Analysis of the Influence of Underground Traffic Tunnels by the Explosion Seismic Effect of the Storage Yard

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Abstract. The dynamic response of the existing deep underground traffic tunnel under the seismic effect of dangerous goods explosion is an important issue that should be actively considered before the construction of the container yard. In order to ensure the safety of the tunnel, this paper first introduces the goods to be stored in the newly built container yard of dangerous goods and their dangerous characteristics. Then, the vibration response of the tunnel wall under the explosion of 1 t, 2.6 t and 6 t TNT is simulated by using Midas GTS finite element analysis software. When the explosive equivalent is 2.6 t, the vibration speed of the tunnel wall is in a safety critical state. The simulation results provide reference suggestions for the types of engineering design stockpiles and limited stockpiles and control the influence of dangerous goods container yard on traffic tunnel from the source.

1. Introduction
With the rapid development of the national economy and society, China is in a period of large-scale construction. New projects should consider the impact on completed projects when selecting sites for construction. When the site selection of dangerous project construction is unreasonable, there will be potential safety hazards. If it is serious, the project will be forced to stop production and relocation, resulting in serious waste of resources. This situation is also inconsistent with the concept of social development today. Due to the imperfection of relevant laws and regulations in China, there is a lack of legal basis for the design of location, category and quantity of dangerous goods container yard, which brings great difficulties to the design and construction of the yard. Therefore, it is very important to carry out quantitative risk assessment before the construction of dangerous goods container yard project, control the risk from the source, and ensure the safety of production.

Based on the analysis of the ground motion characteristics of underground explosion, Jie Li, et al. [1] analyzed and discussed the evaluation criteria of the seismic effect of underground explosion and established the calculation model of ground motion of underground explosion and vibration response spectrum. Donald G. Albert, Shahram Taherzadeh, et al. [2] measured the seismic signals generated by the near-surface explosions of various ground types of explosives and showed two different ground shock waves. With the development of computer technology and the development and improvement of dynamic finite element program, many scholars have used dynamic finite element software to simulate tunnel blasting vibration effect, and achieved good results. Jihong Bi, et al. [3] used the basic theory of finite element and ANSYS software to study the influence of blasting vibration on the existing tunnel. Zhongyun Chen [4] used ANSYS/LS-DYNA to analyze the impact of deep foundation pit blasting and excavation on the adjacent existing tunnel structure. Controlling the impact of blasting vibration on adjacent tunnels is a key technical issue in the construction of water conservancy, railway, and...
transportation projects. The blasting particle vibration velocity control standards are highly empirical, and the safe vibration velocities given by different standards are quite different, so further research and exploration are needed in this regard.

2. Project Introduction
The container yard was built in 2015, and all dangerous goods containers are loaded and unloaded from the front terminal. In order to meet the storage needs of dangerous goods containers, it is planned to build a new dangerous goods container yard behind the terminal. According to the survey data, the traffic tunnel is located at the depth of 56.5 m directly below the construction area of the project. The diameter of a single tunnel is 12 m, and the two tunnels are parallel. The center distance of the tunnel is about 21.5 m, and the double lining protection is adopted. The stratum where the tunnel is located is highly permeable, and if the tunnel is damaged, the consequences of a flood accident will be disastrous. Therefore, it is very important to ensure the safety of traffic tunnels during the operation of the container yard.

3. Types of Stored Goods and Their Dangerous Characteristics
The newly-built storage yard is planned to store all kinds of flammable liquids, liquid desensitization explosives, solid desensitization explosives and other high-risk substances. Examples of typical dangerous goods to be stored in the yard are shown in table 1.

| Commodity Name                        | UNNO  | Corresponding explosives         |
|---------------------------------------|-------|----------------------------------|
| Ammonium picrate, wet,                | 1310  | Ammonium picrate                 |
| Water content by mass not less than 10%|       |                                  |
| Trinitrobenzene, wet,                 | 1354  | Trinitrobenzene                   |
| Water content by mass not less than 30%|       |                                  |

