Design Method of Rigid Blast Wall Under the Explosion of Vehicular Bomb

WANG Qizhen, *WU Hao**

School of Civil Engineering, Tongji University, Shanghai 200092, P.R. China

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Abstract: Blast wall can prevent vehicles from approaching the protective building and can reduce the destructive power of shock wave to a certain extent. However, majority of studies on blast walls have some shortcomings. The explosion test data are few. Most exsiting studies focus on the propagation of shock wave and the influence of blast wall on the propagation of shock wave. Discussion on the main parameters of blast wall design is meagre, such as the design of safety distance, the distance from the blast wall to the protective building, height and width of the blast wall. This paper uses the finite element programme LS-DYNA to design the blast wall. To analyze the convergence of the finite element model and to determine the mesh size of the model, this paper establishes several finite element models with different sizes of meshes to verify the model. Then, the overpressure distribution of the shock wave on the protective building is simulated to implement the blast wall design. The geometric parameters of the blast wall are preliminarily determined. And the influence of the safety distance on the overpressure of the building surface is mainly discussed, so as to determine the final design parameters. When the overpressure is less than 2 kPa, it is considered that there will be no damage to people caused by flying fragments. Eventually, the blast wall height is 3 m, the thickness is 1 m, and the safety distance is 35 m. The proposed method is used to demonstrate the design method, and the final design parameters of the blast wall can thus be used for reference.

Key words: blast wall; vehicular bomb; shock wave; safety distance; numerical simulation

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0 Introduction

As a kind of extreme disaster, explosion brings great threat and harm to the safety of the human and property. Explosion is powerful, destructive, and unpredictable. Since the end of last century, the number of terrorist organizations around the world has also increased, and explosion attack is one of the most common terrorist attacks. Vehicular bomb is the most common and destructive way in explosion attacks. Therefore, research on the protection of the buildings under the explosion of vehicular bomb has become important in anti-terrorism protection. The commonly used way of protection is to build temporary blast wall. With the development of science and technology, the design of blast wall of hazardous chemical factories and other places becomes one of the focuses of future attention and research. Since the constructions of various types of blast walls are the main measures for factory explosion protection, the research of blast wall is of great significance to protect human lives and property.

There have been many explosion attacks around the world, which caused great casualties and property damage, as well as great social panic. For example, in 1995, the federal building in Oklahoma was attacked by a vehicular bomb. This accident witnessed the death of 168 people and the injury of more (Fig. 1[1]). In 1998, the U.S. embassies in Tanzania and Kenya were hit by vehicular bombs, and the two attacks killed 224 people and injured thousands. Moreover, the world trade center in New York was hit by two terrorist attacks, one of

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*Corresponding author, E-mail address: wuhaocivil@tongji.edu.cn.

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which was a vehicular bomb attack in the parking lot of the world trade center, causing heavy casualties. Vehicular bomb, one of the most common types of bomb attacks, tends to have more serious consequences. Terrorists can get closed to their targets through vehicles. Explosives in a vehicle are highly concealed and easy to carry, and the explosion of the vehicle itself can intensify the power of bomb. Here are some other typical vehicular bomb attacks, such as a vehicular bomb exploded in the Lebanese capital, Algeria's capital vehicular bomb attacks, the vehicular bomb attack on the Australian embassy in Indonesia, the vehicular bomb attack in Damascus and so on. These vehicular bomb attacks had caused heavy casualties and property losses, which brought great panic to the society.

Fig.1 Oklahoma vehicular bomb attack[1]

The blast wall can weaken the shock wave and prevent the vehicle from moving to the target when the vehicular bomb attack happens. The shock wave will decay rapidly with the increase of the distance from initiation point. The blast wall has a wide range of applications in the world. Scholars at home and abroad have done a lot of research on the impact of blast wall on the propagation of shock wave and anti-explosion performance by means of experimental and numerical simulation.

In terms of experiment, Ref.[2] conducted an experiment on a small scale to evaluate the sensitivity of explosion parameters in the change of charge weight and the blast wall geometry configuration. They proposed the "protection coefficient" to predict the allowable peak value of reflected overpressure at a certain point through tests. Ref.[3] discussed the influence of the explosion distance, dosage, and location of measuring points on the reflected overpressure of measuring points through explosion tests. Ref.[3] drew an conclusion that the diffracted overpressure behind the wall is generally one order of magnitude smaller than the reflected overpressure of the wall by analyzing the overpressure time history curves.

