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Simulation of plant structure collapse under the action of manganese metal dust explosion

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Abstract

In order to understand the damage of manganese metal dust at the lower limit of explosion concentration under the explosion condition of the factory building, ANSYS/DYNA used TNT equivalent to simulate the damage of the building structure (column, brick wall) by the shock wave of the manganese powder explosion. The research results show that: when the concentration of manganese powder in the limited space reaches a certain level (≥50g/m3), 0.5 ms after the explosion, the concrete at the lower part of the column will be damaged first, that is, cracks will appear, and the damaged concrete will fail. The bricks in the middle of the face are obviously displaced first, the mortar partially fails, and the brick wall structure is damaged. In this case, the wall of the factory building will collapse. The explosion produces significant damage to the building structure (columns, brick walls).

Keywords

Manganese metal starch; explosion effect; damage collapse simulation, ANSYS/DYNA.

1. Introduction

Manganese metal powder is an indispensable and widely used industrial raw material. Manganese metal dust cloud may be generated during the production and operation of manganese metal powder. Therefore, the production of manganese metal powder has potential fire and explosion risks, which may have serious consequences. In recent years, dust explosion accidents at home and abroad have occurred frequently, and these accidents involve a wide range of production industries and dust types [1-2], such as the explosion of aluminum metal dust in Kunshan Zhongrong and Lihua starch enterprises.

In order to understand the danger of dust explosion, scholars have carried out extensive research. References [3-4] studied the sensitivity range of ignition energy and the main influencing factors. Deng Yueyang [5] studied the minimum ignition energy of manganese metal dust through experiments. Numerical simulation of dust and aluminum metal dust explosion teaching. However, the simulation of the damage and collapse of the production plant caused by manganese metal dust explosion has not been published in the publication. Therefore, the author uses ANSYS/DYNA to simulate the damage of the building structure (column, brick wall) by the shock wave of the manganese powder explosion with TNT equivalent, so that the People have an intuitive understanding of the explosion hazard of manganese metal dust.

2. Numerical model establishment

2.1. Dust explosion model

Because the ignition process of manganese dust is very violent, the reaction speed is very fast, and the dust cloud explosion is strong. This simulation adopts the TNT equivalent method to

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simulate the destructive effect of metal dust gas cloud explosion into the destructive effect of TNT explosion, so as to change the amount of dust cloud. Converted to TNT equivalents. The TNT equivalent method is simple and easy to implement, and its defects are ignored in the simulation process.

2.2. Numerical simulation of workshop

The material performance of concrete under impact load has always been a hot spot in explosion-proof design research, and the key to numerical simulation is also the choice of the material model. The dynamic properties of concrete have the following characteristics [6]:

(1) The concrete material has obvious strain to dynamic tension;

(2) The instantaneous stress is proportional to the strain rate, the increase has little to do with the strength of the concrete itself, and the increase in tensile and compressive yield strength has a logarithmic relationship with the elongation;

(3) The axial elongation corresponding to the yield point does not change significantly with the increase of elongation;

(4) The maximum volume expansion also increases with the expansion rate [7];

(5) The energy dissipation capacity also increases with the increase of the strain rate ;

(6) The initial elastic modulus, the quantity changes little, the secant modulus increases with the increase of elongation, etc. [8].

Reinforced concrete frame structures are widely used in commercial and civil buildings due to their flexible layout, easy-to-satisfy production technology and usage requirements, and simple structure.

The simulation workshop is a space workshop of 10m×10m×4m, and the simulation model includes rigid ground model, column model and air model.

2.2.1 Establishment of rigid ground model

The ground adopts a concrete model, and the material is defined by MAT_RIGID_TITLE. The rigid body mass can be calculated by the program by volume and density. The degrees of freedom of all nodes in a rigid body are coupled to the rigid body's center of gravity. Rigid bodies have only six degrees of freedom, no matter how many nodes are defined in the finite element model. Therefore, defining the rigid body as a rigid body in the finite element model can effectively reduce the CPU calculation time. The rigid ground model is shown in Figure 1.

