# Experimental Study on Damage and Protection of Steel Structure Plant under Explosion Impact

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**Abstract.** In this paper, the dynamic response and damage consequence of the steel structure under the blast impact load are investigated by carrying out the full-scale model of the steel structure industrial plant and the near-earth explosion damage test of the local component. The near-ground explosion test was carried out, and the dynamic response and damage consequences of steel structure industrial plant were obtained. The anti-explosion effects of different protective measures were proposed and compared for the weak parts of the structure. The results show that the wall panel of the steel structure industrial plant will produce strong vibration and tear failure under strong impact load. Polyisocyanate oxazolone (POZD) can effectively improve the anti-knock performance of wallboard, and the protection effect of double-side spraying is better than that of back-side spraying, and the effect of front spraying is the worst. The research results provide important engineering value for damage analysis and protection measures of steel structure industrial plant.

**Keywords:** Industrial plant; Steel plate; Near-earth explosion; Structural deformation

## 1 Introduction

The steel structure building has gained widespread application in recent years due to its exceptional durability, cost-effectiveness, and environmentally friendly characteristics. However, the research on anti-explosion impact loads for steel structures remains relatively insufficient, resulting in potential human injuries and economic losses when subjected to accidental explosion loads. In recent years, numerous scholars have conducted a series of studies utilizing numerical simulations combined with field tests to enhance the anti-knock protection of steel structures. In order to mitigate the consequences of subway explosions, Kong et al. [1] developed and validated a numerical model that accurately represents steel structures. Markose et al. [2] investigated the damage characteristics of V-shaped steel plates under various impact loads. Wang et al. [3], on the other hand, improved the explosion resistance by incorporating polyisocyanate oxazolone (POZD) coated steel onto the surface of RC composite structural plate. Hou et al. [4] investigated the impact of POZD on gas burst resistance through the utilization of


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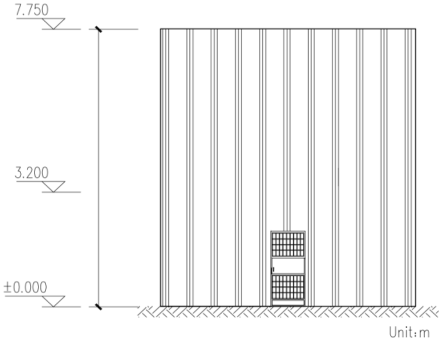
various structural configurations. Wu et al. [5] conducted a comprehensive analysis on the explosion-proof performance of oil tanks by combining experimental testing and numerical simulation, focusing specifically on the influence of polyurea materials with different mechanical properties. Li et al. [6] examined the effect of polyurea on the anti-knock performance against underwater explosions in steel plates under different spraying methods. The failure mechanism of a polyurea aluminum plate structure under underwater shock wave load was investigated by Rijensky et al. [7] through numerical simulation. Bucur et al. [8] conducted a comprehensive investigation on the explosion-proof performance of polyurea sprayed steel plates by integrating field tests and numerical simulations. Wang et al. [9] examined the protective properties of polyurea on steel oil tanks under the combined effects of shock waves and fragments through close-range explosion experiments, elucidating the mechanism behind their combined damage. The present study systematically investigates the explosion-resistant performance of prefabricated steel structure industrial plants through near-field explosion tests conducted on both the intact steel structure plant and its local components. Additionally, variations in POZD spraying thickness and position are considered.

## 2 Test Overview

### 2.1 Model Establishment

According to the existing typical steel structure building, the single-storey single-span light steel structure industrial plant is designed. The main purpose of the test is to study the structural strength of the component, so other functions have been deleted. The plant is a single-storey building with a total height of 7.75 m, a length of 9m and a width of 6 m. The building structure is light portal steel frame structure, seismic fortification intensity is 7 degrees, the plant is equipped with crane beam, the project is destructive test temporary facilities, do not consider fire design. The exterior wall is made of 900 color steel plate with a thickness of 0.476 mm. The roof adopts single-slope single-ridge unorganized drainage, and adopts 0.6 mm thick 820 color steel plate. The model selected one side of the factory building to simulate the damage consequences of the existing typical steel structure industrial plant under strong impact load. The building model of the test plant is shown in figure 1.




