LS-DYNA finite element software to numerically analyze the behavior of railway tunnel structure under the surrounding rock blasting vibration, and suggested that the peak velocity of the particle vibration can serve as a safety criterion for the stability assessment of railway tunnel structure. Chen [11] studied the dynamic response of underground arch structures under blast loading and discussed the interactions between different soil layers. Using finite difference method, Baziar [12] numerically carried out the vibration analysis of a tunnel structure under surface impact load. The results indicated that the main factor affecting the vibration response of the underground structure was the impulse transmitted from the alluvial to the soil layer. Seyedan [13] investigated the reduction effect of soil depth on dynamic soil pressure acted on underground structures systematically by parameter analysis.

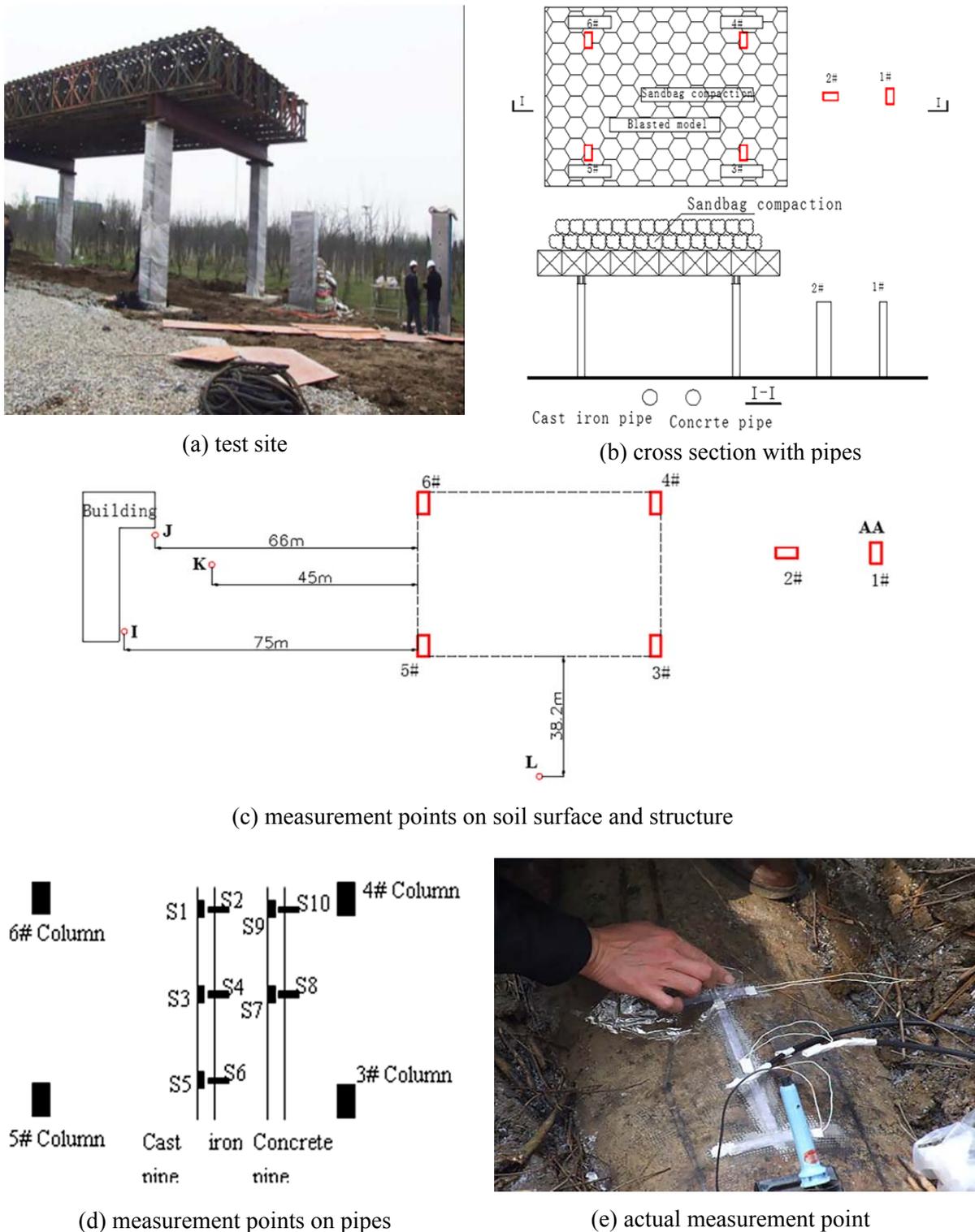
As reported above, most of the relevant studies focus on the responses of ground or nearby superstructure subjected to impact loadings, while the studies involving the response of underground structures against collapse touchdown vibration are much fewer. This paper carried out both field tests and numerical simulations to comprehensively analyze the dynamic response of underground structures under the impact loading due to collapse touchdown. Firstly, a full-scale collapse touchdown test was carried out, where the impact loading was induced by the falling of deck of a single-span bridge; the dynamic response of the nearby underground pipeline was measured. Three-dimensional finite element analysis was carried out to back analyze the field test, which verifies the rationality of the current numerical simulation procedure. Furthermore, the current numerical analysis approach was employed to investigate the dynamic response of an actual subway station under the impact vibration. The findings obtained from both the field tests and numerical analyses are likely helpful in protection of underground structures against blasting loadings.