In numerical simulation, Ref.[4] studied the calculation method of pressure load and anti-explosion efficiency of rigid walls with different inclination angles by means of numerical simulation, and used the least square method to give the calculation formula of the reflected pressure when the inclination angle changes. The simulation results show that the load on the wall inclined to the charge is lower. Ref.[5] used AUTODYNA to conduct numerical analysis on the shock wave resistance ability of several special-shaped blast walls. The results show that different types of blast walls have the effect of weakening shock wave, but at the same explosion distance, different types of blast walls weaken the overpressure peak to different degrees. Ref.[6] studied wave elimination performance of cantilever blast walls by using the finite element programme LS-DYNA. They simulated the propagation of shock wave in the three-dimensional flow field with and without the cantilever barrier, then contrasted the attenuation of shock wave overpressure behind blast walls. The results show that the closer the blast wall is to the center of the explosion, the higher the wall, leading to a better wave elimination effect[6]. Ref.[7] compared and analyzed the difference of wave elimination effect between concrete and water blast walls by combining numerical simulation and explosion tests. Ref.[8] adopted the method of equivalent single degree of freedom to analyze the elastic-plastic characteristics of the blast wall, considering that the wall absorbs energy via deformation to weaken the shock wave. And they pointed out that the blast wall designed based on elastic-plastic analysis can absorb energy to achieve better economic benefits. Ref.[9] used the principle that the interaction between reflected wave and refracted wave can weaken the shock wave to carry out research on the new guardrail type of blast wall. Ref.[10] conducted numerical simulation to study the dynamic response of large-span reticulated shell structure using the finite element programme LS-DYNA when explosion occurred under the protection of blast wall, providing a reference for rational explosion-proof design of reticulated shell structure. Ref.[11] studied the failure analysis of flexible blast wall reinforced by ultra-high molecular polyethylene (UHMWPE) fiber under the explosion by combining test and numerical simulation, then analyzed the propagation of shock wave, deformation and failure mechanism of the flexible blast wall. Ref.[12] studied the impact of traditional blast wall and blast walls with cornices at different angles on shock wave attenuation performance through experiment and numerical simulation. The study shows that, among the three configurations, blast wave attenuation performance of blast wall with inclination angle of 45° facing the explosive direction is the best.

Generally, research on blast walls has the following shortcomings: (1) The explosion experiment is the most accurate and effective method for explosion research, but destructive and costly. Therefore, it is not practical to collect data through experiments. Futhermore, the explosion experiment of the blast wall in the world is scarce, thus the time-history curves of incident and reflected overpressure obtained through experiments are few, and the data to verify the numerical model are limited; (2) At present, most research focuses on the propagation of shock wave and the influence of blast wall on the propagation of shock wave. However, there is little discussion on the main parameters in blast wall design, such as safety distance, height and width of the blast wall.

Based on the existing explosion test data of Mu et al.[3], multiple groups of models were firstly established for model verification. Numerical simulations of the near ground explosion with several sets of rigid blast walls are carried out. After comparison and verification with the test data, the mesh sizes of the final finite element model are determined and the design steps of the blast wall are also given. The rigid blast wall is designed without considering the structural response and deformation absorbing energy. In this paper, the peak overpressure criterion of building glass is taken as a standard. When the overpressure is less than 2 kPa, it is considered that there will be no damage to people caused by flying fragments. After determining the geometric parameters of the blast wall, the safety distance between the blast wall and the building is constantly changed to ensure that the ordinary five-storey frame structure will not produce high-speed glass fragments that cause injuries in the conventional vehicular bomb attacks.

1 Finite Element Model of the Blast Wall

1.1 Introduction of the experiment

Mu et al.[3] conducted the TNT explosion tests of the blast wall which was divided into three groups with four shots in each group. The test parameters are listed in Table 1, where the explosion distance is the distance from the explosive to the blast wall.

Table 1 TNT explosion test parameters of the blast wall

Group	Charge weight of TNT / kg	Burst height / m	Explosion distance / m
1	0.8	0.6	2, 3, 4, 5
2	0.2, 0.4, 0.6, 0.8	0.6	3
3	1, 2, 4, 5	0.6	3

The schematic of test is shown in Fig.2[3]. Mu et al.[3] gave eight overpressure time-history curves of six measuring points in the three groups of tests. When the explosion distance is 4 m and TNT charge weight is 0.8 kg, the time-history curves of shock wave overpressure at points 1, 4 behind the wall are presented. When the explosion distance is 3 m and TNT charge weight is 0.8 kg, the time-history curves of shock wave overpressure at points A, B in front of the wall are obtained. When the explosion distance is 3 m and the mass of TNT charge is 4 kg, the time-history curves of shock wave overpressure at points A, B in front of the wall and points 1, 4 behind the wall are obtained. These existing test overpressure time-history curves are used to verify the finite element model.

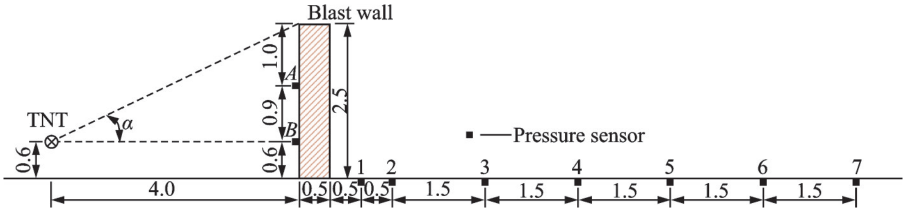


Fig.2 Schematic of test[3] (unit: m)

