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Influence of aggregate spatial distribution of concrete against projectile penetration

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Abstract. Coarse aggregate settlement may occur during concrete pouring, which affects the ability to resist projectile attack. In order to study the anti-penetration performance of concrete, and obtain high penetration resistance concrete, mesoscale finite element model of different aggregate space distribution of concrete was established, the numerical simulation of long rod rigid projectile penetrating into different concrete was conducted. The results showed that aggregate settlement had great influence on target scabbing; aggregate size and settlement had limited influence on projectile residual velocity.

1. Introduction

Concrete is widely used in civil engineering, and its performance to resist projectile penetration has attracted wide attention in military field [1]. Aggregate settlement may occur after concrete vibration. The maximum aggregate size is different of different concrete. Therefore, it is of engineering practical significance to study the effect of aggregate spatial distribution on the anti-penetration performance of concrete.

The influence of aggregate on penetration was studied by experiment and numerical simulation. The effects of aggregate gradation, size and type on cratering and scabbing were experimental studied by Bludau et al. [2]. The effect of aggregate size on the residual velocity of projectile was experimental studied by Werner et al. [3]. Wriggers et al. [4] gave the method of establishing the mesoscale finite element model of concrete. Fang et al. [5] numerically simulated the effects of aggregate size, aggregate strength and aggregate volume fraction on projectile deflection in deep penetration. At present the numerical simulation of penetration was based on thick target, there was a lack of research on thin targets. The influence of the spatial distribution of aggregate needs to be further studied.

In this paper, numerical simulation of penetrating mesoscale concrete was carried out, and the influence of aggregate size and aggregate settlement on target scabbing and projectile residual velocity was studied.

2. Numerical simulation

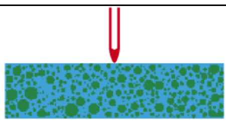
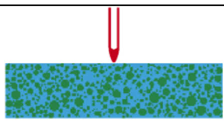
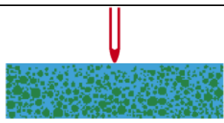
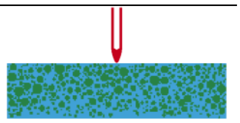
2.1. Mesoscale finite element model and scheme

Projectile. The mass of the projectile was 556 g, the diameter d was 30 mm, the ratio of length to diameter was 5, the caliber-radius-head was 3, and the initial velocity was 800 m/s.

Concrete target. The diameter of the target was $20d$, the thickness was $5d$, the volume fraction of coarse aggregate was 40%, and the continuous gradation was adopted. In this paper, four targets are studied, as shown in table 1, taking into account the maximum aggregate size and aggregate settlement.

Modeling process. The large aggregate was easier to settlement, so the large aggregate was generated first. Under the dynamic load, the crack is mainly through the aggregate, so the connection between aggregate and mortar could be simplified as a common joint. The cracks are sensitive to the mesh size, so the whole target plate was refined, and the non-reflective boundary was added to the cylindrical side to simulate the large-size target.

Table 1. Penetration scheme

Number	1	2	3	4
Section				
Maximum aggregate size (mm)	40	31.5	31.5	31.5
Aggregate settlement	no	no	yes	yes

2.2. *Material constitution*

Projectile. When the initial velocity is less than 1000 m/s, the head of the projectile usually does not erode and can be simplified as a rigid projectile, thus improving the computational efficiency.

Concrete target. The concrete around the projectile head was plastic under high pressure of penetration load. HJC constitutive model can describe the mechanical characteristics of concrete like material under high pressure; due to the lack of mechanical parameters of mortar, 43MPa concrete was used as a substitute in this paper [6]. The JH-2 constitutive model describes the high pressure damage behavior of brittle materials [7]; granite was used as coarse aggregate in this paper, and its constitutive parameters were shown in [8]. The concrete far away from the projectile head was brittle under the action of the tensile wave. The minimum hydrostatic erosion criterion was used to simulate the crack.

3. Result analysis

The scabbing and the perforation projectile could effectively kill the objects in the building, which were characterized by the scabbing diameter (figure 1) and the projectile residual kinetic energy, respectively.