## 2. Field Test

To reasonably determine the blasting demolition plan of an existing viaduct bridge and to estimate its influence on the nearby underground pipeline, it was proposed to carry out a large-scale test near the site of the bridge. The bridge body is mainly divided into two parts: the approach road and the main bridge. The main bridge is a simple support and rigid frame-continuous system. The prototype bridge is 3,765.5 m long and has 22 joints, the joint length being between 128 and 144 m.

### 2.1. Instrumentation of the Testing System

The main purpose of this test is to study the influence of collapse touchdown of bridge deck on the surrounding environment. The four columns of bridge have cross-sectional dimensions of 1 m (length)  $\times$  0.55 m (width) and a height of 7 m. Grade C60 concrete block is used to account for the weight of bridge structure, which is applied at the top of steel bridge deck (Figs. 1 a and 1b). The 1# measuring point is located 75 m away from the edge of the blasting zone and is located on a pillar foundation of adjacent building; the 2# measuring point is located 66 m away from the edge of the blasting zone and is located on the pillar foundation of the same building; the 3# measuring point is 45 m distance from the edge of the blasting zone and is arranged on soil surface. It is located at the side camera; 4# measuring point is 38.2 m distance from the edge of the blasting zone, and placed on soil surface too, and is located at the front camera. The acceleration measuring points are arranged on the 1# column that is to be blasted. The specific measuring point arrangement is shown in Figure 1c. The two buried pipes are shown in Figure 1(b). They are located in the ground soil between the columns, respectively made of cast iron and concrete pipe and with both a depth and a diameter of 1.5 m. Strain gauges are adhered to each of the monitoring points arranged on the pipes (Figs. 1d and 1e). As Figure 1f shows, three measuring points were arranged on the cast iron pipe and two measuring points are arranged on the cement pipe; besides, each point is arranged with both hoop and axial strain gauges.



**Figure 1.** Field test schedule

**2.2. Test on-site Observation**

Two high-definition cameras are installed for the blasting test. As captured by the cameras that columns 5# and 6# on the left side are first detonated. At about 150 ms after detonation, columns 5# and 6# begin to fall. At about 300 ms, the bridge surface tends to incline by about 5°. The right columns 3# and 4# detonate about 320 ms later than that of columns 5# and 6#. All the columns fully

collapse at about 1420 ms after the detonation of columns 5# and 6#. The collapse process of the one-span bridge system is shown in Figure 2.