1.2 Finite element model

The finite element model is a three-dimensional solid model composed of air, TNT, rigid ground and a rigid blast wall. The rigid ground is implemented by the keyword *RIGIDWALL_PLANAR, and the rest are modeled by 8-node hexahedral elements. The rigid blast wall is represented by LAGRANGE (*SECTION_SOLID) mesh, TNT and air are represented by ALE (*SECTION_SOLID_ALE) mesh. TNT mesh and air mesh are set as common nodes. This paper uses the keyword*CONSTRAINED_LAGRANGE_IN_SOLID to achieve the fluid-solid coupling among air, TNT, and the blast wall. The boundary conditions of the rigid blast wall are fixed at the bottom and free at the top, and the air boundary is set as nonreflecting boundary. Fig.3 shows the finite element model and Fig.4 shows the propagation of shock wave. In the experiment, the blast wall almost had no deformation. This paper only studies the distribution of explosion load on the blast wall and measuring points, without paying attention to the structural response. Therefore, in the model, the blast wall adopts rigid body material model, which is realized by the keyword *MAT.RIGID. The density ρ is 3×10^3 kg/m^3, elasticity modulus E is 2.1×10^5 MPa, and Poisson's ratio υ is 0.3.

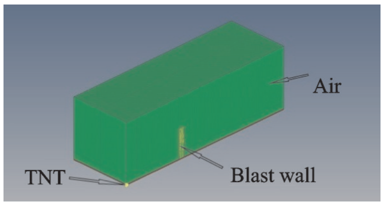
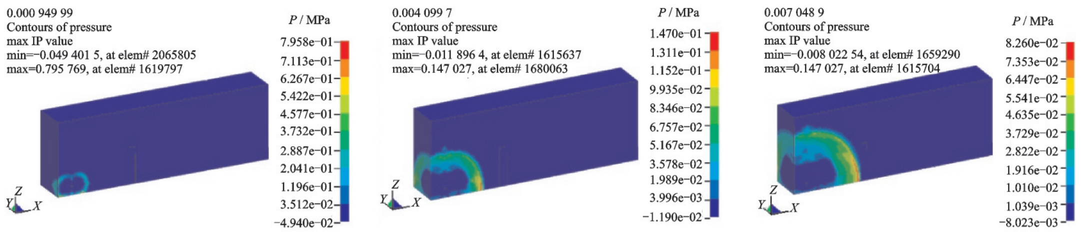
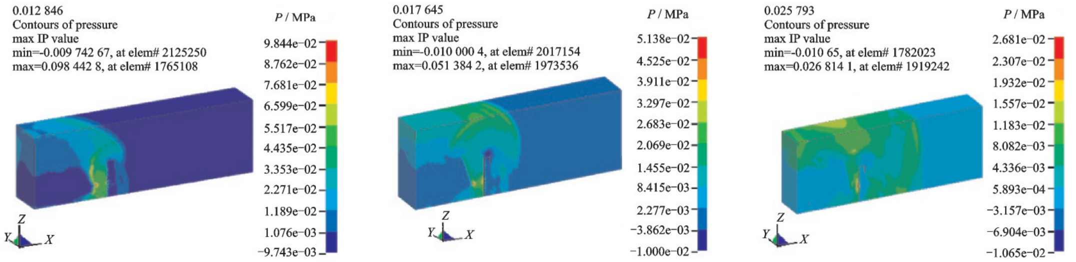


Fig.3 Finite element model



(a) 0.949 99 ms (b) 4.099 7 ms (c) 7.048 9 ms



(d) 12.846 ms (e) 17.645 ms (f) 25.793 ms

Fig.4 Propagation of shock wave propagation

Air is non-viscous ideal gas, adopting the *MAT_NULL material model, whose equation-of-state uses linear polynomial equation as follows

$$P=c_0+c_1\mu+c_2\mu^2+c_3\mu^3+(c_4+c_5\mu+c_6\mu^2)E_0$$

where P is the pressure; c_0—c_6 are the coefficients of EOS; $\mu=1/(V-1)$, here, V is the relative volume; and E_0 the initial internal energy. Table 2 lists the air material parameters.

Table 2 Air material parameters

Density ρ/ $(\mathrm{kg \cdot m^{-3}})$	Coefficients of EOS							E_0/ $(\mathrm{J \cdot m^{-3}})$
	c_0	c_1	c_2	c_3	c_4	c_5	c_6	
1.29	0	0	0	0	0.4	0.4	0	0.25

TNT uses the high energy explosive combustion model (*MAT_HIGH_EXPLOSIVE_BURN) to simulate its explosion process. The model needs the density of TNT material ρ, detonation velocity D, Chapman-Jouget pressure PCJ and other parameters. And JWL equation is selected as the equation of state.

$$p = A\left(1 - \frac{\omega}{R_1 V}\right)\mathrm{e}^{-R_1 V} + B\left(1 - \frac{\omega}{R_2 V}\right)\mathrm{e}^{-R_2 V} + \frac{\omega E_0}{V}$$

where P is the detonation pressure; V the relative volume; E_0 the initial internal energy per unit volume; and A, B, R_1, R_2 and ω are the constants of the material. Table 3 lists the parameters of TNT material model and the equation of state.