The goods listed in table 1 are typical solid desensitized explosives. Solid desensitized explosives are a homogeneous solid mixture formed by moistening the explosive substance with water or alcohol or diluting the explosive substance with other substances in order to suppress the explosive properties of explosive substances. When the packaging of the goods is damaged and the explosive substances such as water or alcohol volatilize, the goods can explode under certain conditions. Explosives exploded on the surface and instantly transformed into high temperature and high pressure products. The explosion product expands in the air and compresses the air strongly to form the blast air shock wave. At the same time, it loads the surrounding medium and produces a group of outward propagating stress waves. The stress wave propagating in the geological medium will cause seismic waves in a certain range [5]. Seismic waves include: longitudinal compression wave (P wave), longitudinal sparse wave (N wave), shear wave (S wave) and Rayleigh surface wave (R wave) [5].

4. Explosion Numerical Simulation Analysis
4.1. Software and Model Building
Midas GTS (Geotechnical and Tunnel Analysis System) is a kind of finite element analysis software for geotechnical and tunnel structure developed by organically combining the universal finite element analysis kernel with the professional requirements of geotechnical structures [4]. The software is suitable for seepage analysis, consolidation analysis, dynamic analysis and other environments. The project mainly uses its dynamic analysis function for numerical simulation. This function includes: dynamic analysis of any load such as earthquake and blasting, modal analysis, response spectrum analysis, time history analysis, including seismic wave database, automatic generation of seismic waves, and combined functions of static analysis results [6]. Explosion is a complex instantaneous process. Due to the complexity of the explosive mechanism and its influencing factors, there is
currently no effective measurement method and it is impossible to accurately determine every detail of the explosion process. According to the relevant empirical formula and the monitoring results of blasting vibration, the size and attenuation of the explosion shock wave are inferred. The usual practice in numerical simulation is to assume that the blasting input load is a triangular pulse wave \[ 7 \].

The load form needs to determine the peak load and the action time of the blasting load. The peak pressure acting on the hole wall is as follows equation (1) \[ 8-9 \]:

\[
P_r = \frac{n \rho_e d_c^2}{2(k+1)} \left( \frac{d_c}{d_b} \right)^{2k}
\]

In the equation, \( P_r \) is the peak pressure of the hole wall; \( \rho_e \) is the explosive density; \( D \) is the explosive detonation velocity; \( d_c \) is the charge diameter; \( d_b \) is the blast hole diameter; \( k \) is the adiabatic index, usually 3; \( n \) is the shock wave collision pressure increase Multiple, generally \( n=8 \).

Regarding the action time of the blasting load, it is generally believed that the duration of the shock wave action when the explosive explodes is about 0.1 s, and the action time of the explosive gas pressure is about 0.001 to 0.1 s. For the action time of the blasting load, the action time of the blasting load is assumed to be 0.1 s, in which the rise time is 1 ms and the fall time is 6 ms \[ 7 \]. Figure 1 is a schematic diagram of the blasting load curve. In the figure, the horizontal axis is time (ms), and the vertical axis is the explosion pressure (MPa) acting on the blasthole wall.

![Figure 1](image1.jpg)

**Figure 1.** Explosive pressure curve.

The tunnel model is established, the tunnel is set with double-layer lining, and vibration detection points are set at the four quadrant points of each tunnel, and numerical simulation analysis is performed, as shown in figure 2. The detection points of the left tunnel are numbered clockwise as 1-4; The detection points of the right tunnel are numbered lockwise as 5-8.