(a). 0ms



(b). 25ms



(c). 120ms



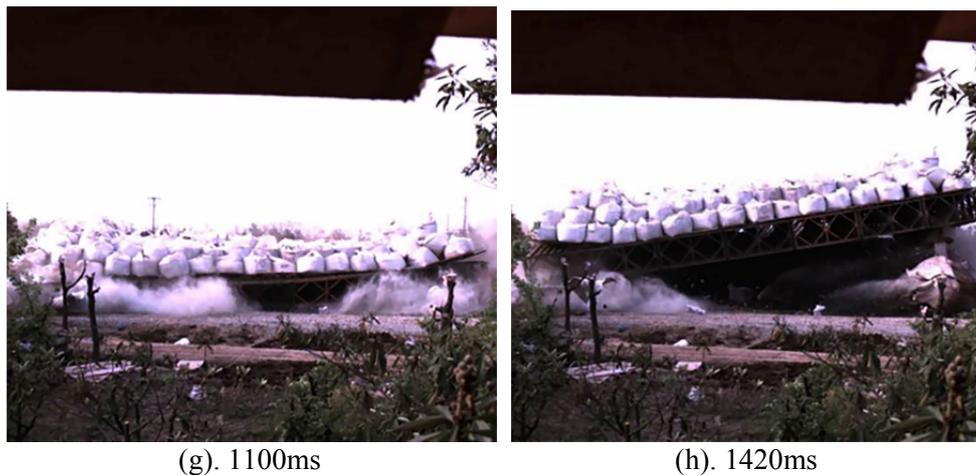
(d). 200ms



(e). 300ms



(f). 925ms



(g). 1100ms

(h). 1420ms

**Figure 2.** Test observations at different times

On the 2nd position; it was observed that the 5# and 6# columns are basically intact at 25 ms after blasting. After the time of detonating is about 120 ms, the 5# column began to fall; after the time of detonating is about 200 ms, 6# began to fall, at which time 5# has dropped by about 10 cm; After the time of detonating is about 300 ms, the 5# column drops about 0.5 m, and the top of the 5# column start to separate from the bottom of the bridge deck (the falling speed of the bridge deck is greater than the free fall of the soil bag), the 6# column drop less than 20 cm; After the time of detonating is about 925 ms, 5 # column touchdown. After the time of detonating is about 1.1 s, the 6# column touchdown is as shown in Fig. 2.

### 3. Test Results and Analysis

#### 3.1. Strain Monitoring Results

Unfortunately, during the test the strain gauges of S3 and S6 malfunctioned, and no valid test data were obtained. The results measured by other strain gauges are shown in Table 1.

**Table 1.** Results of strain monitoring of underground pipelines during blasting demolition

NO.	Measuring point	Maximum strain / $\mu\epsilon$	Maximum stress /MPa
S01	Cast iron pipe between 5 and 3 column axes (axial)	33.01	5.15
S02	Cast iron pipe between 5 and 3 column axes (hoop)	54.98	8.58
S03	Cast iron pipe between 5 and 6 cylinder axes (axial)	---	---
S04	Cast iron pipe between 5 and 6 column axes (hoop)	53.31	8.32
S05	Cast iron pipe between 3 and 4 column axes (axial)	67.21	10.48
S07	Central axis cement pipe (axial)	85.53	3.34
S08	Central axis cement pipe (hoop)	15.27	0.60
S09	Cement pipe (axial) between 5 and 6 column axes	16.80	0.66
S10	Cement pipe (hoop) between 5 and 6 column axes	13.95	0.54

#### 3.2. Analysis of Test Results.

In the test, the maximum dynamic stress is calculated according to the maximum dynamic strain measured, and the dynamic stress is calculated by the following formula:

$$\sigma_D = E_D \cdot \epsilon_D \quad (1)$$

where  $\sigma_D$  is calculating the dynamic stress (MPa);  $E_D$  is dynamic elasticity modulus (MPa);  $\epsilon_D$  is

measured dynamic strain ( $\mu\epsilon$ ).

Using the measured strain values during the blasting touchdown process, the axial and hoop stresses of the measuring point on the pipeline are calculated, as shown in Table 1. The static elastic modulus of concrete is 30 GPa, and the static modulus of cast iron pipe is 120 GPa. The maximum amplitude of compressive stress of concrete pipe is 3.34 MPa, experienced at the measuring point S07. The maximum tensile stress appears at the position of S09, with a value of 0.66 MPa. As the design compressive and tensile strengths of concrete are respectively 14.3 MPa and 1.96 MPa, indicating that the concrete pipeline is safe under the touchdown loading. The maximum tensile stress of cast iron pipe appears at the position of S05, with a value of 10.48 MPa. For the pipe diameter ranging from 40-2600 mm, the design tensile strength is 420 MPa, suggesting that the cast iron pipe is also safe.

#### 4. Conclusions

In this paper, field test was performed to investigate the influence of blasting demolition of a large-scale elevated bridge on the dynamic response of two nearby underground pipelines. The field test showed that the vibration responses of the soil and underground structure caused by the collapse touchdown are mainly vertical, which attenuate rapidly with the distance away from the touchdown location, and the impact effect has little influence on small pipes. The effect on large diameter tunnel, however, should be treated seriously, and the work will be the next work.

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