Table 3 Parameters of TNT material model and equation-of-state

Density ρ/ $(\mathrm{kg \cdot m^{-3}})$	Velocity of detonation V /$(\mathrm{m \cdot s^{-1}})$	C-J detonation pressure PCJ / MPa	A / MPa	B / MPa	R_1	R_2	ω	E_0 / $(\mathrm{J \cdot m^{-3}})$	V
1.63×10^3	6.93×10^3	2.1×10^4	3.71×10^5	3.23×10^3	4.15	0.95	0.3	7×10^9	1

2 Model Verification

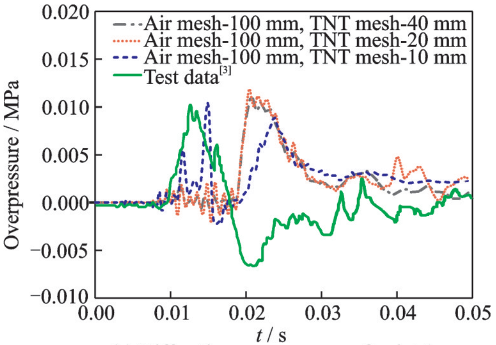
2.1 Model verification process

This chapter is based on Mu et al.[3] team's TNT explosion tests of the blast wall, using the method of comparative analysis. The results of numerical simulation are compared with the shock wave overpressure time-history curves at different measuring points obtained by tests. Furthermore, the convergence of finite element models is verified, and the correctness of material parameters and numerical algorithm is verified.

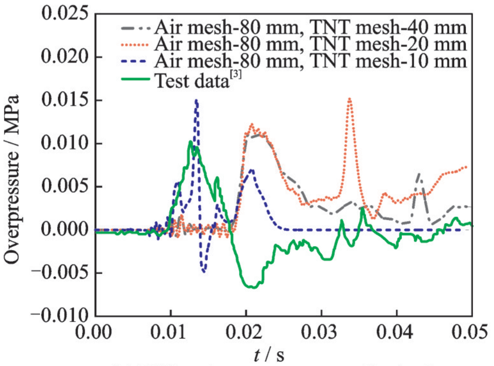
2.2 Preliminary comparison

To discuss the convergence of the mesh and to seek the best mesh size, the size of air mesh is first defined as 100 mm, where the air mesh near TNT is locally refined to the same size as the TNT mesh, the blast wall mesh size is defined as 50 mm, and the mesh sizes of TNT with a dosage of 0.8 kg are defined as 40, 20 and 10 mm. Later, the same method is adopted to establish different models with air mesh of 80 mm, and the air mesh near the TNT is locally refined to the same size as that of the TNT mesh. The blast wall mesh is of 50 mm, and TNT mesh sizes of 40, 20 and 10 mm.

In Fig.5, when the explosion distance is 4 m, the air mesh sizes are 100 mm and 80 mm, the size of wall mesh is 50 mm, and the sizes of mesh of TNT are 40, 20 and 10 mm. The simulation results of shock wave overpressure time-history curves of measuring point 1 behind the blast wall are compared with the experimental curve of point 1. When the air mesh is 100 mm and the TNT mesh is 10 mm, the shock wave overpressure curves are in good agreement, and the air mesh and TNT mesh are eventually determined.



(a) Diffraction overpressure of point 1



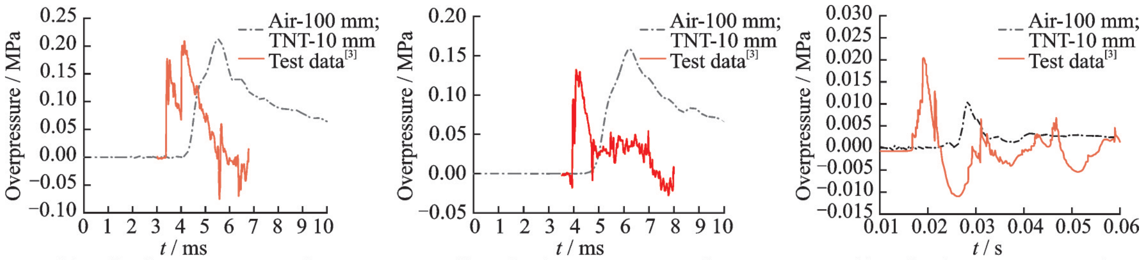
(b) Diffraction overpressure of point 1

Fig. 5 Comparison curves (0.8 kg TNT, explosion distance is 4 m, and burst height is 0.6 m)

2. 3 Further comparison

After all the mesh sizes are determined, other experimental curves and numerical simulation results were compared to further verify the model. Then the size of air mesh is 100 mm, the size of TNT mesh is 10 mm, and the air mesh near the TNT is locally refined to the same size as that of the TNT mesh. The explosion distance is 3 m, the burst height is 0.6 m and the TNT charges are 0.8 and 4 kg. Next, this paper compares the time history curves of shock wave overpressure obtained by numerical simulation with the experimental curves of the corresponding measuring points. Fig.6 shows the curves for comparison and verification. The simulated results of the diffraction overpressure curves of the measuring points behind the wall are close to the test data. However, the arrival time of the reflected overpressure shock wave in front of the wall is about 1 ms later than the test data, and there is a certain difference between the overpressure peak of each measuring point and the test date.

