Evaluation Study on the Interaction Between Underground Water-Sealed Cavern and Above-Ground Storage Tanks

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Abstract. During the blasting excavat.ion process of the underground cavern, the layers below the top arch layer are usually excavated with vertical holes in the ladder section. Based on the dynamic theory of blasting impact, the finite element analysis software ls-dyna and COMSOL are used to determine the dangerous points in the process of open-cut and under-cut and the blasting point with the greatest impact on the building according to the design scheme of ground storage tanks and buildings, and establish a blasting analysis Numerical model The vibration amplitude of the ground storage tank and the dynamic response of the storage tank during the blasting process of the maximum explosive quantity were analyzed, and the deformation and stress distribution of the foundation and storage tank were obtained; the maximum amplitude of the building during the blasting and excavation process was further analyzed, Evaluate the reliability of the blasting excavation process of buildings in underground caverns.

Keywords: underground cavern · Oil storage tank · Blasting · Evaluation of safety

1 Introduction

In the process of large underground cavern blasting excavation, in order to adapt to the rapid and mechanized construction requirements, the layers below the top arch layer are usually excavated by ladder vertical hole blasting, single cycle blasting volume is large, blasting generated by seismic waves will have an impact on the safety of ground facilities (storage tanks and buildings).

The current research on the dynamic response of the structure under blast loading, including the effect of blast on the tank, has been carried out by domestic and foreign scholars, and mostly focused on the engineering background conditions such as tunnel, foundation and slope, mainly through theoretical calculations, numerical simulations and field test observations [1–9]. Due to the transient nature of the explosion conditions,

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researchers mostly use finite element software, such as ANSYS, LS-DYNA, MIDAS GTS, FLAC 3D, etc., to restore the real scenario, and Li Bo [10] combined the numerical calculation data with the actual measurement results of the storage tank explosion to analyze and confirm the correctness of the finite element model. Due to the variability of the storage tank structure and the related literature mainly deals with the nature of explosives, blast wave propagation characteristics, explosion risk and safety evaluation system, and the dynamic response of the storage tank body under the action of blast load [11–20].

For the problem of the impact of underground blasting excavation on existing buildings above ground, scholars at home and abroad have continuously conducted studies [21–23].

2 Analysis of the Impact of Blasting Excavation on Above-Ground Storage Tanks

Therefore, this paper applies the finite element analysis software ANSYS and COMSOL to this problem, determines the hazard points of open and concealed excavation process according to the design plan of above-ground storage tank and the alignment of the tunnel, numerically simulates the blasting process, analyzes the dynamic response of storage tank and above-ground building under the effect of foundation vibration caused by blasting, and evaluates the safety of above-ground storage tank and building under the effect of blasting excavation of underground cavern.

COMSOL was used to numerically simulate the generation and propagation of seismic waves during blasting excavation, extract the surface displacement and amplitude of the ground storage tank, and import the corresponding data into the finite element software ANSYS as a dynamic load applied to the ground storage tank foundation, and consider the common influence of hydraulic static load and self-weight to analyze the dynamic response of the ground storage tank and evaluate its safety.Three analysis points were selected as shown in Fig. 1 to carry out the numerical simulation of blasting and dynamic response analysis of the above-ground storage tank.

The propagation law of blasting vibration waves in rock media is greatly influenced by the characteristics of media and charging parameters, and is very much influenced by topography and geomorphology, and the number of free surfaces also has a large

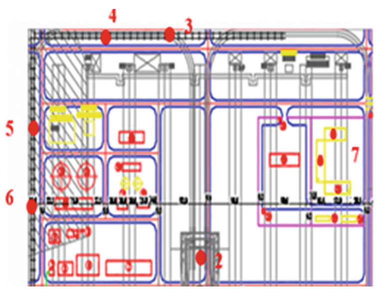

Fig. 1. Roadway blasting measurement point layout

influence on propagation. According to the propagation law of blasting vibration wave, when rock blasting adopts column charge or extended charge, the blast stress wave propagated in the rock is column surface wave. A shock wave is formed in the rock near the charge chamber, and as the shock wave propagates outward. Stress amplitude continues to decay, wave speed decreases, and finally evolves into a stress wave, and the further propagation and decay of the stress wave, and evolves into a seismic wave.

