

# Seismic Effect Analysis of the Adjacent Longitudinal Box Culvert for the Utility Tunnel

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## Abstract

The utility tunnel has the vital significance of the underground public facilities construction for the modernized urban construction inevitable trend. The traditional utility tunnel was used as one of the approaches to achieve sustainable developments. The whole energy supply and distribution system in china will need to be restructured and reworked. Thus, there is still a limited research available on the seismic effect of the utility tunnel. So that, this paper aims to fulfil this research need by investigating the FEA of the adjacent longitudinal box culvert for the utility tunnel is deployed under the circumstance of seismic effect through ABAQUS software concerning to Amplitude A, B and C with time period of 53.47sec, 53.73sec and 53.79sec. The result indicates that, the seismic stress of the box culvert specifically the box culvert including certain soil parts with seismic time and load were found grey zone which is needed greatest warning zone before failure. Finally, the displacement time-history are then studied in the paper which meets the requirements duration from 10 to 20 times. The displacement change is caused by the subsidence of the soil foundation due to the displacement values on the corresponding corner points are much different.

**Keywords:** Box culvert, FEM model, Seismic effect analysis, Underground structure, Utility tunnel.

## 1. Introduction

Utility tunnel is a type of underground structure that accommodates various public facilities. It is an important component of urban lifeline infrastructure.[1-3] Whose security and stability not only for the normal running of the city has a vital role, and to ensure that urban disaster prevention capabilities, meaning even more important. Jorge from the perspective of human health and safety risks of the utility tunnel may make specific requests.[4] In addition to this, the utility tunnel is the most sustainable development of urban underground space facilities, will be incorporated into urban underground space planning. At the same time, utility tunnel has so many advantages there easy to maintain and will not cause traffic jams, noise and environmental pollution, can easily be added municipal pipe and so on.[5] However, there is still limited research to date on the seismic analysis of the utility tunnel. The shape of utility tunnels is circular and multi-circular, the box shape tunnels are used in underground cavities, subway stations, especially in shallow buried mine tunnels. These utility tunnels have been constructed by either the cut-and-cover method or shield tunneling method depending on the geological conditions. The cut-and-cover method is used to construct the precast box culvert utility tunnel. Meanwhile, this paper focusses on the box-shaped and shallow-buried concrete structures. Because it is preferable due to simple construction, reduces construction time and maintenance cost as well as low seismic risk.[6-8] At present, the seismic design of underground structures commonly used in China mainly adopts three methods: static method, quasi-static method and dynamic response analysis method. This paper mainly used the quasi-static method which is namely the displacement method. The reaction displacement method simulates the structure elements, and the soil is replaced with a spring of equivalent stiffness. The method of applying



the seismic load of the reaction displacement method is to first study the motion of the three-dimensional soil layer, and apply the maximum displacement of the upper and lower bottom positions of the soil layer to the end of the soil spring away from the structure. Finally, the utility tunnel has many advantages over traditional method of laying lifelines. This paper established a three dimensional finite element model through ABAQUS software concerning to Amplitude A, B and C, as well as the seismic effect of the utility tunnel which is made up of adjacent longitudinal precast box culvert with the flexible joint. Besides, the soil in a concerning seismic load has been simulated to obtain stress and displacement time-history. The finite element model is preferable to simulate the numerical solution of the problems under the condition of assembled box culvert using ABAQUS software, and the results provide to the analysis of the longitudinal precast box culvert and construction practices.[9-13]

## 2. Materials and Methods

### 2.1 Geometrical Parameters

In order to study the behavior of all the possible standard adjacent box culverts three dimensional finite element model were prepared for the standard size of longitudinal box culvert as per GB50010-2010.[14] This model included three dimensional solid elements soil (C3D8) and three dimensional solid elements for concrete floor reaction (C3D8) and Box culvert (C3D4) having geometric and material linearity. Moreover, the elements are standard meshed separately. So that, the mesh element generated high on the part soil and least on the part floor reaction. In addition to this, the total mesh generates 357,119 elements and 101,390 nodes. Thus, the stress and displacement was studied for all the load steps of double box tested using brick element including flexible connection concerning to soil beneath, side soil, adjacent box culvert and floor reaction. [15, 16]

