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Research Paper

Numerical Analysis of Trench Blast-Induced Vibration on Tabriz Drinking Water Pipelines

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Abstract: Nowadays, duo to mining and construction activities' progression, the need to utilize blasting has been increasing in order to reduce time and cost. The use of blast for drilling and crushing rock, in addition to its advantages, has disadvantages, the most important of which is ground vibration. Vibration caused by the blast is an important and significant part of the blast process and controling its amount in order to reduce possible damage to the surrounding areas, is always necessary. In this paper, the field data of the blast in the second line of the Tabriz water pipeline project have been collected using three-component Blast Recorder seismographs. By modeling the process of blast in ANSYS-Autodyn finite element software, the behavior of the blast zone environment is simulated. The average of numerical modeling errors compared to field surveys is estimated at about 20%. According to the numerical modeling, the most critical state of velocity entering the pipeline is less than the allowable blast standards near the pipeline, and the maximum stress, strain, and displacement in the boundary of pipe and soil are equal to 17.24 MPa, 135 µmm /mm, and 0.18 mm, respectively.

Keywords: Blasting, Ground vibration, PPV, Water pipeline, ANSYS-Autodyn.

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INTRODUCTION

Various factors which affect ground vibration, are classified into two categories. The first category contains controllable parameters and the second category contains uncontrollable parameters. Uncontrollable parameters include the geology and discontinuities of the region and the composition of the rock mass [1]. Since 1980, the parameter of the peak particle velocity has been accepted as one of the main criteria for evaluating structural damage [2]. Despite the development of more ground vibration prediction methods, distance-scaled empirical equations are still the most popular blast-induced vibration prediction methods as shown in Table 1 [3].

Table 1. The most important equations of ground vibration prediction

Year	Reference	Equation
1962	USBM [4]	$PPV = K \times \left(\frac{R}{Q^{1/2}}\right)^{-b}$
1963	Langefors and Kihlström [5]	$PPV = K\left(\frac{R}{Q^{3/2}}\right)^{b/2}$
1968	Ambraseys and Hendron [6]	$PPV = K\left(\frac{R}{Q^{1/3}}\right)^{-b}$
1973	Bureau of Indian Standard [7]	$PPV = K\left(\frac{Q}{R^{2/3}}\right)^{b}$
1983	Ghosh and Daemen [8]	$PPV = K\left(\frac{R}{Q^{1/2}}\right)^{-b} e^{-\alpha R}$ $PPV = K\left(\frac{R}{Q^{1/3}}\right)^{-b} e^{-\alpha R}$

Xu [9] investigated the dynamic response of the pipe under surface explosion by using a numerical method. He concluded that if the diameter of the pipe is assumed to be constant, as the distance between the explosive material and the pipe increases, the stress in the pipe will decrease, and if the distance between the explosive material and the pipe is assumed to be constant, the pipe with a small diameter will bear more stress. Also, he found that the effect of the distance of the explosive material from the pipe is much more than the diameter of the pipe in the tension created in the pipe [9]. Parviz [10] investigated the stress and pressure caused by the explosion on the pipe buried in the soil using LS-DYNA finite element software. The results of his research showed that the fluid pressure inside the pipe contributes a lot to the stability of the pipe. He concluded that by increasing the density of the fluid inside the pipe, less tension and pressure are introduced into the pipe. Also, by reducing the density of the soil used in the modeling, the behavior of the soil acts like a damper, and less stress and pressure are applied to the pipe [10]. Bakhsandeh [11] investigated the vibrations caused by the explosion and its effects on oil and gas pipelines with a numerical method in Autodyn software. He compared his modeling results with the empirical equations presented in similar geological conditions for limestone and also compared the peak particle velocity obtained from the modeling results with the existing standards for explosions in the vicinity of pipelines. The results showed the good accuracy of the modeling and no damage was done to the pipelines [11].

METHODOLOGY

Geographical location and seismic data collection

Figure 1 shows the location of the explosive trench and the three-component seismographs in relation to the main Tabriz water pipeline during the blasting operation. The aim of the project is to investigate the effects of the vibrations of the second line trench on the first water supply pipeline of Tabriz. The purpose of this arrangement is to fully investigate the effects of vibration on the steel, houses, and the travertine rock mass around the explosion area.

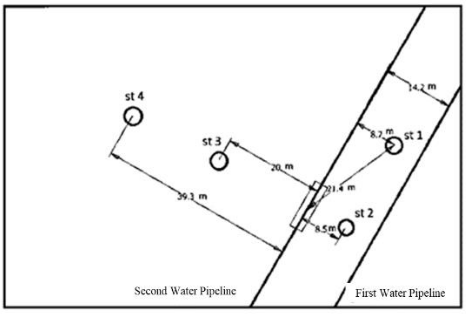

Figure 1. Explosive trench position relative to seismographs

Numerical modeling

The geometry of the main model consists of four sections: rock mass, soil, explosives material and pipe. The shape of the ground is created as a cube with dimensions of 10 x 22 x 45 meters. Figure 2 shows the location of the water pipeline and the soil around it in relation to the explosive trench. The part of the ground filled with compacted soil is modeled with a cube with dimensions of 22 x 22.4 x 4 meters and other parts of the model consist of the rock mass. Explosives were created in the form of holes with a depth of 3 meters and a radius of 51 mm.

In Autodyn software, the JWL equation is used to calculate the volume-pressure relationship of the gas resulting from the explosion. In this relation, the energy released from the explosive material is obtained as equation 1. In this equation A, B, R1, R2 and ω are constant values for each explosive material obtained from the laboratory test. V equals the relative volume of the explosive and E equals the specific energy.