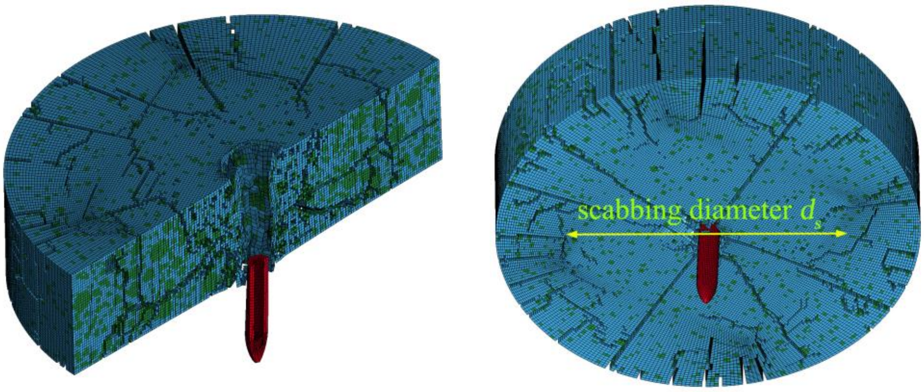


Figure 1. Target damage

3.1. *Target damage*

Using the dynamic software LS-DYNA to solve the problem, the damage result of target 2 is shown in figure 1. Radial cracks occurred in the far region of the target under tensile stress. Sparse wave was transmitted from the target surface, and then scabbing occurs. It took a long time for the scabbing to completely separate from the target. Here only calculated the initial moment of the scabbing formation.

Figure 2 and table 2 show the comparison of dimensionless scabbing diameters (d_s/d) of four targets. The size difference of coarse aggregate is limited, which did not reflect the difference in scabbing diameter. The volume fraction of the aggregate on the back of the target 3 increased and the target 4 decreased. The tensile strength of the aggregate is higher than that of the mortar, and the increase of the volume fraction will help to reduce the scabbing diameter. Compared with the target 2, the dimensionless scabbing diameter of the target 3 decreased by 10.6 %, and the target 4 increased by 9.8 %, as shown in table 2.

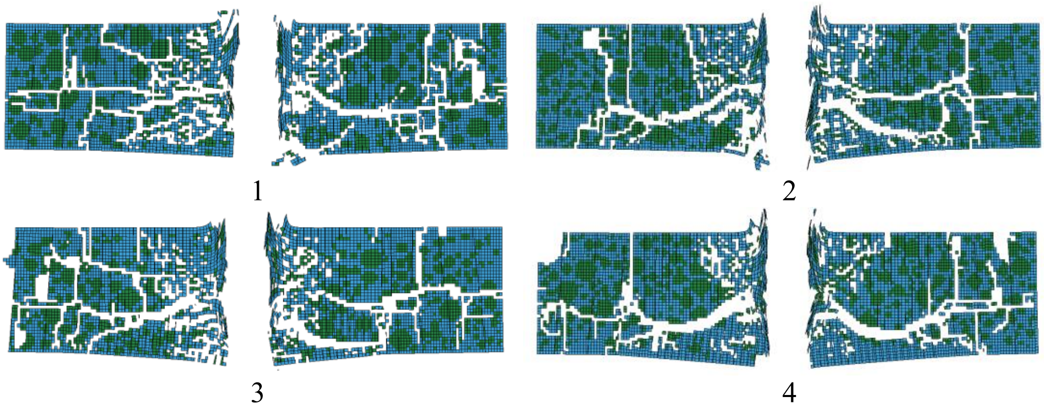


Figure 2. Scabbing

Table 2. Scabbing diameter

Number	1	2	3	4
d_s/d	13.4	13.2	11.8	14.5

3.2. Residual kinetic energy of projectile

Table 2 shows that the size and settlement of aggregate have a limited effect on the residual kinetic energy of the projectile. During the penetration process, the projectile passed through a large amount of aggregates, which reduced the randomness, so the influence of the spatial distribution of aggregates was limited.

Table 3. Residual kinetic energy of projectile

Number	1	2	3	4
Residual velocity (m/s)	624	615	618	614
Residual kinetic energy (%)	60.8	59.1	59.7	58.9

4. Conclusions

In this paper, the influence of aggregate size and aggregate settlement on penetration was studied, and the following conclusions were obtained:

1. The scabbing diameter of the target was not sensitive to the aggregate size (31.5 mm and 40 mm), but sensitive to the aggregate settlement.

2. The influence of aggregate size and aggregate settlement on the residual kinetic energy of projectile was limited.

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