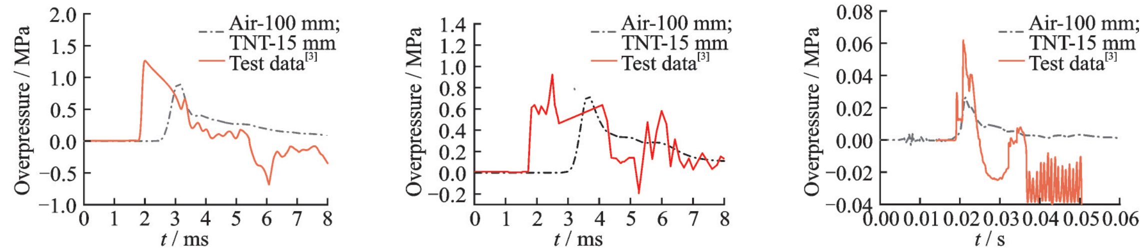
There are many factors influencing overpressure in the explosion experiment. Some complex factors are not considered in the numerical simulation, which may lead to the above deviation. For example, the delay of the sensor recording the detonation time in experiment will cause the inconsistency between the numerical simulation and experiment in detonation time. Therefore, the difference of the detonation time in each image can be ignored. In addition, during the experiment, the pressure sensor may be affected by explosion, resulting in errors in the measurement results and so on. However, it can be seen from the comparison curves that the order of magnitude of simulation results and test data are same, and the overpressure of shock wave first rises and then drops rapidly, which is in line with the characteristics of chemical explosion. In conclusion, the finite element model of the blast wall established in this paper can reasonably predict the shock wave



(a) Reflection overpressure of point *A* (0.8 kg TNT)

(b) Reflection overpressure of point *B* (0.8 kg TNT)

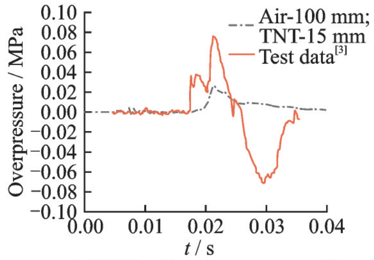
(c) Reflection overpressure of point 4 (0.8 kg TNT)



(d) Reflection overpressure of point *A* (4 kg TNT)

(e) Reflection overpressure of point *B* (4 kg TNT)

(f) Diffraction overpressure of point 1 (4 kg TNT)



(g) Diffraction overpressure of point 4 (4 kg TNT)

Fig.6 Comparison curves

overpressure load on the structure.

3 Design Method of the Blast Wall

3.1 Design scenario

This chapter shows the design method of the blast wall under the explosion of vehicular bomb. Given the current frame structure, whose redundancy is generally high, when a vehicular bomb attack happens the current frame structure will not collapse generally. Moreover, the threat often comes from buildings' glass fragments and other flying projectiles. Therefore, it is required to ensure that the building will not produce high-speed fragments during the process of designing the blast wall. Most of the ordinary buildings do not use explosion-proof glass, so the explosive attack can bring a great threat to personal safety. This paper briefly introduces three damage criteria of buildings under explosion attack. Based on the overpressure time history curves and the characteristics of building's glass in this paper, this chapter only considers the impact of the overpressure peak of shock wave on the damage of building's glass. When the overpressure is less than 2 kPa, it is considered that there will be no damage to people caused by flying fragments. In addition, due to the limitation of computational capability, this paper only presents the protection design of a five-storey building (15 m high), aiming to show the design steps of the blast wall via the design process in this paper.

The blasting damage threshold of the structure without protective measures is shown in Fig. 7. Based on the geometric characteristics of conventional vehicular bomb, the parameters of explosives are preliminarily determined. The charge weight of TNT is 45.359 2 kg (100 lb), the burst height is 0.5 m, and the explosion distance is 1 m. To reduce the number of scenario in question, this paper adopts fixed geometric dimension parameters of the blast wall, and only discusses the influence of safety distance. In view of the fact that the height of the blast wall is limited and cannot be too high in practice, this paper takes 3 m as height and 1 m as thickness. According to Fig.7, the critical damage threshold of glass without protective measures under the explosion of 100 lb TNT is approximately 270 m, and the slight damage threshold of glass is 400 m. In this paper, the safety distance between the blast wall and the protective building is initially set as 10 m, and then it is gradually increased until safety requirements are satisfied. Fig.8 shows the simulated layout of a vehicular bomb attack[13].