### 2.2 Material Properties

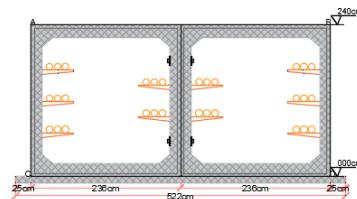
The absence of some material property data, the properties parameter of the subsoil and the culvert concrete were calculated by FEM analysis. This method based on the observational property data (soil, box culvert, floor reaction) was used to gained displacement of the culvert section from the FEM analysis, and results was reasonable. [17] Methods comparing with each other, the finite element ABAQUS software was used to model and analyze concerning to Amplitude A, B and C. The displacement of two culverts including reaction floor with overlying soil on both side was calculated when the two culverts were flexible connected and the gap between them was tied using screw bolt. The corresponding stress and displacement diagram was obtained. Because the elastic modulus of box culvert and soil is four orders of magnitude different, the elastic displacement of soil is observed, and the adjacent box culvert is considered as a flexible connection, and its elastic displacement or deformation can be neglected. Moreover, the basic material parameters shown in Table 1 and the single detailed section size shown in Table 2 as well as it's cross section of utility tunnel including its corner numbering also shown in Figure 1. [14]

**Table 1** Material property of the instance modeling

Instance	Size(m)	Unit type	Modulus of elasticity(Pa)	Poisson's Ratio	Density (Kg/m3)
Soil	30x30x30	C3D8	4E7	0.3	2000
Box culvert	2X2	C3D4	3.25E10	0.3	2400
Floor Reaction	30X5.22	C3D8	3.25E10	0.3	2400

**Table 2** Single box culvert section size

Inner Size (m)	Width( m)	Height (m)	Length (m)	Thickness		
				Roof (m)	Floor(m)	Side wall (m)
2x2	2	2	2	0.2	0.2	0.18

**Figure 1** Cross section of utility tunnel and its corner numbering

## 2.3 Seismic Load

### 2.3.1 Damping Calculation

Damping source system is difficult to quantify. Damping forces in the structural vibration may come from many sources of the energy loss during hysteretic loading, viscoelastic material properties and external joint friction. Among these damping forces, the resistance form may be different from each other. Damping form called viscous damping is the most widely used, in which the damping force is velocity proportional.[18-20] For seismic actions, usually explicit method will be taken as the first choice in ABAQUS combined with Rayleigh damping. It is considered that the damp ratio of the adjacent longitudinal box culvert is between 2% to 5%. For the first-order vibration modes of the adjacent box culverts, the uniform value of material damping parameters is 5% of the ultimate damping 0.528. According to the orthogonality between the mass matrix and stiffness matrix, the fraction of critical damping of a given mode can be written as obtained to be used as input values. Solve the equations as follows;

$$\xi = \frac{\alpha}{2\omega_1} + \frac{\beta\omega_1}{2} = \frac{\alpha}{2\omega_2} + \frac{\beta\omega_2}{2} \quad (1)$$

$$\alpha = \frac{2\xi\omega_1\omega_2}{\omega_1 + \omega_2}, \beta = \frac{2\xi}{\omega_1 + \omega_2} \quad (2)$$

Where  $\alpha$  is the parameter of mass proportional damping with 1.605 and  $\beta$  is the parameter of stiffness proportional damping with 0.174,  $\omega_{1/2} = 3.04\pi$  which is a frequency measured in rad/s. Its value is the first and second frequency obtained by modal analysis. In general, the mass proportional damping will damp the lower frequencies and the stiffness proportional damping will damp those higher frequencies.[10, 16, 18]

### 2.3.2 Modal Analysis

The main function of the medium modal analysis is to determine the natural frequency and mode shape of the structure, because many dynamic analyses transient dynamics analysis, harmonic response analyses, etc. are based on the results of modal analysis. So that, the basic equations solved by typical undamped modal analysis are classical eigenvalue problems.[10]

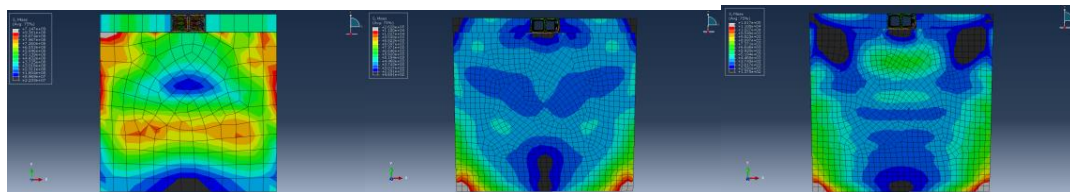
$$K\varphi_i = \omega_i^2 M\varphi_i \quad (3)$$

Where  $K$  is the stiffness matrix;  $\varphi_i$  is the mode shape vector of the first order (eigenvector);  $\omega_i = 2\pi f$  which is the natural frequency of the first order mode ( $\omega_i^2$ ); and  $M$  is the mass matrix.