Columnar packet explosion generated hole wall pressure pulse, after attenuation formed on the excavation surface of the dynamic load, hole wall pressure according to the impedance matching method of uncoupled charge. The dynamic load on the excavation surface is

$$P = 0.25 * Pb(t)/L_1^2 \tag{1}$$

included, $Pb(t) = P_0 e^{-\gamma \frac{t}{t_0}} \sin(\frac{4\pi}{1+t_0/t})$;

$L_1 = 1\text{m}$ is the range of load action;

Due to the large size of the underground cavern vault, a two-dimensional plane stress model of the underground cavern vault was established to shorten the calculation time, and the finite element software COMSOL was used for the numerical simulation analysis of explosive detonation and seismic wave propagation.

2.1 The Effect of Blasting on Above-Ground Storage Tanks at Measurement Point 2

For the location of measurement point 2, the depth of the source is 10m, the minimum linear distance between the source and the ground storage tank is 389m. According to the geotechnical survey data of the underground cavern reservoir, the numerical model for blasting analysis of the location of measurement point 2 of the underground cavern reservoir is established as shown in Fig. 6.

The numerical model for blast analysis at location 2 of the above ground cavern reservoir is shown in Fig. 2. The complete model mesh contains 73,305 domain cells and 5,441 boundary elements, with a dense mesh at the blast point and in the rock layer around the tank. Boundary loads and constraints are applied at each boundary and the transient solver time step is 2e-6s, giving a total solution time of 0.5s. Linear cells are used to reduce the numerical dispersion of the wave front.

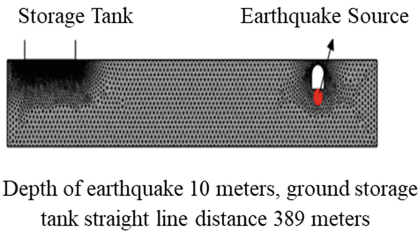

Fig. 2. Numerical model for blast analysis at location 2 of the above-ground cave vault measurement point

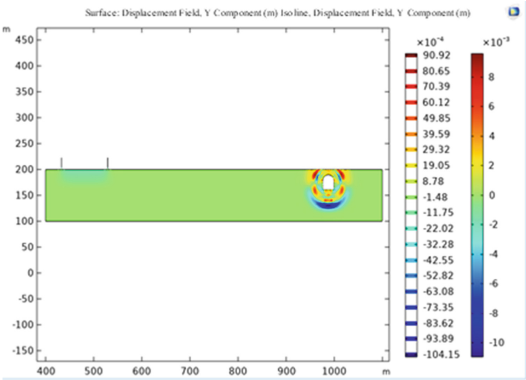

Fig. 3. Cloud plot of ground displacement from blasting at a typical moment (t = 0.42s)

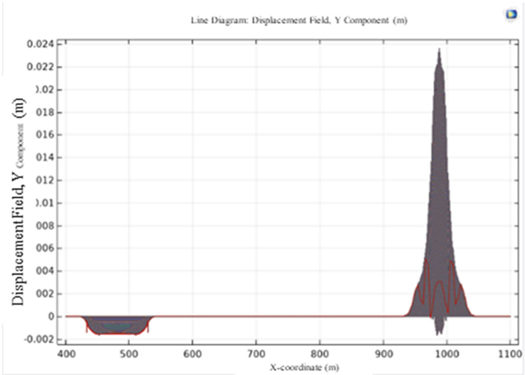

Fig. 4. Distribution of surface displacements at typical moments (t = 0.42s)

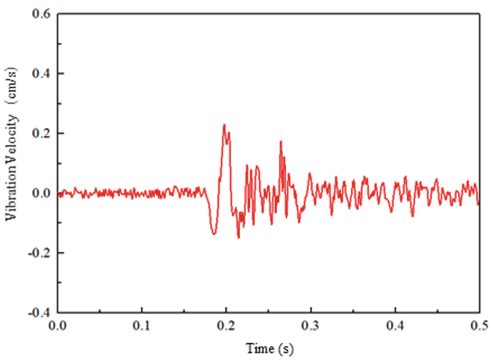

Fig. 5. Vibrational velocity of tank foundations at location 2 in the above ground cavern