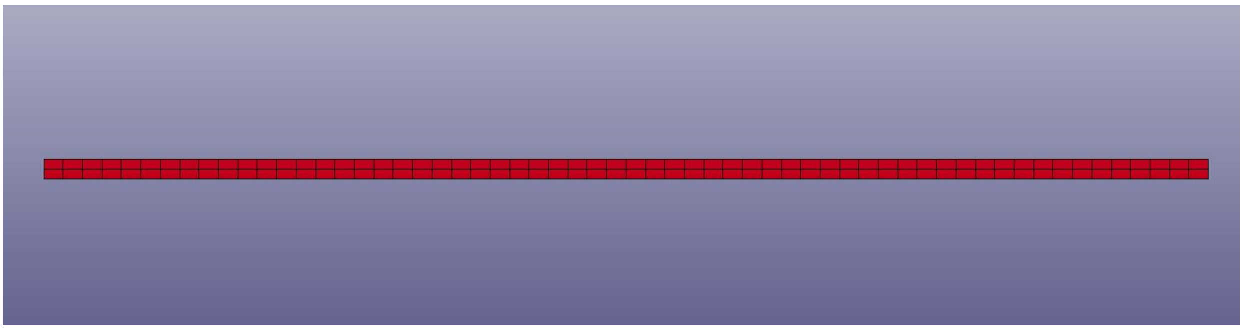

Fig. 1 Rigid ground model

Table 1 Rigid ground parameter

variable	MID	R0(kg/m^3)	E(Pa)	PR(Pa)
Variable parameter	1	2800	210109	0.3

The variable description is as follows:

MID —— material identification number;

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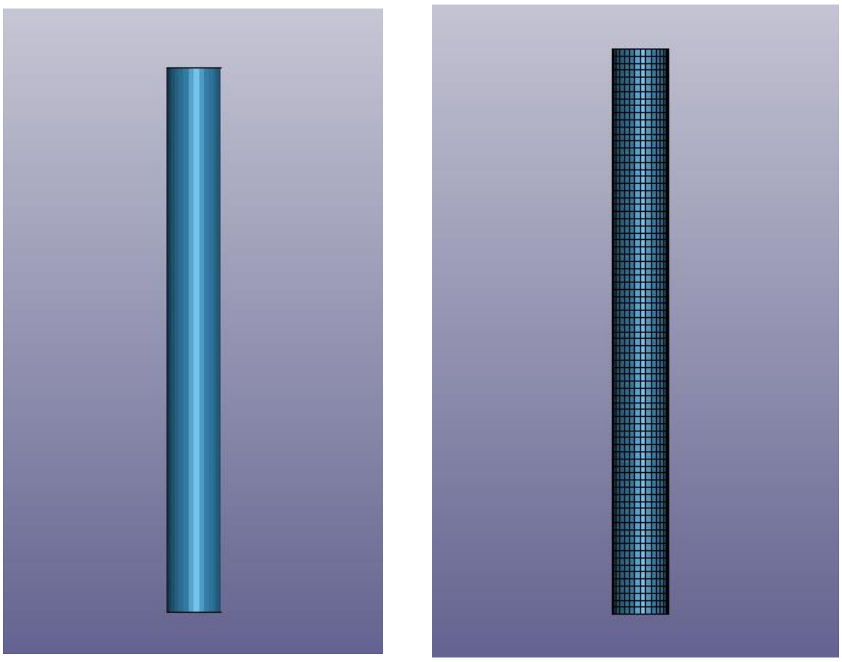
R0——Material density;

E —— Young's modulus;

PR —— Poisson's ratio.

2.2.2 Building column model of factory building

The diameter of the column is 400mm and the height is 4000mm. This simulation only considers the condition of the column itself, and does not consider its bearing and load. Therefore, if the column is damaged, it can be regarded as the damage to the plant structure. The column adopts the failure model MAT_BRITTLE_DAMAGE model, replaces the crack with the damage value, and judges the expansion of the crack by observing the damage cloud diagram.



a Modeling diagram b grid diagram

Fig. 2 Column modeling diagram

The column parameters are shown in Table2.

Table 2 Plant column parameter

variable	MID	R0(kg/m^3)	E(pa)	PR(pa)	TLIMIT(kPa)
Variable parameter	2	2500	210109	0.2	5

The variable description is as follows:

MID —— material identification number;

R0——Material density;

E —— Young's modulus;

Pr——Poisson's ratio;

TLIMIT —— Tensile strength.

