Explosion Dynamic Response Analysis of Loess Double-Line Tunnel Considering Ground Stress

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Abstract. Based on the coupled Euler-Lagrange (CEL) algorithm, the numerical simulation model of free air field and small clear distance two-line tunnel explosion in loess is established. The reliability of the numerical model is verified by the comparison between the air-field air explosion and the traditional empirical formula. The results show that when the scale distance is greater than 0.3m/kg $^{1/3}$, the numerical simulation results agree well with the empirical formula. When CEL explodes, measuring points are arranged at the invert, soffit and arch of the tunnel, and the speed, acceleration and stress quickly reach the peak and constantly oscillate, and the attenuation speed is rapid and the attenuation degree is fast. When CEL explodes at the arch, the effect of shock wave is very weak, and the measuring point closest to the explosion source has the most obvious response, and the stress concentration is relatively obvious at the arch Angle.

Keywords: Euler-Lagrange coupling; Explosive impact; Numerical simulation

1 Introduction

In recent years, domestic and foreign scholars have done a lot of research on the dynamic response of tunnel explosion, the main parameters include the displacement [1], strain [2], acceleration [3], velocity [4] and so on. Gao Jinjin et al. [5] found the weakening effect of segment joints on tunnel structural stiffness and integrity, and proposed protective measures. Through numerical simulation, Luo Gang et al. [6] Based on Cole shock wave semi-empirical formula, Vernon bubble motion equation and D'Alembert principle, carried out research on underwater explosion and suspended tunnel under moving load. Zhou et al. [7] verified the reliability of finite element simulation through tunnel scale model and LS-DYNA software. Inan Keskin et al. [8] verified the impact of surface explosion on underground tunnels through finite element method FEM, which can predict the pressure and settlement of lining when tunnels are subjected to surface impact loads. Yang et al. [9] used CEL numerical simulation method to study the dynamic behavior and damage evolution law of undersea tunnel under explosion load. Wu Weichao et al. [10] used finite element software and full scale experiment to study the damage of the specimen through multi-point collaborative explosion. Zhao Debo et al. [11] verified the agreement between the numerical simulation and the traditional

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empirical formula by using the dynamite-air-structure-soil fluid-structure coupling model, and mapped the structure of the one-dimensional axismetrical model to the three-dimensional coupling model, and found the propagation law of eccentric explosion damage at the near and far explosion ends and shock waves.

In order to better predict the variation law of tunnel explosion structure stability and post-disaster protection measures, CONWEP and coupled Euler-Lagrange(CEL) algorithm in ABAQUS and explicit dynamic analysis were used to simulate the response of a double-line tunnel on loess under the action of a single hole accidental explosion. The reliability of the numerical simulation is verified by comparing the overpressure time history with the traditional empirical formula, and the CONWEP method and CEL method are compared and analyzed. Finally, the response characteristics of highway tunnel under explosion load are studied.

2 Simulation of Explosion Process in Free Air Field

2.1 Model Establishment and Material Parameter Setting

In this section, a numerical model of 1/8 free air field explosion is established based on ABAQUS software. Euler components are used for explosives and air domains. The explosive size is defined as 0.3m×0.3m×0.3m, which is converted to 44.31kg TNT. The asymmetric boundary surface of the model is non-reflective boundary condition, and the symmetric boundary surface is symmetric boundary condition, and the material assignment is carried out at the same time.

In the ABAQUS software, TNT adopts JWL simulation, and the material parameters are shown in Table 1. the air adopts the ideal gas equation of state，The specific material parameters are shown in Table 2.

Table 1. JWL state equation parameters for TNT explosives

arg	$\rho/(g\cdot cm^{-3})$	$v_D/(m\cdot s^{-1})$	A / Pa	B / Pa	ω	R_1	R_2
TNT	1650	6930	$3.73e^{11}$	$3.74e^{9}$	0.35	4.15	0.9

Table 2. Ideal gas equation of state parameters

Stats	$\rho/kg\cdot m^3$	R	P/kPa	$C/(J/(kg\cdot c^0)$	$\eta/(M\cdot s/m^2)$
Numerical	1.23	287	101	718	1.85e-5

2.2 Numerical Simulation Results and Analysis

In order to study the propagation law of shock wave, measuring points A, B, C, D (detonation center distance is 0.5m,1 m,2 m,3m) are selected. The overpressure curve is shown in Fig. 1, the comparison diagram of empirical formulas is shown in Fig. 2.