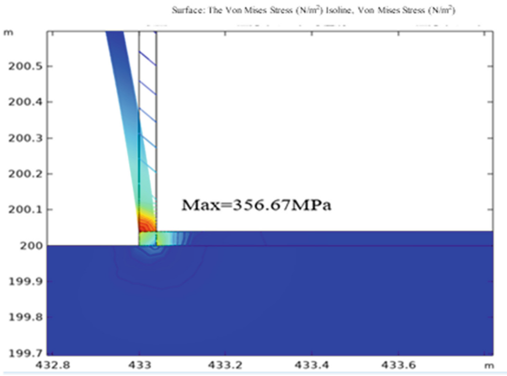

Fig. 6. Stress distribution cloud at tank weld location

The Blasting Safety Regulations use the magnitude of the longitudinal wave velocity as the basis for determining structural vibration damage, so by extracting the ground displacement from the blasting at different moments as shown in Fig. 3, the surface displacement and amplitude distribution of the storage tank at measurement point 2 as shown in Figs. 4 and 5 were obtained. From the figure, it can be obtained that the maximum vibration velocity generated by the tank during the blasting open excavation of the underground cavern (depth 10m) is 0.23cm/s, and the maximum longitudinal displacement generated by the tank is 0.18cm.

As the maximum stress in the ground storage tank is located in the bottom of the tank weld position, so directly establish a two-dimensional plane stress numerical model, analysis to obtain the maximum Mises stress in the stress concentration, consider the oil pressure and the self-weight of the pipe wall and other static loads, and the displacement load applied to the bottom of the tank, analysis to obtain the tank weld position as shown in Fig. 6 stress distribution cloud, the maximum stress in the tank is 356.67MPa. m^2.

2.2 The Effect of Blasting on Above Ground Storage Tanks at Measurement Point 3

For the location of measurement point 3, the depth of the source is 22.3m and the minimum linear distance between the source and the above ground storage tank is 48m. Based on the geotechnical survey data of the underground cavern, a numerical model for the blast analysis of the location of measurement point 3 is established as shown in Fig. 7.

Figure 7 shows the numerical model for the blast analysis at location 3 of the above-ground cavern reservoir measurement point. The complete model mesh contains 74,483 domain cells and 5,419 boundary elements, with a dense mesh at the blast point and in the rock layer around the tank. Boundary loads and constraints are applied at each boundary and the transient solver time step is $2e^{-6}$s, giving a total solution time of 0.5s. Linear cells are used to reduce the numerical dispersion of the wave front.

By extracting the ground displacements generated by blasting at different moments as shown in Fig. 8, the surface displacements and amplitude distributions at the location

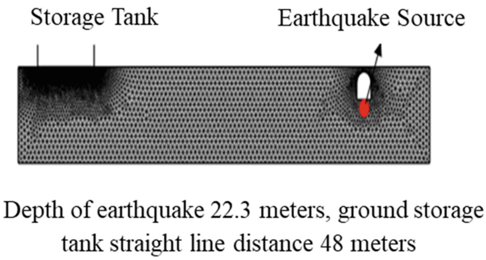

Fig. 7. Numerical model for blast analysis at location 3 of the above ground cave vault measurement point

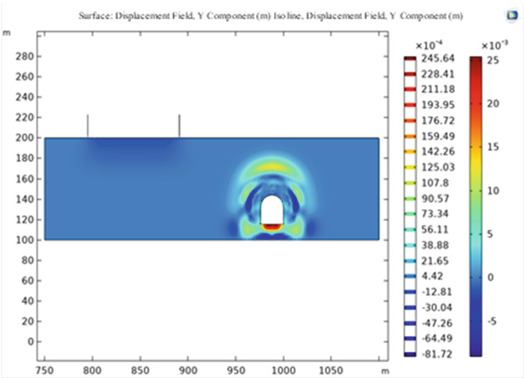

Fig. 8. Cloud of ground displacement from blasting at a typical moment (t = 0.48s)

of the storage tank at measurement point 3 as shown in Figs. 9 and 10 were obtained. From the figure, it can be obtained that the maximum vibration velocity generated by the tank during the blasting and concealed excavation of the underground cavern (depth 22.3m) is 1.26cm/s and the maximum longitudinal displacement generated by the tank is 0.68cm.