2.2.3 Air Model Establishment

The air model adopts the MAT_NULL material model, as shown in Figure3.

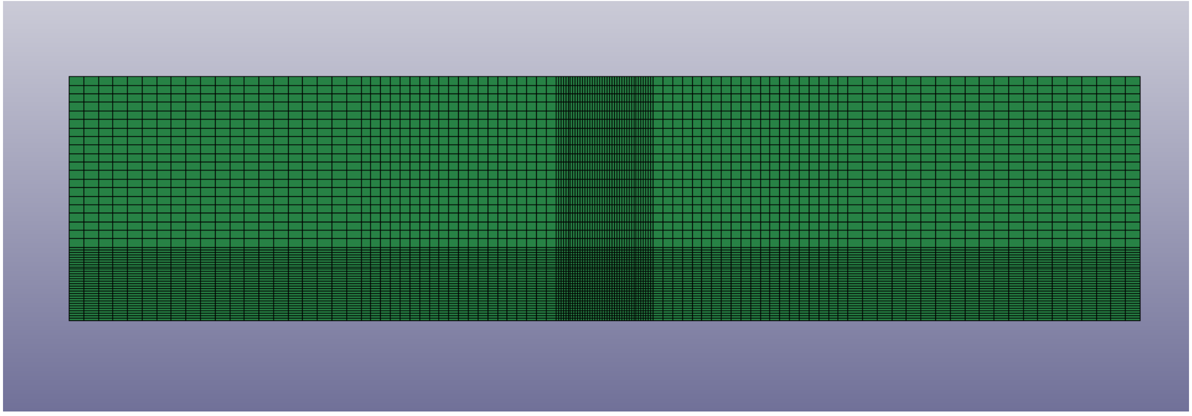


Fig. 3 Air model diagram

Air parameters are shown in Table3.

Table 3 Air parameter

variable	MID	R0(kg/m^3)	PC(Pa)	MU	TEROD	CEROD
Variable parameter	3	1.185	-10	1.844010^{-5}	0	0

The variable description is as follows:

MID - Material identification number;

R0——Material density;

PC——cut-off pressure (≤0.0);

MU——dynamic viscosity coefficient;

TEROD——V/V_0 relative volume, if this parameter is equal to zero, the tensile corrosion is not activated;

CEROD - V/V_0 relative, if this parameter is equal to zero, compressive corrosion is not active.

2.2.4 Building the brick wall model of the factory building

At present, there are two main types of simulation methods for brick walls. The first type is the monolithic model, which is simplified as a whole, and the complex interaction between the internal mortar and bricks is not considered, and the analysis is carried out according to the same continuous material type. The second category is the separation model, which takes bricks and mortar as independent components and considers the interaction between them [9].

Due to the relatively high strength of the bricks, the mortar layer between the bricks is a weak layer. Li Lisha, Du Jianguo, Zhang Honghai et al[10]. found in their experiments that the damage of the brick wall under the shock and vibration load occurred in the mortar layer, while the bricks did not fail.

So we can set the material model of the brick to the rigid body MAT_RIGID material by defining each brick of the brick wall model as a rigid brick wall, as shown in Figure 4.

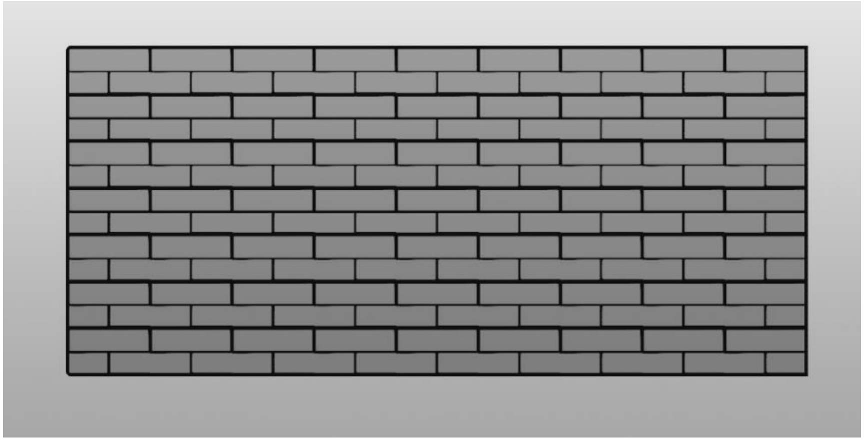


Fig. 4 Brick wall model drawing

The brick parameter table is shown in Table4.