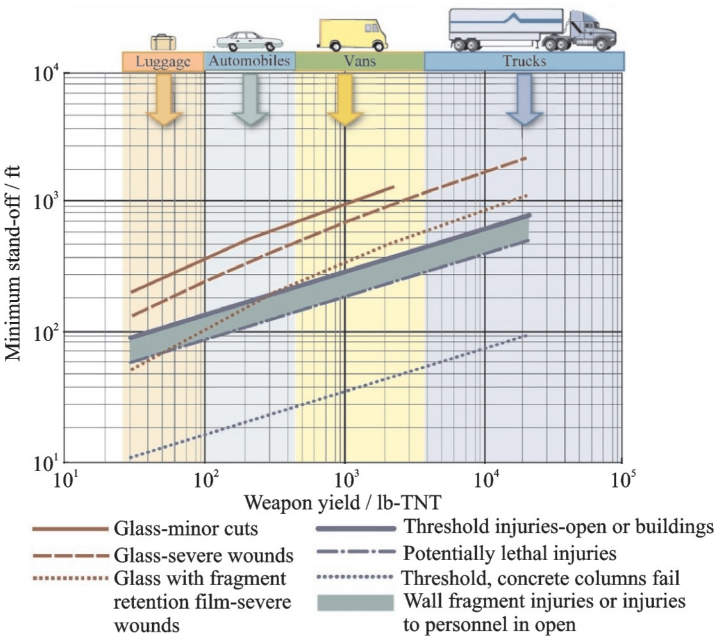


Fig. 7 Blasting damage threshold (FEMA2003)[13]

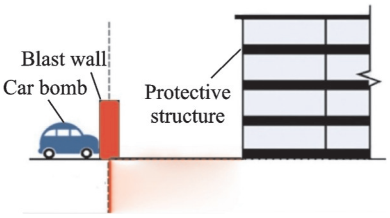


Fig. 8 Design scenario layout[13]

3. 2 Finite element model

The finite element model presented in this paper, whose air mesh is 100 mm and TNT mesh is 10 mm, can be used to reasonably simulate the shock wave overpressure on the structure in a vehicular bomb attack. Here, the establishment method of the finite element model is the same as that in Section 1, while the difference is that a protective building is added in the model. This paper studies the distribution of explosion load on the building under the protection of the blast wall, so as to ensure that the glass on the building surface is not damaged and not create flying fragments to hurt people. The structural response of the building is not concerned, therefore, the protective building in the model is taken as a rigid body, and the fluid-solid coupling of the building with air and TNT is considered. To be consistent with the actual scenario, the boundary condition is fixed at the bottom. As the computational capability of computers is limited, the finite element model established in this section adopts 1/4 symmetrical structure on the premise of ensuring the mesh accuracy requirements and meeting the requirements of actual working conditions. Fig. 9 shows the finite element model and Fig. 10 shows the propagation of shock wave when the safety distance is 10 m. Fig. 11 shows the reflection pressure curves of building's surface at different heights when the safety distance is 10 m.

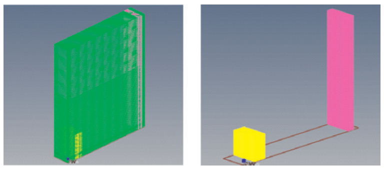
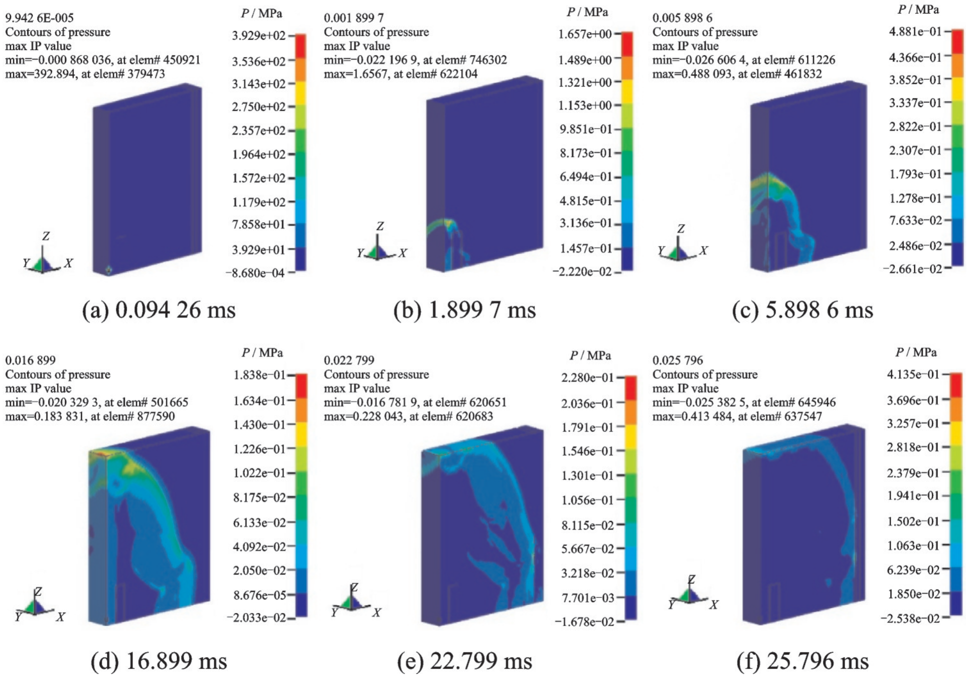


Fig. 9 Finite element model



(a) 0.094 26 ms (b) 1.899 7 ms (c) 5.898 6 ms

(d) 16.899 ms (e) 22.799 ms (f) 25.796 ms

Fig. 10 Propagation of shock wave (safety distance is 10 m)

3. 3 Evaluation criteria

Three failure criteria commonly used in anti-explosion design are as follows.