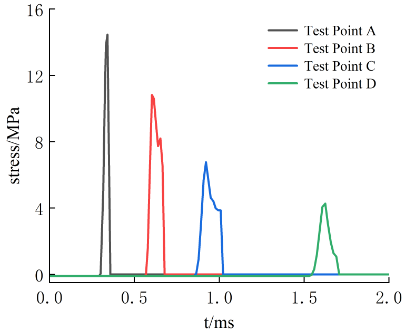


Fig. 1. Pressure time history curve under different burst distance conditions

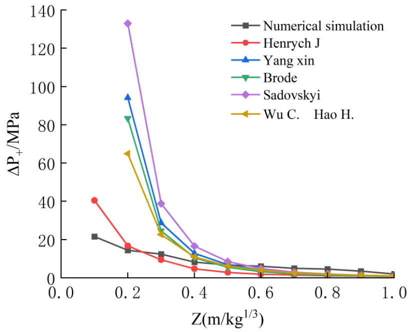


Fig. 2. ΔP+-Z curve comparing numerical simulation with empirical formula

As can be seen from Fig. 1, when the shock wave has not reached the measuring point, the overpressure of each point is 101kPa atmospheric pressure of air. When the shock wave reaches the measuring point, the overpressure rapidly increases to the peak value, and then rapidly decreases to 0. The overpressure of the explosion shock wave is negatively correlated with time. As can be seen from Fig. 2, when the proportional distance is less than 0.3m/kg$^{1/3}$, the numerical simulation results are smaller than the empirical formula; when the proportional distance is greater than 0.3m/kg$^{1/3}$, the numerical simulation results are in good agreement with the empirical formula, and with the increasing of the proportional distance, the results are closer to the empirical formula. It provides the feasibility for the following loess tunnel explosion.

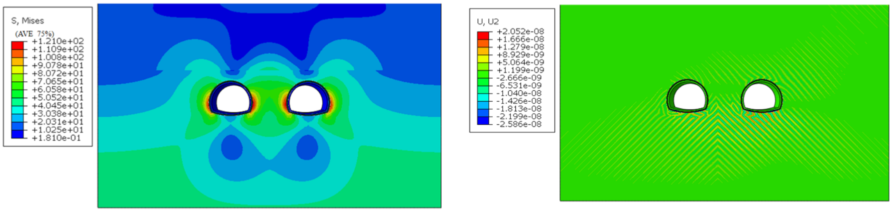
3 Tunnel Profile and Geostress Balance

In this paper, taking a loess tunnel from Yinchuan to Kunming highway as an example, the finite element ABAQUS numerical simulation is used. The primary lining of the tunnel uses C20 concrete, the thickness of the primary lining is 25cm, the second lining of the tunnel uses C25 concrete, the thickness of the second lining is 50cm, the upper layer of the loess is Malan loess, the thickness of the surrounding rock is 20m, and the lower soil is Shizhu loess, the thickness of the surrounding rock is 40m. The tunnel distance of the double-line tunnel is 1D, and the surrounding rock and lining are both Mohr-Coulomb model. The specific material properties are shown in Table 3.

Table 3. Finite element model parameter settings

Materials	E/MPa	ν	ρ/kg·m³	C /kPa	φ(°)
Malan loess	150	0.38	1800	28	23
Lishi loess	240	0.39	1900	41	24
C20	20000	0.20	2400	30	36
C25	28000	0.25	2400	30	36

In-situ stress equilibrium is to make the model only subject to INITIAL stress in the initial analysis step, with no initial strain or very small initial strain. When the initial strain reaches 10^{-4}m, the equilibrium result is better. The result of in-situ stress balance is shown in Fig. 3. The maximum displacement value is 2.052×10^{-8}m, the initial stress is 121Pa, and there is obvious stress concentration at the corner of the tunnel. In summary, the result of ground stress balance is good.