Table 4 Brick parameter

variable	MID	R0(kg/m^3)	PR(pa)	G(GPa)
Variable parameter	4	1600	0.3	2.5

The variable description is as follows:

MID - material identification number;

R0——Material density;

Pr——Poisson's ratio;

G - shear modulus. The mortar parameter table is shown in Table-5.

Table 5 Mortar parameter

variable	MID	E(Gpa)	R0(kg/m^3)	PR(pa)	G(GPa)
Variable parameter	5	1.44	1900	0.2	0.03

The variable description is as follows:

MID ——material identification number;

E——Young's modulus;

R0——Material density;

Pr——Poisson's ratio;

G——shear modulus.

3. Numerical simulation of explosion

3.1. TNT Equivalent Simulation

There are many methods for LS-DYNA to simulate explosive explosion, including Lagrange method, Eulerian method and ALE method. The principles based on each method are quite different, and the later modeling and parameters are also inconsistent. The material model of the explosive used in the explosion simulation generally selects the material type -MAT_HIGH_EXPLOSIVE_BURN. Therefore, MAT_HIGH_EXPLOSIVE_BURN is selected as the explosive material model in this simulation.

This explosion simulation is simulated by the TNT equivalent method. In the tests of other scientists such as Hertzberg M, Cashdollar K.L and Zlochower.I.A [11], the combustion of dust cloud is similar to the combustion of gas under constant volume conditions, so the manganese metal dust cloud The simulation calculation is similar to the gas, and the volume is $400m^3$ in the space of 10m×10m×4m confined space. The lower explosion limit of manganese metal dust is $50g/m^3$, which is much smaller than the optimal concentration of $500g/m^3$ obtained by the minimum ignition energy in the 1.2L Hartmann tube experiment. Therefore, in the subsequent explosion simulation, the lower explosion limit of manganese metal dust is $50g/m^3$. m^3, the hazard caused by its explosion can be simulated.

Combustion equation for manganese metal:

$$[\,Mn] + 1\,/\,2\{O2\,\} = (\,MnO) + 385186\,J \tag{1}$$

It can be seen from the above formula that the combustion heat of the manganese metal powder is about 140000kJ/kg.

The formula for calculating the TNT equivalent of a steam cloud explosion.

$$W_{TNT} = \frac{AW_f Q_f}{Q_{TNT}} \tag{2}$$

where:

A——TNT equivalence coefficient of steam cloud, take 4%;

WTNT——TNT equivalent of steam cloud, Kg;

Wf——Total mass of fuel in steam cloud, Kg;

Qf——The combustion heat of the fuel, kJ/kg;

QTNT—The explosion of TNT;

QTNT=4520kJ/kg.

Taking the manganese metal dust cloud of $45g/m^3$ evenly distributed in the workshop space of $400m^3$, there are

$$w_f = \frac{400\times50}{1000} = 20kg \tag{3}$$

The TNT equivalent is :

$$W_{TNT} = \frac{AW_f Q_f}{Q_{TNT}} = \frac{0.04\times20\times14000}{4520} = 2.4778kg \tag{4}$$

Place 2.4778kg of TNT in the space to replace the dust explosion simulation, and the placement position is shown in Figure5:

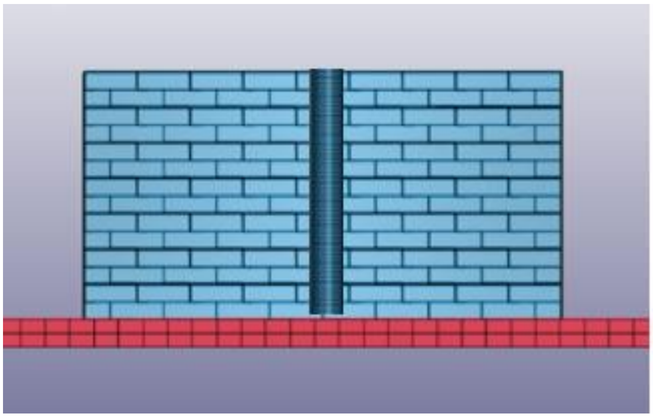


Fig. 5 Explosive placement diagram

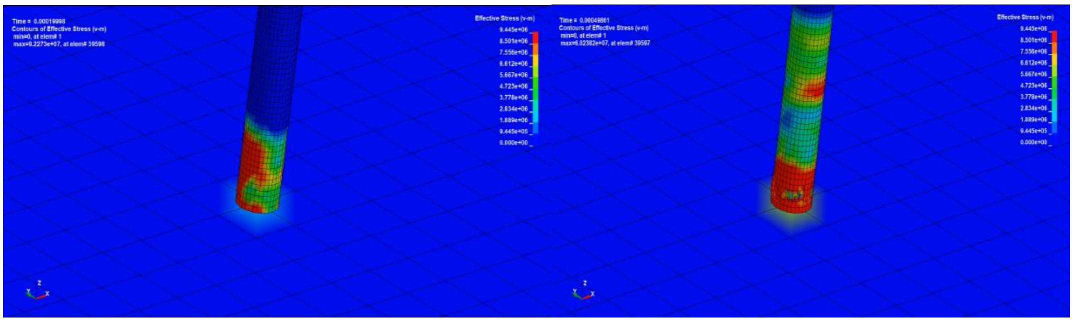
3.2. Model loads and failure criteria

In order to simulate the failure mode of the column and brick wall, the MAT_ADD_EROSION failure model is added to the material model of the column and brick wall. MAT_ADD_EROSION failure model The material failure model often used in LS-DYNA can define a variety of failure criteria for materials, mainly including stress and strain. In the calculation, if the stress or strain of a certain element reaches the set failure standard, the element will fail, it will be deleted from the model, and it will no longer bear the load, so as to simulate the cracking failure of the brick wall. The failure data used in this paper is 0.15 for the failure concrete and 0.0025 for the failure strain of the brick wall [12].

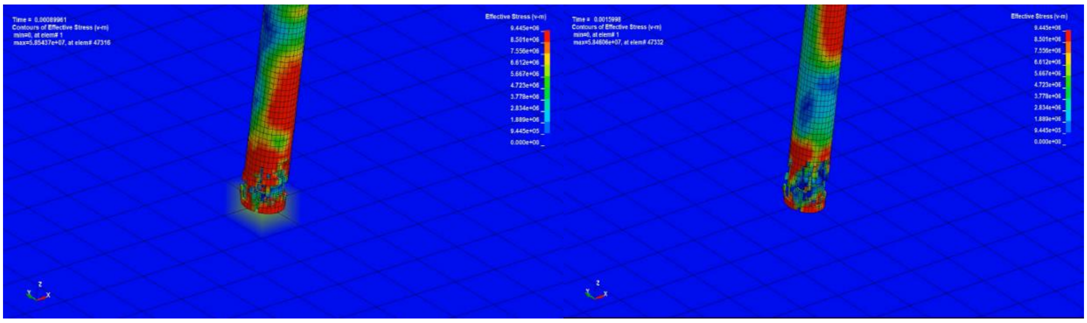
In this simulation, an initial gravity acceleration load of 9.8 m/s^2 is given to the column and concrete model.

3.3. Analysis of simulation results

The simulation process of the impact and damage of the column in the infinite airspace is shown in Figure6.