(1) Peak overpressure criterion: the peak overpressure failure criterion takes the peak overpressure as the factor to judge the damage grade of buildings. Since the peak overpressure failure criterion does not consider the overpressure action time, its ratio-

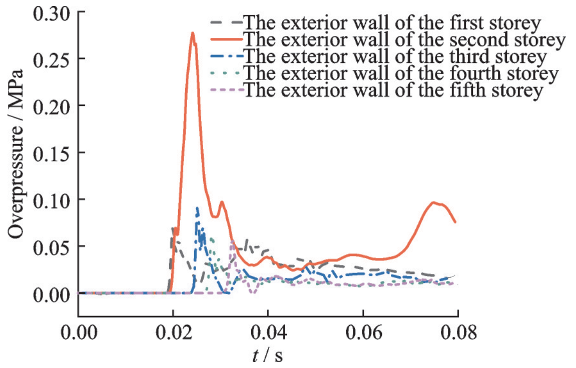


Fig.11 Reflection overpressure of windows located on exterior wall of each floor (safety distance is 10 m)

nality needs to be judged in use. The relationship between the peak overpressure of shock wave and the extent of damage to the building are illustrated in Table 4.

Table 4 Degree of peak overpressure damage to buildings[14]

Δp / kPa	Extent of damage to the building
0.5—2	Glass is partially damaged
2—12	All the glass is broken
12—30	Doors and Windows are broken, and small cracks appear in the brick walls (0.5 mm)
30—50	Brick wall has cracks (0.5—5 mm), and reinforced concrete roof has cracks
50—76	Wall cracking (50 mm), reinforced concrete roof cracking seriously
76—100	Brick walls collapse and reinforced concrete roofs collapse
100—200	Earthquake-resistant reinforced concrete structure damages
200—300	The steel bridge is broken

(2) Impulse criterion: impulse is also a damage factor. The impulse criterion selects the impulse obtained from the overpressure time-history curve integral to determine the damage degree of the building. This damage criterion considers both overpressure and time effect.

(3) Overpressure-impulse criterion: the damage ability of the shock wave to the target refers to whether the shock wave can maintain a certain pressure effect on the target within a period of time, so the criterion has a certain amplitude and time significance[15]. Based on this criterion, correlation curves of overpressure-specific impulse of different damage grades are given, and the damage degree can be judged according to the overpressure and impulse of target points. The overpressure-impulse criterion is more widely used and the results are more accurate, but this criterion is not as intuitive as the peak overpressure criterion.

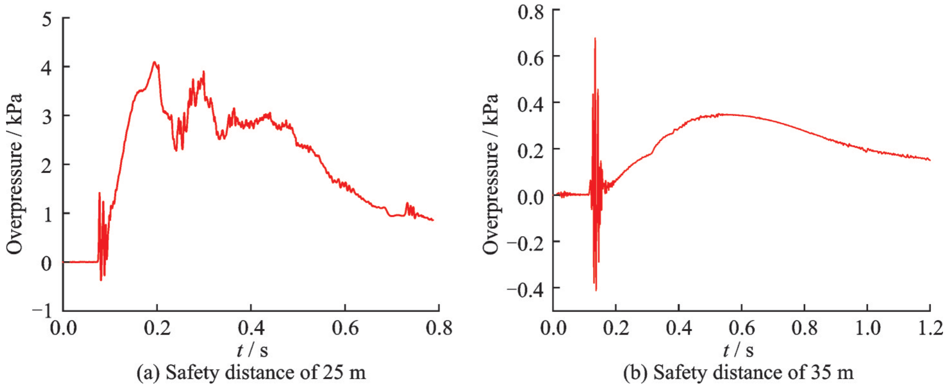
For the explosion-proof of building glass, the damage evaluation criterion of shock wave overpressure on buildings and the test data at home and abroad should be taken as the criterion that the glass is not broken and does not produce flying pieces to injure people. Therefore, the glass shall also be subjected to a shock overpressure not greater than 0.020 MPa[16]. Judging from the peak overpressure criterion in Table 3, when the safety distance is 10 m, the peak overpressure is greater than 2 kPa and shattering failure of building's exterior glass already happens. The damage degree on the second storey is the fourth level, and the peak reflection overpressure on the second storey is the highest. To ensure that the glass is not badly damaged, this paper need to increase the safety distance or make the blast wall height higher. In addition, the height of blast wall should not be too high, so this paper chooses to increase the safety distance to 20 m for numerical simulation. When the safety distance is changed to 20 m, the peak reflected overpressure value of the building on the second storey is also the maximum, that is 15 kPa, which is greater than 2 kPa. According to the overpressure criterion, most of the windows are broken.