(a)Schematic drawing (b)Field drawing

**Fig. 1.** Building model

At the same time, considering that polyurea elastomer has good anti-explosion effect, and spraying on steel plate can effectively prevent steel plate corrosion and have a certain aesthetic effect, polyurea reinforced color steel plate and ordinary color steel plate anti-explosion test are used in local component tests, and their different damage consequences are compared, so as to explore the protective effect of polyurea on color steel plate. The field real explosion test was carried out under three conditions: ordinary unreinforced color steel plate, polyurea spray blasting surface, polyurea spray back blasting surface, and polyurea double-sided spraying, as shown in figure 2 below. Some parameters of polyurea are shown in table 1.

(a)Unreinforced color steel plate (b)Reinforced colored steel plate

**Fig. 2.** Reinforced member

**Table 1.** Polyurea material parametersl

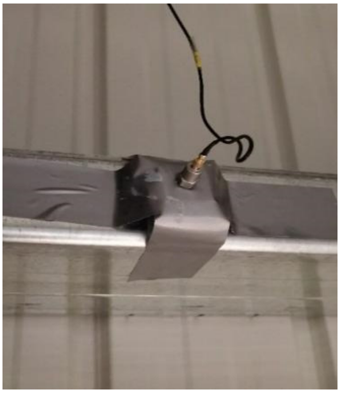
| Test item | | Detection result | Detection basis |
|---|---|---|---|
| Tensile strength | | 26.16 MPa | GB/T 528-2009 |
| Elongation at break | | 414 % | |
| Tearing strength (7 d) | | 149 N/mm | GB/T 529-2008 |
| Low temperature flexability (-30 ℃) | | No crack | GB/T 16777-2008 |
| impermeability (0.4 MPa,3 h) | | Impermeable | GB/T 16777-2008 |
| Oil resistance | | Free of bubbles、No shedding、No cracking、No discoloration | GB/T 9274-1988(2004) |
| Abrasion resistance (CS-10,750 g/500 r) | | 0.005 g | GB/T 1768-2006 |
| Adhesive force (pulling ethod) | With steel plate | 10 MPa(9.33 MPa ~10.92 MPa) | GB/T 521.1-2008 |
| | With concrete block | 5 MPa(3.99 MPa ~5.24 MPa) | GB/T 5210-2006 |

## 2.2 Measuring System and Load Condition

According to the actual building height, the position of displacement sensor, acceleration sensor and air pressure sensor is determined, considering the difference of strong impact load between the bottom and the top of the plant. The field layout of the air pressure sensor, acceleration sensor and displacement sensor on the explosion facing surface is shown in figure 3.

(a)Air pressure sensor (b)Displacement sensor

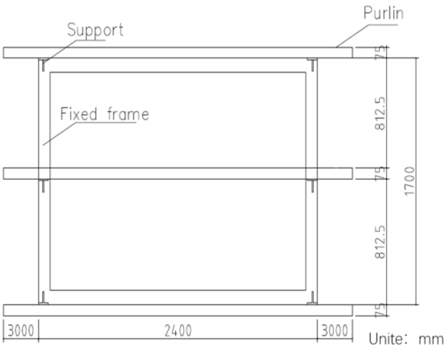
(c)Plate acceleration sensor



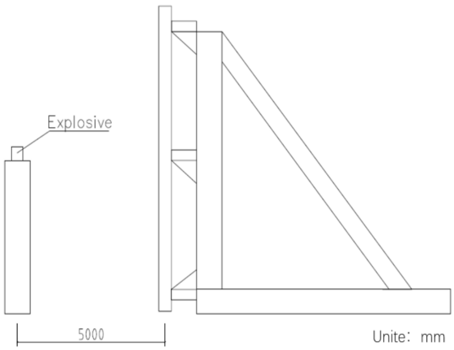
(d)Skeleton acceleration sensor

**Fig. 3.** Sensor layout

As shown in figure 4, the test arrangement of local components was divided into three groups: one group was near-explosion test of ordinary colored steel plate, the other group was near-explosion test of 1mm polyurea reinforced colored steel plate, and the other group was 2 mm polyurea reinforced colored steel plate near-explosion test. The detonation distance of 5 m was adopted in the three groups of tests, and the explosive quantity was divided into three working conditions of 100 g, 200 g and 300 g. The firing order was arranged as shown in table 2 below.