As the maximum stress of the ground storage tank is located in the bottom of the tank weld position, so directly establish a two-dimensional plane stress numerical model, analysis to obtain the maximum stress concentration Mises stress, consider the oil pressure and self-weight of the pipe wall and other static loads, and in the bottom of the tank displacement load, analysis to obtain as shown in Fig. 11 tank weld position stress distribution cloud, the maximum stress of the tank is 402.71MPa.

2.3 The Effect of Blasting on Above Ground Storage Tanks at Measurement Point 4

For the location of measurement point 4, the depth of the source is 33.5 m, the minimum linear distance between the source and the above-ground storage tank is 48 m. According to the geotechnical survey data of the underground cavern, the numerical model for

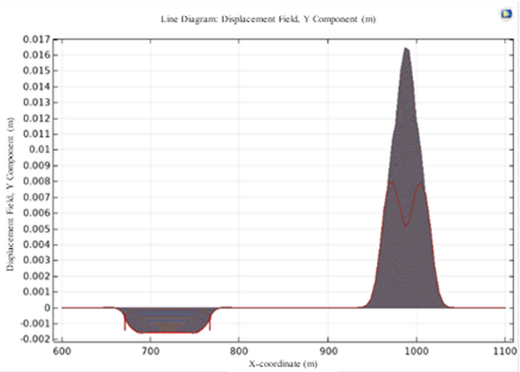

Fig. 9. Distribution of surface displacements at typical moments (t = 0.48s)

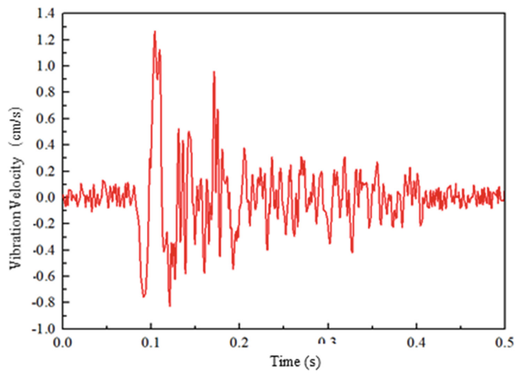

Fig. 10. Vibrational velocity of tank foundations at location 3 in the above ground cavern

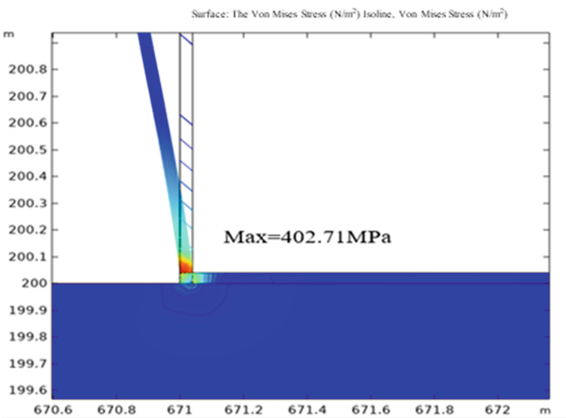

Fig. 11. Stress distribution cloud at tank weld location

blasting analysis of the location of measurement point 4 of the underground cavern is established as shown in Fig. 12.

The numerical model for the blast analysis at location 4 of the above ground cavern reservoir is shown in Fig. 12. The complete model mesh contains 74828 domain cells and 5418 boundary elements, with a dense mesh at the blast point and in the rock layer around the tank. Boundary loads and constraints are applied at each boundary and the transient solver time step is $2e^{-6}$s, giving a total solution time of 0.5s. Linear cells are used to reduce the numerical dispersion of the wave front.

By extracting the ground displacements generated by blasting at different moments as shown in Fig. 13, the surface displacements and amplitude distributions at the location of the storage tank at measurement point 4 as shown in Figs. 14 and 15 were obtained. From the figure, the maximum vibration velocity generated by the tank during the blasting and concealed excavation of the underground cavern (depth 33.5m) is 0.89cm/s and the maximum longitudinal displacement generated by the tank is 0.56cm.