To meet the safety requirements, the safety distance needs to be further increased. The safety distance is transferred to 25 m for numerical simulation. The finite element model of air-TNT-protective building with a safety distance of 25 m is imported into LS-DYNA. The time-history curve of shock wave overpressure at the bottom of the second- storey window (where the overpressure peak is the largest) is shown in Fig. 12(a). The peak value of the reflected overpressure on the second storey is

4.1 kPa, which exceeds 2 kPa corresponding to the basic non-destructive degree (level 1) of the peak overpressure criterion. In summary, when the safety distance is 25 m, the safety requirements of the peak overpressure criterion cannot be satisfied.

Based on the previous simulation results, the safety distance continues to increase, and the safety distance of the finite element model changes to 35 m. The overpressure time-history curve of the building surface on the second storey when the safety distance is 35 m is shown in Fig.12 (b), whose peak reflected overpressure value is only 0.68 kPa, which meets the requirements of the peak overpressure failure criterion. Futhermore, the overpressure changes slowly after 0.2 s, which is similar to quasi-static loading, thus the time effect of overpressure does not need to be considered.

Since glass is a brittle material and will be damaged when its stress reaches an elastic limit, it is easy to respond to shock wave quickly, considering small transverse size of window glass between supports. Therefore, in the quasi-static load area of explosion, it is often broken. Hence, it is appropriate to use the overpressure criterion as the critical value of failure[14]. The reason why impulse criterion is not selected as the evaluation standard here is that if the overpressure is too low at the minimum critical value, the target will not suffer damage even if the duration of load is longer and the impulse is larger[17]. In the quasi-static loading area, the curve tends to the horizontal asymptote, and the specific impulse becomes unimportant, and the damage degree mainly depends on the peak overpressure[15]. Therefore, it is feasible and safe that the peak overpressure failure criterion is chosen, and the impulse criterion and overpressure-impulse criterion are not discussed.



(a) Safety distance of 25 m

(b) Safety distance of 35 m

Fig.12 Reflection overpressure of windows located on exterior wall of the second floor

4 Conclusions

(1) The convergence of mesh is discussed on the basis of the explosion test of Ref.[3]. To satisfy the rationality and efficiency of numerical simulation, the size of air mesh is 100 mm and that of TNT mesh is 10 mm. The simulation results agree well with the test data[3].

(2) The method for designing blast wall is proposed using the finite element programme LS-DYNA. The final design parameters of the blast wall can be as a reference. Limited by the processing capability of computer, the geometrical size of the blast wall in this paper is determined to be 3 m in height and 1 m in thickness. Only the distance between the blast wall and protective building is discussed. After simulation, it is found that when the safety distance is 35 m, the safety requirements can be met.

(3) To decrease the damage of glass and to ensure personal safety when explosion happens, the peak overpressure failure criterion is taken as standard. The influence of the peak reflected overpressure is considered and influence of the effect time of

shock wave overpressure can be ignored. When the overpressure is less than 2 kPa, it is considered that there will be no damage to people caused by flying fragments in this paper. Simulation results demonstrate that the reflected overpressure value at the exterior wall of the second storey was the largest. When the safety distance is 35 m, the peak reflected overpressure is 0.68 kPa, which meets the safety requirements.

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Authors Ms. **WANG Qizhen** received her B.S. degree in Ocean University of China, Qingdao, China, in 2019, and she is now studying for a master's degree in Tongji University, Shanghai, China. She majored in the blast resistant civil structures.

Prof. **WU Hao** received his B.S. and Ph.D. degrees in PLA University of Science and Technology, Nanjing, China, in 2004 and 2009, respectively. He is engaged in basic theory, material development and engineering application research in the field of impact and explosion resistance effect and engineering protection.

Author contributions Ms. **WANG Qizhen** established the finite models, conducted the analysis, and wrote the manuscript. Prof. **WU Hao** contributed to the guide of the finite model analysis and planned the design process of the blast wall.

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汽车炸弹爆炸作用下的刚性防爆墙设计方法

王启珍， 吴 昊

（同济大学土木工程学院，上海 200092，中国）

摘要：防爆墙可以阻挡袭击车辆的行进，在一定程度上削减爆炸冲击波的威力。然而现有研究大多集中于冲击波的传播和防爆墙对冲击波传播的影响方面，缺乏防爆墙主要设计参数分析。为此，本文采用有限元程序LS-DYNA设计防爆墙，通过建立几种不同网格尺寸的有限元模型，探讨有限元模型的收敛性，并经模型验证确定防爆墙模型的最终网格尺寸。最后，通过数值模拟得到了冲击波在防护建筑表面的超压分布，以进行防爆墙的设计。设计过程中首先确定了防爆墙的几何参数，然后重点讨论了安全距离对建筑物表面超压的影响，并最终确定防爆墙的设计参数。模拟结果表明：当超压小于2 kPa时，建筑外墙玻璃不会产生飞溅破片对人体造成伤害，因此将其作为设计准则。确定后的防爆墙高度取3 m，厚度取1 m，安全距离取35 m。按所提的防爆墙设计方法得到的设计参数可作为设计参考。

关键词：防爆墙；汽车炸弹；冲击波；安全距离；数值模拟