(a)Skeleton front view




(b)Skeleton side view

**Fig. 4.** Partial component test layout

Combined with relevant prefabricated industrial plant building design specifications, the test plan is formulated as follows:

(1) The TNT charge is 100 kg, placed on the flat ground, the detonation center is about 100 m away from the explosion facing surface of the plant, and the projection of the detonation center is located in the center of the two-cross building. The side view of the real explosion test is shown in Figure 3-9. The sensor data is obtained by the test

data acquisition instrument, and the structural dynamic response analysis is conducted on it.

(2) The TNT charge is 500 kg, placed on the flat ground, the detonation center is about 100 m away from the detonation surface of the plant, and the projection of the detonation center is located in the center of the two-storey building, in order to obtain the overall damage consequences of the industrial plant and analyze the test data.

(3) The charge of TNT is 100 g, and the detonation center is 5 m away from the detonation surface of the plant.

(4) The charge of TNT is 200 g, and the detonation center is about 5 m away from the detonation surface of the plant.

(5) The charge of TNT is 300 g, and the detonation center is about 5 m away from the detonation surface of the plant.

The arrangement of test conditions is shown in table 2.

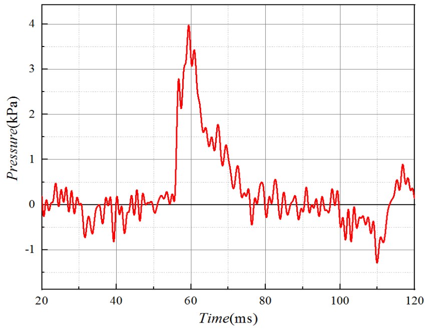
**Table 2.** Test condition

| Sequence number | Working condition | Explosive charge | Charge projection position | Detonation distance (m) | Proportional distance ($m/kg^{1/3}$) |
|---|---|---|---|---|---|
| 1 | Prototype building | 100 kg | Structural center of building | 100 | 21.54 |
| 2 | | 500 kg | | 100 | 12.59 |
| 3 | Ordinary /1mm/2mm polyurea color steel plate | 100 g | | 5 | 10.77 |
| 4 | | 200 g | | 5 | 8.54 |
| 5 | | 300 g | | 5 | 7.47 |

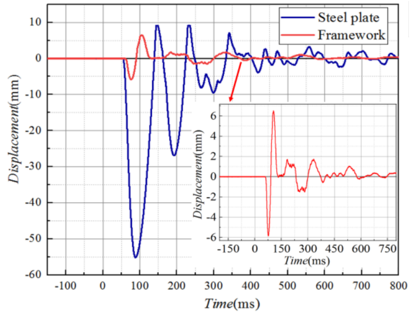
# 3 Test Results

## 3.1 Damage Effect Test of Prototype Building

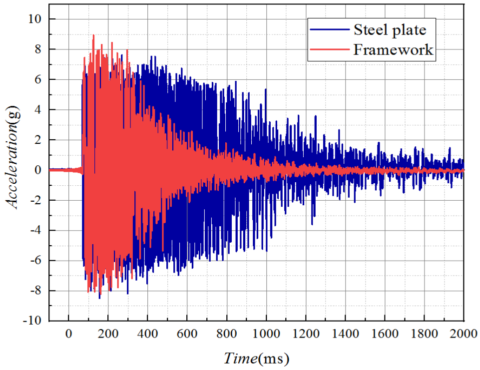
The first shot was tested with a proportional distance of 21.54 m /$kg^{1/3}$. The peak value of shock wave overpressure measured on the explosion facing surface of the plant model was 3.91 kPa, the displacement of the explosion facing wall panel was 55.124 mm, and the maximum displacement of the explosion facing purlin could reach 6.416 mm. Strong vibration will occur. Compared with the skeleton, the vibration amplitude is larger, the frequency is fast, and the duration is long. The test waveform of each data is shown in figure 5.