a 0ms b 0.3ms

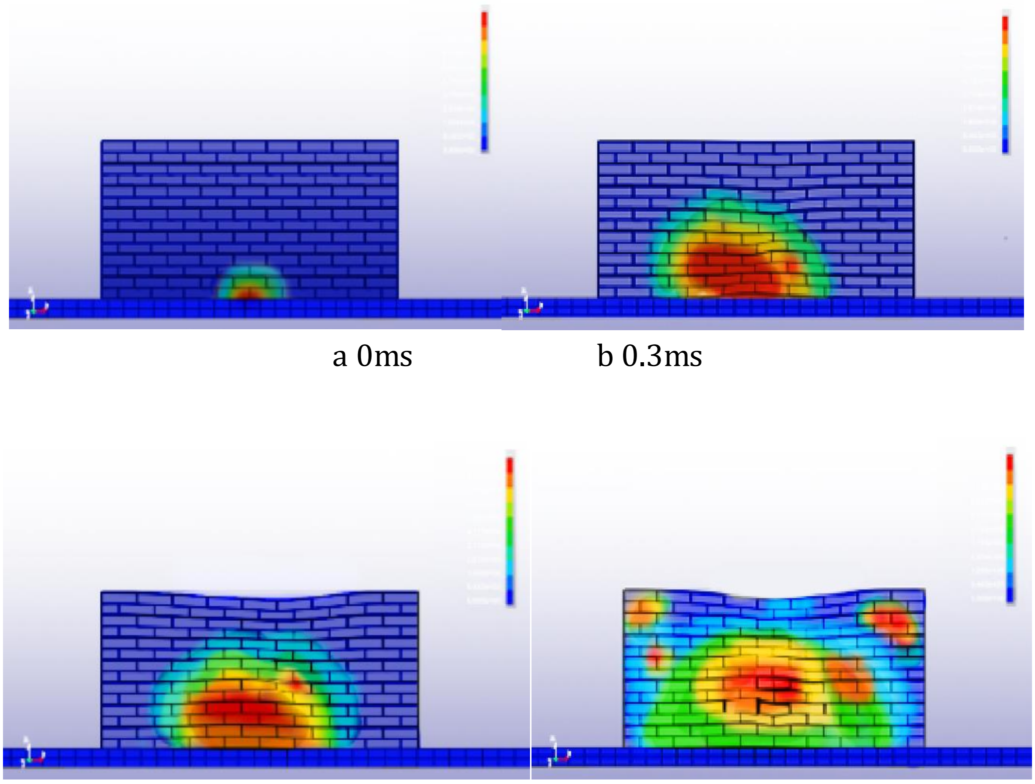


c 0.4ms d 0.5ms

Fig. 6 Explosion diagram

It can be known from Figure6 that after the explosive explodes, the blast shock wave spreads to the surrounding space immediately. 0.3ms, the shock wave propagates to the bottom of the column. With the continuous impact of the shock wave, the local stress at the bottom of the column gradually increased, forming a red high-stress area, and the high-stress area continued to spread upward to the central area of the column, and the concrete at the bottom of the column cracked. A red high stress area was formed in the middle of the column at 0.4ms. As time goes by, the red high stress area in the middle gradually moves to the top of the column. When it is about 0.5ms, the lower concrete is first damaged, that is, cracks appear, and the damaged concrete fails.

Figure7 shows the simulation process of the impact on the brick wall and the degree of damage in the infinite airspace. It can be seen from Figure7 that after the explosive explodes, the explosion shock wave spreads to the surrounding space immediately. 0.3ms, the shock wave propagates to the bottom of the brick wall. With the continuous impact of the shock wave, the local stress at the bottom of the 0.3ms brick wall gradually increased, forming a red high stress area, and some areas of the brick wall mortar began to deform, and the bricks were displaced. At 0.4ms, a red high stress area was formed in the middle of the center of the brick wall. With the passage of time, the stress spreads to various parts of the brick wall, forming various stresses of different magnitudes. When it reaches about 0.5ms, the middle bricks first undergo significant displacement, the mortar partially fails, and the brick wall structure is damaged. Here In this case, the walls of the factory buildings will collapse.



a 0ms b 0.3ms

c 0.4ms d 0.5ms

Fig. 7 Explosion simulation diagram of brick wall

4. Conclusion

1) After the explosion, the explosion shock wave spreads to the surrounding space, and the damage to the bottom of the column is an instantaneous increase from 0.3 ms to 0.5 ms. When it reaches about 0.5 ms, the lower concrete is destroyed first, that is, cracks appear, and the damaged concrete i.e. invalid.
2) After the explosion, the impact on the brick wall in the infinite airspace gradually increases from the local stress at the bottom of the brick wall upwards. When it reaches about 0.5ms, the middle brick first shifts significantly, the mortar partially fails, and the brick wall structure is damaged, in which case the walls of the building will collapse.
3) ANSYS/DYNA uses TNT equivalent to simulate the damage of manganese powder explosion shock wave to building structure (column, brick wall), when the concentration of manganese powder in limited space reaches a certain level ($\geq 50 g/m^3$), The explosion produces significant damage to the building structure (columns, brick walls).

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