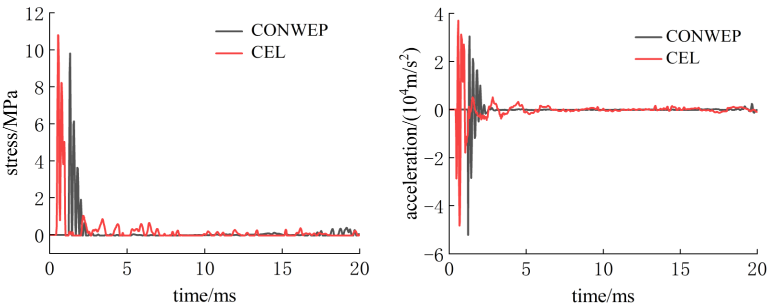


(a) Mises stress nephogram (b) Displacement nephogram

Fig. 3. Results of initial in-situ stress equilibrium

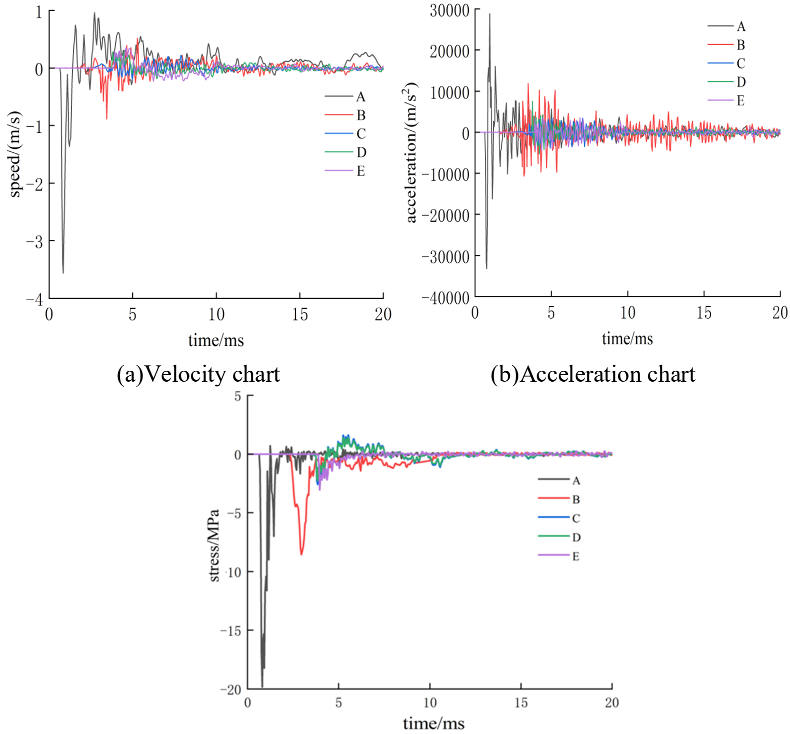
4 CONWEP and CEL Methods Were Compared and Analyzed

The CONWEP method does not need to consider the stiffness and inertia of the air. In the interaction module, TNT explosive yield, explosion type, initiation reference point and initiation point action reference surface are defined. The time history curve of explosion shock wave overpressure in CONWEP algorithm decreases exponentially. In CEL algorithm, Lagrange grid is used to model surrounding rock and lining, and Euler network is used to model TNT and air. TNT-Air, air - lining, lining - surrounding rock are automatically calculated and tracked using a penalty contact algorithm. The surrounding rock adopts symmetric boundary constraints and fully fixed constraints, and the Euler boundary is set as the non-reflective boundary of outflow.The dynamic response of lining was compared by CONWEP method and CEL method, as shown in Fig. 4. Research is also conducted from the center of blasting floor A, arch Angle B, arch waist C, D and arch top E, as shown in Figure 5.



(a) Overpressure diagram (c) Acceleration graph

Fig. 4. Comparison of the two explosion modes



(a)Velocity chart (b)Acceleration chart

(c)Stress chart

Fig. 5. Deformation characteristics and response rules of different measuring points

The CEL method is faster, 0.6ms faster than the CONWEP method, but the calculation time is doubled. However, there is a small difference in the peaks of overpressure, stress and acceleration between the two. The explosion shock wave first propagates to point A, and the response at point A is the most significant. For example, the velocity reaches 3.56m/s at 0.84ms, and the acceleration reaches 33196m/s^2 at 0.762ms. The stress reaches 19.80MPa at 0.80ms. Then the shock wave reaches the left and right soffit position and finally propagates to the vault position. In this process, each parameter continuously oscillates and becomes stable with the passage of time.

5 Conclusion

Based on CONWEP and Euler-Lagrange (CEL) algorithm, a numerical model of accidental explosion in a single hole of loess tunnel was established, and the time-history analysis dynamic response of tunnel lining was studied. It plays an important role in the anti-explosion performance of tunnel structure and the explosion-proof design of underground space. The following conclusions are drawn:

(1) Compared with the traditional empirical formula, when the proportional distance is less than 0.3m/$kg^{1/3}$, the numerical simulation results are smaller than the empirical

formula; When the proportional distance is greater than 0.3m/kg $^{1/3}$, the numerical simulation results are in good agreement with the empirical formula.

(2) After the ground stress is balanced, CEL explosion overpressure, stress and acceleration response time of 0.6 ms slightly faster than CONWEP method, but the difference between fluctuation trend and peak is smaller. Measuring points are arranged at the invert, soffit and vault, and it can be seen that the velocity, acceleration and stress rapidly peak and constantly oscillate. The measuring point closest to the explosion source has the most obvious response, and the stress concentration is relatively obvious at the arch Angle, and the attenuation rate and degree of each parameter are rapid. When the shock wave reaches the vault, the effect of shock wave is very weak.

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