(a)Air pressure at the detonation surface




(b)Explosion face displacement



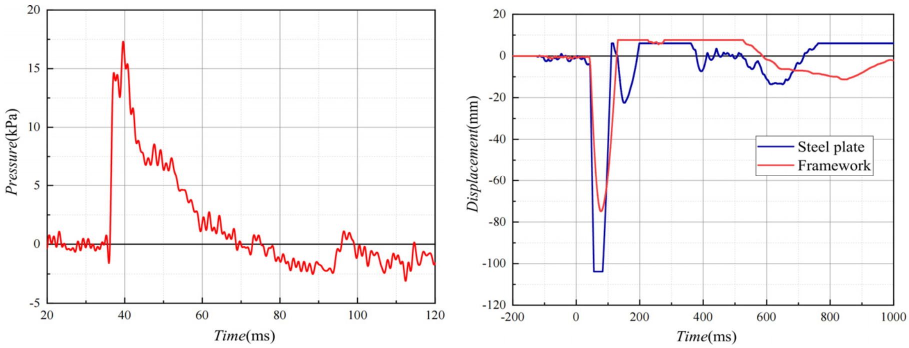

(c)Acceleration on the burst surface

**Fig. 5.** First shot test waveform

No obvious damage was seen in the overall structure of the first shot test plant, the explosion facing panel was slightly dented (figure 6), some wall color steel plates on the back explosion surface were loosened, the main load-bearing components of the test plant, such as steel columns and steel beams, were not damaged, the concrete foundation pile was not damaged, and no damage was found in the wall purlin.

**Fig. 6.** The blasting surface is deformed

The second round was conducted on the basis of the first test at a proportional distance of 12.59 m/kg$^{1/3}$. Strong blast impact load has a great impact on the upper part of the plant. The effect value of strong impact load on the 5 m space of the model is significantly greater than that at the bottom of the model. The air pressure on the explosion facing surface of the plant is up to 17.57 kPa, while the air pressure on the back explosion surface of the plant is about 7.53 kPa. Lead to part of the displacement sensor to exceed the range and damage, after the test repair, screening, to obtain the estimated structural displacement, the maximum displacement of the wall to meet the explosion surface color steel plate is greater than 103.97 mm, the maximum displacement of the bursting surface purlin can reach 74.762 mm. According to the test data, the movement of the structural wall panel and purlin is irregular compared with the 100 kg TNT real explosion test after the explosion, the vibration gradually shows symmetry after the vibration release, and the wall panel and purlin are deformed, and the displacement can not be recovered. Due to the imperfect debugging of the test system in the early stage, all the acceleration sensors fell off and were damaged, and the data was confused and could not be quantitatively analyzed. The waveforms of air pressure and displacement are shown in figure 7.




(a)Air pressure at the detonation surface (b)Explosion face displacement

**Fig. 7.** Second shot test waveform

After the second shot test, the explosion facing surface of the test building was seriously damaged (figure 8), most of the color steel plate was damaged, and the color steel plate was torn or self-tapping fell off at the connection between the explosion facing color steel plate and the self-tapping, resulting in the wall color steel plate falling off, most of the sensors were seriously damaged, and each span of the bursting facing purlin was damaged to different degrees. The purlins bend and deform in the middle of each span, and the damage degree of the structural purlins at about 5.5 m in the upper part is significantly greater than that of the lower 2.2 m structure. The damage of the back explosion surface wall color steel plate is mainly concentrated in the structure of 6 m, and some of the connection parts of the color steel plate tear and fall off, which causes the joint effect, resulting in the overall color steel plate fracture and fall off, and the back explosion surface purlin structure has not found obvious damage. No obvious damage was found on both sides of the test building. No obvious damage was found to the reinforced concrete foundation and the anchor rod at the connecting position between the plant and the foundation. After careful observation of the high-speed camera, it was found that the wall panel of the test building was more strongly shaken when subjected to the strong impact load generated by 500 kg TNT explosive.