![Figure 2](image2.jpg)

**Figure 2.** Tunnel model and detection point setting.

4.2. Stress Change Simulation Analysis

The vibration response of tunnel wall under the explosion of 1 t, 2.6 t and 6 t TNT is simulated respectively, and the longitudinal stress nephogram at 0.01 s, 0.05 s and 0.1 s is intercepted to study the stress propagation path and instantaneous distribution, as shown in figures 3-5.
In the deformable solid medium, the mechanical vibration is manifested as the change of the particle velocity and the corresponding change of the stress and strain state. Changes in stress and strain state propagate in the form of waves, called stress waves [10-11]. The interface between the disturbed area and the undisturbed area is usually called the wave front, and the propagation speed of the wave front is called the wave velocity. At 0.01 s, the stress wave is concentrated at the explosion point and has not been transmitted to the surroundings, and the wave shock surface is concentrated near the blasting point and has not been transmitted to the surroundings; At 0.05 s, the stress wave propagated to the vicinity of the tunnel, and the response of the tunnel lining increased sharply; at 0.1 s, the stress wave had dissipated to the surroundings and the tunnel wall response decreased. Since the distance between the two tunnels and the ground is relatively large, and the distance between the two tunnels is relatively small, the simulated explosion point is located directly above the center point of the two tunnels, and the instantaneous response is almost completely symmetrical during simulation. Figures 6-11 simulate the vibration response time history and maximum principal stress diagrams of the tunnel wall when 1 t, 2.6 t, and 6 t TNT explode.

Figure 3. Stress propagation path and instantaneous stress cloud diagram at 0.01 s.

Figure 4. Stress propagation path and instantaneous stress cloud diagram at 0.05 s.

Figure 5. Stress propagation path and instantaneous stress cloud diagram at 0.1 s.

Figure 6. Time history diagram of 1 t TNT Explosion Response.

Figure 7. Maximum principal stress cloud map of 1 t TNT explosion tunnel wall.

Figure 8. Time history diagram of 2.6 t TNT Explosion Response.

Figure 9. Maximum principal stress cloud map of 2.6 t TNT explosion tunnel wall.
Figure 10. Time history diagram of 6 t TNT Explosion Response.

Figure 11. Maximum principal stress cloud map of 6 t TNT explosion tunnel wall.

From the analysis of the above figure, it can be seen that when 1 t TNT explodes, the response of the right wall of the tunnel, namely detection points 2, 6 is the largest, reaching 6.2 cm/s, which meets the safety requirements. It can be seen from the maximum principal stress envelope diagram that the stress is concentrated near the top of the tunnel, about 1.95 MPa.

According to the analysis of the above figure, when the 2.6 t TNT exploded, the right wall of the tunnel, namely detection points 2 and 6, had the largest response, reaching 17.6 cm/s, which was in a critical state and basically met the safety requirements. It can be seen from the maximum principal stress envelope diagram that the stress is concentrated near the top of the tunnel, about 4.225 MPa.

From the analysis of the above figure, it can be seen that in the case of 6 t TNT, the right wall of the tunnel, namely detection points 2, 6 has the largest response, reaching 31.6 cm/s, which has exceeded the safety allowable value. It can be seen from the maximum principal stress envelope diagram that the stress is concentrated near the top of the tunnel, about 9.75 MPa.

5. Conclusion
(1) It can be seen from the numerical simulation analysis that the greater the equivalent of explosives, the greater the peak vibration velocity of the tunnel wall, and the greater the impact on the tunnel. When the explosive equivalent is 2.6 t, the vibration velocity of the tunnel wall is in a safety critical state, and the maximum vibration velocity is located at the detection points 2 and 6 of the two tunnels.

(2) From the above analysis, it can be obtained that even when the explosion equivalent is small, the seismic effect caused by it can also have a large adverse effect on the tunnel. In view of the importance of the traffic tunnel and the difficulty in repairing its damage, the construction unit should give full consideration when applying for stockpiles and the design unit designing the layout of the stockyard. At the same time, the risks arising from the storage of other inflammable and explosive dangerous goods and even the transportation, loading and unloading operations in the port area should be subject to quantitative risk assessment.

Deficiency
(1) In the analysis, only the consequences of the accident were considered, and the probability and conditions of the accident, especially the protective effect of containers and packaging on dangerous goods were not discussed, which exaggerated the overall risk of the construction project.

(2) Due to the large variety of storage goods applied for in construction projects, some of which are taboo, the storage yard has a large storage capacity and the goods are stored in a concentrated manner. When an accident occurs, it may cause a domino effect and expand the impact of the accident.

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