### 3. Results and Discussion

#### 3.1 Stress analysis of box culvert under earthquake

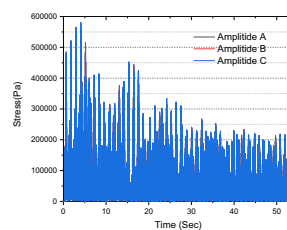
The output database files in ABAQUS were read by visualization module to create contour plots, animations, XY plots, and tabular output of the results. The displacement is not supported by visualization mode, so it is read in data file, which identifies the displacement elements and the level of stress at that point. [21, 22] According to the results of ABAQUS software calculation, the stress of the adjacent longitudinal jointed box culvert is obtained, as shown in Figure 2.



(a) Amplitude A with 53.47sec (b) Amplitude B with 53.73sec (c) Amplitude C with 53.79sec

**Figure 2** The stress time-history for Amplitude A, B and C

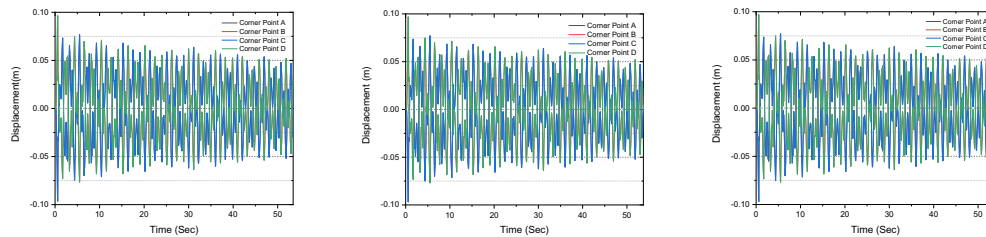
According to Figure 2 (a), that the stress of the box culvert is symmetrically distributed as a whole, but contrary to the front stress distribution, the stress in the box culvert and certain soil parts which indicate the grey zone is large, and the black zone which is located at the foundation soil also small. Thus, the maximum stress indicates the largest absolute value appearing at the box culvert of amplitude A with 577KPa. The black zone has the smallest stress value which is located at the foundation soil. Based on the Figure 2 (b), the maximum stress indicates the largest absolute value appearing at the box culvert of amplitude B with 580KPa. The black zone has the smallest stress value which is located at the foundation soil. Based on the Figure 2 (c), the maximum stress indicates the largest absolute value appearing at the box culvert of amplitude C with 581KPa. The black zone has the smallest stress value which is located at the foundation soil of amplitude C. The following describes the stress of the box culvert under earthquake action of the amplitude A with time period of 53.47sec, amplitude B with time period of 53.73sec and amplitude C with time period of 53.79sec as well as its stress time-history graphs are as shown in Figure 3.



**Figure 3** The stress time-history for Amplitude A,B and C

### 3.2 Deformation analysis of box culvert under earthquake

The adjacent box culvert analyzes the deformation or displacement of the corner point which is called upper and lower part of the displacement time-history. The deformation or displacement of each corner point is calculated by the ABAQUS software. According to the ABAQUS software visualization, the deformation or displacement is positive downward. The following describes the deformation of the box culvert under earthquake action, and its displacement time-history graphs are as shown in Figure 4.



(a) Amplitude A with 53.47sec (b) Amplitude B with 53.73sec (c) Amplitude C with 53.79sec

**Figure 4** The displacement time-history for each corner point and Amplitude A,B and C

According to Figure 4 (a), the displacement distribution of the box culvert parts are different. However, the displacement values on the corresponding corner points of A-C and B-D are much different. The displacement value between the left (Corner point A and C) and right (Corner point B and D) part direction of the amplitude A with time period of 53.47sec is 0.153m. Based on the Figure 4 (b), the displacement value between the left (Corner point A and C) and right (Corner point B and D) part direction of the amplitude B with time period of 53.73sec is 0.154m. Based on the Figure 4 (c), the displacement value between the left (Corner point A and C) and right (Corner point B and D) part direction of the amplitude C with time period of 53.79sec also 0.154m. It is obvious that the deformation of the box culvert is large, and the displacement change is caused by the subsidence of the soil foundation.

### 4. Conclusions

This study developed the seismic effect analysis of the adjacent longitudinal box culvert for the utility tunnel and the following conclusions are drawn;

- A. The seismic stress in the box culvert and certain soil parts are indicated by grey zone. So that, it needs greatest warning zone before failure. This provides great convenience to study the seismic stress distribution of the adjacent longitudinal box culvert structures.
- B. The deformation or displacement of the box culvert is large, and the displacement change is caused by the subsidence of the soil foundation. Because the displacement values on the corresponding corner points are much different.

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