(a)The blast face is damaged (b)Back blow to the face

**Fig. 8.** The model is damaged

### 3.2 Damage Effect Test of Reinforced Local Component

(1) Damage test of unreinforced color steel plate

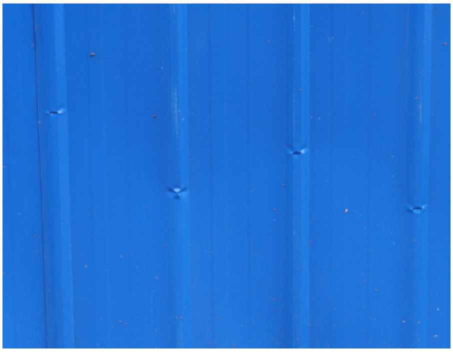
When the proportional distance is 10.77m /kg1/3, the color steel plate in the span and the purlin contact part due to purlin constraints and slight deformation, not with the purlin contact part is not found obvious deformation, as shown in figure 9. When the charge is 200 g and the explosion distance is 5 m, the longitudinal span of the steel plate is partially deformed, and the self-tapping joint of the steel plate and purlin is dented, as shown in figure 10. When the charge is 300 g and the explosion distance is 5 m, the longitudinal span of the steel plate has a large depression, and the purlin contact part has obvious deformation, some steel plate and purlin self-tapping joint tear, the damage mode is consistent with the prototype test, and the local steel plate is broken by the broken stone phenomenon, as shown in figure 11.

**Fig. 9.** Damage consequence of 100 g explosive plate

(a) The steel plate is damaged in the longitudinal span

(b) Purlin contact damaged

**Fig. 10.** Damage consequence of 200 g explosive plate



(a) The steel plate is damaged in the longitudinal span

(b) Purlin contact damaged

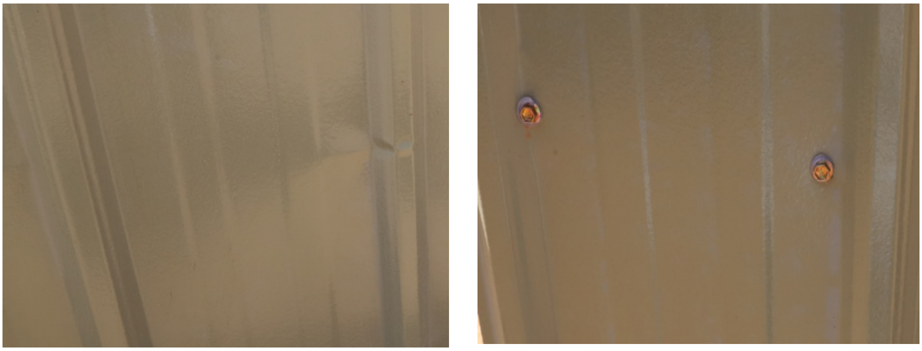
(c) Tear at self-tapping joint (d) Broken stone breakdown

**Fig. 11.** Damage consequence of 300 g explosive plate

(2) Damage analysis of 1 mm polyurea reinforced color steel plate

When the charge is 100 g and the explosion distance is 5 m, the color steel plate in the span and purlin contact part due to purlin constraints and slight deformation, compared with the unreinforced color steel plate deformation degree is low, not with the purlin contact part no obvious deformation, as shown in figure 12. When the charge is 200 g and the explosion distance is 5 m, the local deformation of the longitudinal span of the steel plate is less and the deformation degree is small, the deformation of the self-tapping joint of the steel plate and purlin is not obvious, and the breaking phenomenon is not found at the self-tapping joint, and the damage consequences are shown in figure 13. When the charge is 300 g and the detonation distance is 5 m, the structural change is not obvious compared with the test of 200 g. When the charge is 600 g and the explosion distance is 4 m, the longitudinal span of the steel plate and the contact part of the purlin are obviously deformed, the damage mode is the same as that of the unreinforced color steel plate, and the steel plate and purlin are not torn at the self-tap connection, verifying the effectiveness of the polyure-reinforced color steel plate, and the steel plate surface is not broken by the broken stone, as shown in figure 14. The displacement time-history curve of steel plate under each working condition is shown in figure 15. According to the displacement time-history curve, double-sided spraying polyurea color steel plate has the smallest displacement, and the explosion-proof effect is slightly better than that of spraying polyurea on the back explosion surface, while the explosion-proof effect of spraying polyurea on the front explosion surface is the worst.