As the maximum stress in the ground storage tank is located in the bottom of the tank weld position, so directly establish a two-dimensional plane stress numerical model, analysis to obtain the maximum Mises stress in the stress concentration, consider the oil

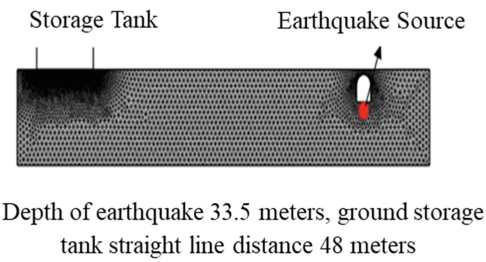

Fig. 12. Numerical model for blast analysis at location 4 of the above-ground cave vault measurement point

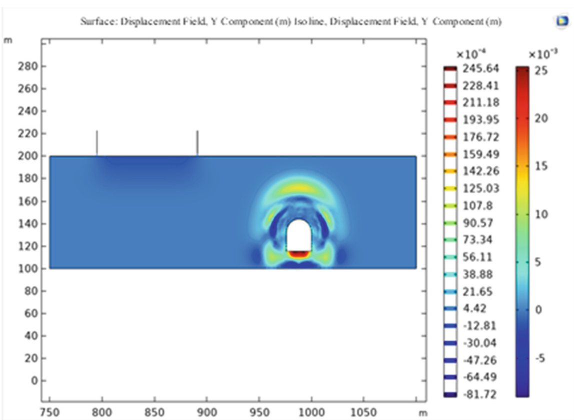

Fig. 13. Cloud of ground displacement from blasting at a typical moment (t = 0.41s)

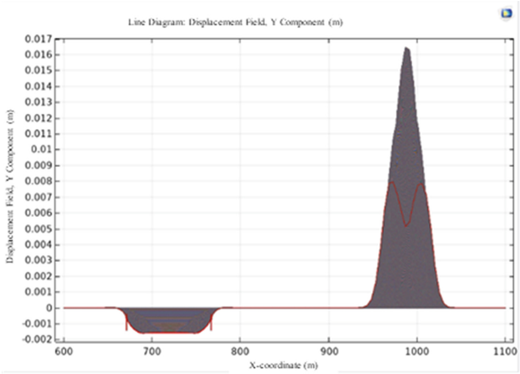

Fig. 14. Distribution of surface displacements at typical moments (t = 0.41s)

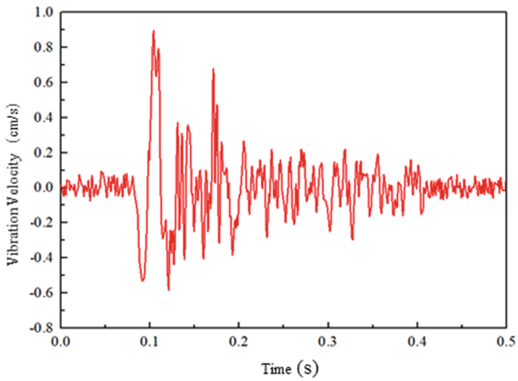

Fig. 15. Vibrational velocity of tank foundations at location 4 in the above-ground cavern reservoir

pressure and the self-weight of the pipe wall and other static loads, and the displacement load applied to the bottom of the tank, analysis to obtain the tank weld position as shown in Fig. 16 stress distribution cloud, the maximum stress in the tank is 388.37MPa.

3 Analysis of the Impact of Blasting Excavation on Ground Level Buildings

In order to study the effect of blasting excavation of the underground cavern on the surface buildings (dormitory building, canteen, general building, fire fighting complex, etc.), the method used in the previous chapter was used to analyse the peak surface vibration velocity at the location of the buildings during the blasting process. With reference to the safe permissible vibration velocities specified in the Blasting Safety Regulations, a maximum vibration velocity of 2.7cm/s was obtained for the surface buildings.