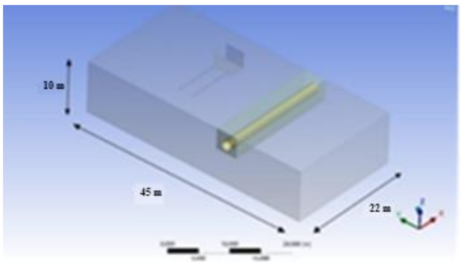

Figure 2. 3D model geometry in ANSYS software

Table 2 shows the geomechanical characteristics of the limestone mass. For this explosion, the wavelength was estimated to be 1.65 meters. By examining the proposed dimensions and after sensitivity analysis of the mesh dimensions and their distributions, the dimensions of the optimal mesh elements for the rock mass and soil were considered to be 25 cm. Solid or shell elements are used for mesh generation of rock masses, soil and explosives, and shell elements are used for pipes. A 10 cm square element is used to mesh the pipe. In Autodyn software, impedance boundaries or transmit boundary are used so that the waves do not reflect inside after hitting the wall of the model and do not cause errors. This boundary condition is applied to the parts of the block that are not free.

Table 2. Geomechanical characteristics of the limestone [12]

Rock mass parameter	Unit	Value
Density	Kg/m3	2680
Elastic modulus	GPa	34
Poisson ratio	-	0.3
Shear modulus	GPa	13.3
Bulk modulus	GPa	25.7

Findings and argument

According to the investigated parameter of the peak particle velocity, the diagrams of velocity- time for three radial, tangential and vertical components have been extracted at a distance of 14.2 meters from the center of the explosion and on the pipeline and are shown in Figure 3.

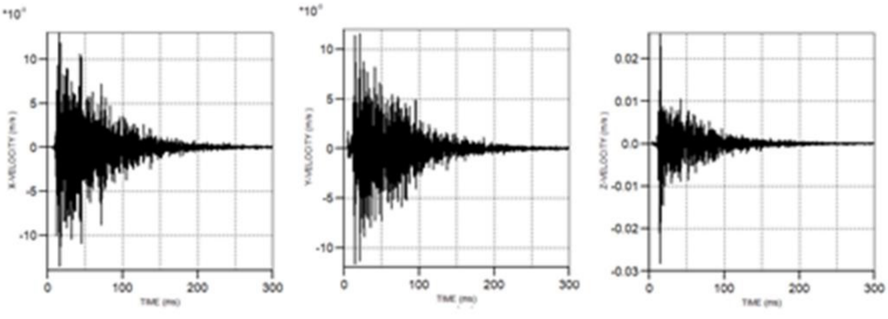

Figure 3. Diagrams of velocity - time of radial, tangential and vertical components at 14.2 meters' distance from the explosion center in numerical modeling

After solving the main models of the first explosion, the effects of the explosion on the pipeline were investigated. Figure 4 shows the diagrams of maximum stress, strain and displacement caused by the first explosion.

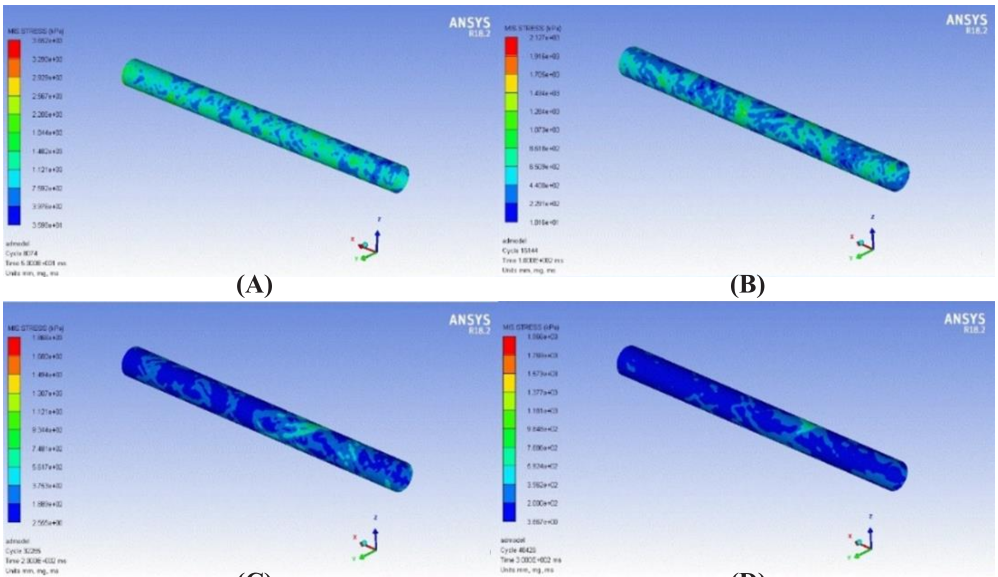

Figure 4. Effective stress (Von Mises) in the pipeline with time in the first explosion after the passage of **A:** 50 ms, **B:** 100 ms, **C:** 200 ms, **D:** 300 ms

CONCLUSIONS

In this paper, after the field sampling of the explosion and the analysis of its results, explosion modeling was done in ANSYS-Autodyn finite element software. These modelings were done in a continuous environment consisting of rock mass and soil without considering their discontinuities. Numerical modeling was done to validate the model and correct propagation of waves and compare them with the results of seismic data. The results obtained from the numerical model showed an average error of about 20%. The peak particle velocity at a distance of 14.2 meters from the explosion center and on the pipeline is calculated to be around 30 mm/s. The explosion results showed that the maximum stress, strain, and displacement at the pipe boundary and its surrounding environment are 17.24 MPa, 135 µmm/mm, and 0.18 mm, respectively.

According to the peak particle velocity obtained and also the stress results checked on the pipeline, it can be said that the amount of explosive material and also the explosion pattern used are suitable and the pipes are not damaged due to the explosion.

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