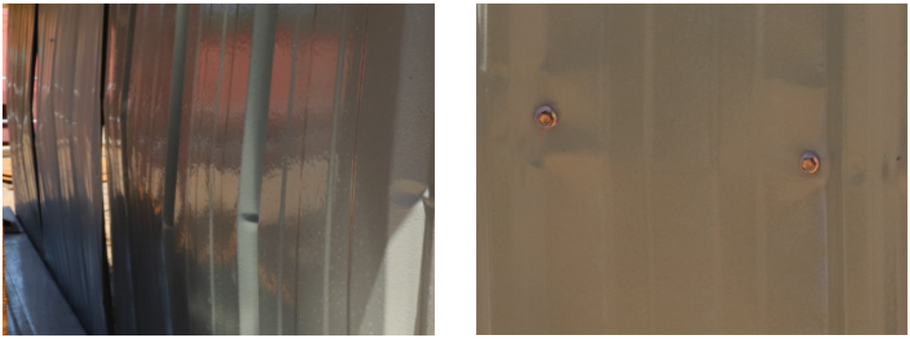
**Fig. 12.** Damage consequence of 100 g explosive 1mm polyurea steel plate



(a) The steel plate is damaged in the longitudinal span

(b) Purlin contact damaged

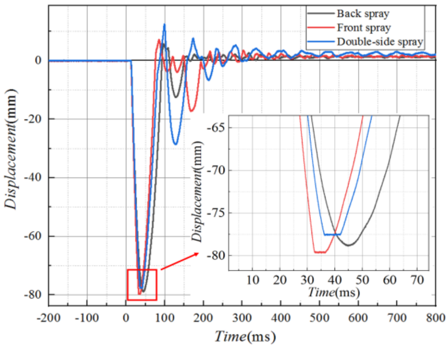
**Fig. 13.** Damage consequence of 200 g explosive 1mm polyurea steel plate



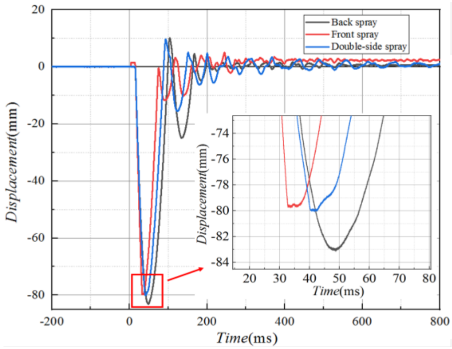
(a) The steel plate is damaged in the longitudinal span

(b) Purlin contact damaged

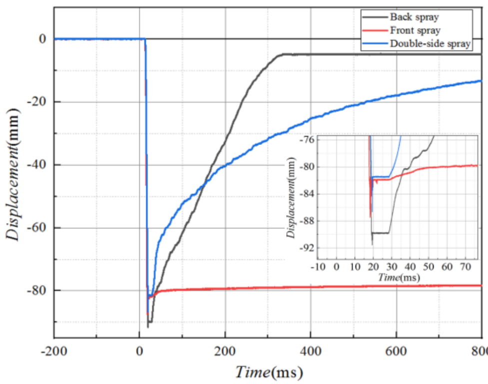
**Fig. 14.** Damage consequence of 600 g explosive 1mm polyurea steel plate