The results of the vibration velocity analysis for the seven measurement points are shown in Figs. 17–19. From the graphs, the maximum surface velocity at measurement point 2 is 1.12cm/s, with a building safety factor of 2.41; the maximum surface velocity

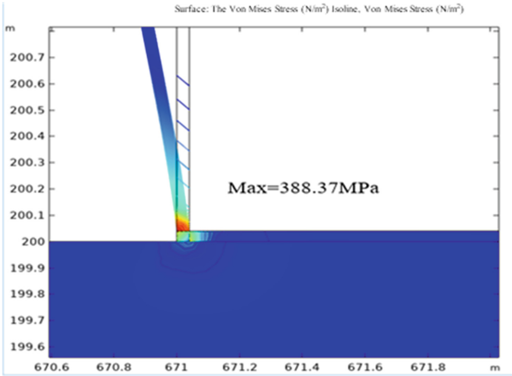

Fig. 16. Stress distribution cloud at tank weld location

at measurement point 3 is 0.72cm/s, with a building safety factor of 3.75; the maximum surface velocity at measurement point 4 is 0.57cm/s, with a building safety factor of 4.73.

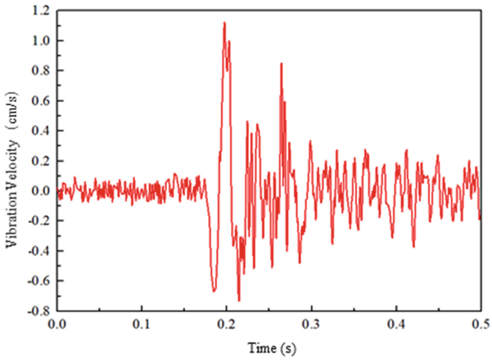

Fig. 17. Foundation vibration velocity at location of ground building measurement point 2

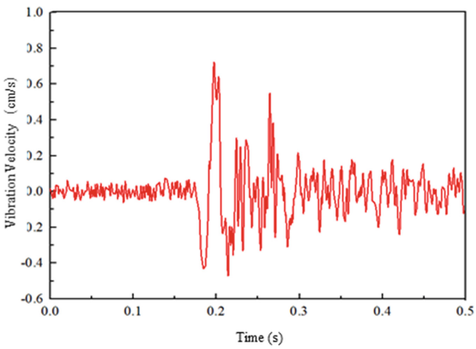

Fig. 18. Foundation vibration velocity at location 3 of the ground building measurement point

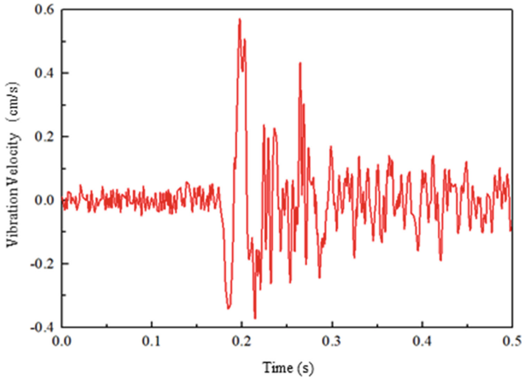

Fig. 19. Foundation vibration velocity at location 4 of the ground building measurement point

4 Evaluation of the Impact of Blasting Excavation on Above-Ground Storage Tanks and Buildings

Through the above analysis can be obtained from the underground cavern blasting excavation on the ground storage tank and building impact evaluation results. The ground storage tank location ground vibration velocity peak of 1.26cm/s,the maximum longitudinal displacement of the tank foundation is 0.68cm. Tank structure additional Mises stress of 63.25MPa, taking into account the combined effect of the tank's own gravity and hydrostatic load, the ground storage tank in the tank bottom and According to the ground tank design data, the allowable stress at the bottom of the tank and pipe wall welding is 490MPa, so the safety factor of the tank under blasting excavation and its own static load is 1.22, which is greater than the allowable safety factor of 1.15, so the tank is safe.

For above-ground buildings (canteen, dormitory building, complex building and other structures), the peak surface vibration velocity generated under the action of blasting seismic waves is 1.12 cm/s. According to the Blasting Safety Regulations, it is known that the maximum vibration velocity safely allowed for this type of buildings is 4.2 cm/s. Therefore, each building is safe with a minimum safety factor of 3.75.

It is recommended that real-time vibration monitoring be carried out during construction blasting, a detailed blasting plan for the cave bank be formulated according to the construction progress and allowable safe vibration speed of the surrounding facilities, the construction blasting charge be controlled in strict accordance with the specification requirements, and the blasting plan be adjusted and optimized in a timely manner according to on-site vibration monitoring to ensure that the vibration impact on the nearby facilities meets the allowable safe vibration speed required by the Blasting Safety Regulations and other standards.

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