(a) 100g explosive action 1 mm polyurea steel plate displacement




(b) 200g explosive action 1 mm polyurea steel plate displacement




(c) 600g explosive action 1 mm polyurea plate displacement

**Fig. 15.** Displacement time history curve of 1 mm polyurea steel plate

(3) Damage analysis of 2 mm polyurea reinforced color steel plate

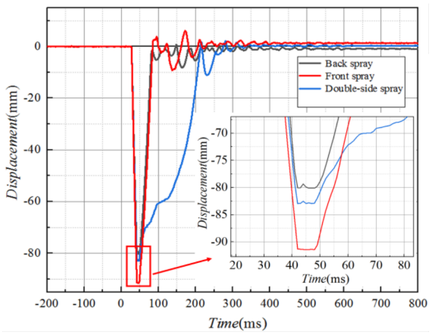
When the charge is 100 g and 200 g explosion distance is 5 m, the color steel plate span and purlin contact parts are not significantly deformed, not with purlin contact parts are not found obvious deformation, steel plate and purlin self-tapping joint deformation is not obvious, as shown in figure 16. When the charge is 300 g and the detonation distance is 5 m, the structure is slightly deformed, and the deformation is mainly concentrated in the longitudinal span of the color steel plate and the connection of the self-tapping, and the depression deformation occurs. When the charge is 600 g and the explosion distance is 4 m, the longitudinal span of the steel plate and the contact part of the purlin are obviously deformed, the damage mode is the same as that of the unreinforced color steel plate and 1 mm polyurea reinforced color steel plate, but the deformation degree is lower than the previous two, and the steel plate and purlin self-taping joint does not tear, further verifies the effectiveness of the polyurea reinforced color steel plate. The surface of the steel plate is not broken by the broken stone, as shown in figure 17, and the displacement time-history curve of the steel plate under various working conditions is shown in figure 18. According to the displacement time-history curve, the displacement of the polyurea color steel plate on the back explosive surface is not much different from that of the double-side spraying polyurea color steel plate, but the displacement deformation is smaller than that of the single-side spraying of the blasting surface, and the explosion-proof effect of the single-side spraying of the blasting surface is the worst.

**Fig. 16.** Damage consequence of 200 g explosive 2 mm polyurea steel plate

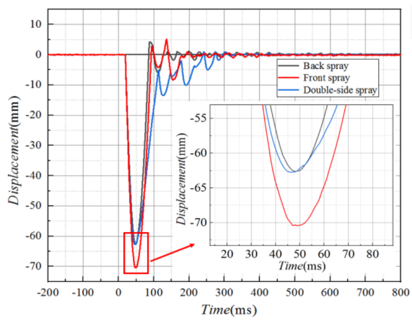
(a) The steel plate is damaged in the longitudinal span

(b) Purlin contact damaged

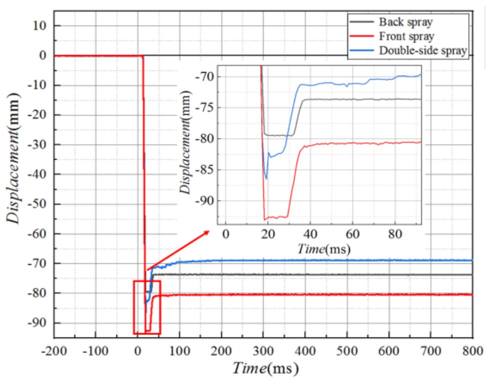
**Fig. 17.** Damage consequence of 600 g explosive 2 mm polyurea steel plate




(a) 100g explosive action 2 mm polyurea steel plate displacement




(b) 200g explosive action of 2 mm polyurea steel plate displacement




(c) 600g explosive action of 2 mm polyurea steel plate displacement

**Fig. 18.** Displacement time history curve of 2 mm polyurea steel plate

## 4 Conclusions and Suggestions

By conducting near-earth explosion damage tests on prototype plant and full-size reinforced plant model, this paper clarifies the dynamic response of the structure, explores the weak parts of the structure, proposes and validates the reinforcement methods, and summarizes the following conclusions:

(1) Strong vibration occurs when the prototype building is subjected to explosion impact load, which leads to tearing and damage of the wall panel;

(2) Polyurea elastic ability can effectively improve the anti-knock ability of wall color steel plate. Among them, the antiknock protection effect of double-sided spraying polyurea is slightly better than that of spraying polyurea on the back explosion surface, and the antiknock ability of spraying polyurea on the front explosion surface is the

worst. To a certain extent, double-sided spraying polyurea can prevent the damage of splashing products such as gravel on the color steel plate.

(3) The anti-explosion test proves that the important plant targets set on the ground are highly vulnerable and easily damaged under the action of explosion load. It is suggested to strengthen or add basements inside the important plant. The wall of the building is reinforced with backburst surface or double-sided spray film material.

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