Study on Explosion Resistance of Reinforced Concrete Slab Wrapped with Glass Fibre Reinforced Polymer (GFRP)

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Abstract. A new type of reinforced concrete slab wrapped with glass fibre reinforced polymer (GFRP) is proposed, which is composed of GFRP profile slab wrapped with reinforced concrete slab. In order to master the anti-explosion performance of the new composite slab structure under the action of explosion, the dynamic response results of the new wrapped glass fibre reinforced concrete slab structure and the ordinary concrete slab structure under the action of explosion are analyzed and compared by using ANSYS/LS DYNA and fluid structure coupling algorithm. The results show that the new wrapped glass fibre reinforced concrete slab structure, which through the sand bonding treatment of GFRP ribbed slab and inner surface, GFRP slab is closely combined with concrete, giving full play to the superposition effect of GFRP and concrete on explosion impact resistance, which has better explosion impact resistance than ordinary reinforced concrete slab structure, and provides important support for the application of GFRP reinforced concrete composite structure.

Keywords. Explosion; GFRP; concrete; combined structure; anti-explosion performance.

1. Introduction

Glass fibre reinforced polymer (GFRP) is a kind of composite material with high strength, good durability and light weight. In particular, GFRP material has obvious advantages over ordinary concrete in impact resistance, but it also has disadvantages such as weak stiffness, weak shear capacity, high price and prone to brittle failure. The shear capacity of concrete material is obviously stronger than that of tensile capacity, which is just complementary, the combination of the two materials makes up for the shortcomings of the two materials and gives full play to the advantages of the two materials. The application research of the composite structure of GFRP and concrete in civil engineering has become a new hotspot. Hillman and others first proposed GFRP concrete composite structure. GFRP profile can also be used as formwork during construction, and bear part of the structural role instead of reinforcement [1]. Based on the above research, scholars from various countries have put forward many different combination forms of GFRP concrete composite beam slab structures, some of which have been applied in practical engineering, mainly in bridge structures [2-10].

There are two main methods for the study of structural dynamic response under explosion: test and numerical analysis. Considering the economy and safety, the numerical analysis method has become the main means of the study of explosion. Daniel (1997) used the finite element program LS DYNA to analyze the dynamic interaction of soil structure system composed of underground buried structures under the impact of underground explosion [11]; Syruin (1997) studied the dynamic response of closed structures with various shapes and materials under explosion by means of numerical analysis, and

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compared them by experiments [12]. Du (2006) developed the explicit finite element calculation program LS DYNA, added viscoelastic artificial boundary conditions, established a three-dimensional viscoelastic plastic dynamic response analysis model of underground structure, and discussed and analyzed the dynamic response analysis of underground structure under explosive explosion [13]. Camena (2011) used the numerical simulation of low velocity impact tests on glass fabric/epoxy laminates through the LS-DYNA finish element (FE) code [14]. Ning (2013) conducted finite element analysis on the penetration resistance of glass steel composite plates through LS-DYNA, applied loads and boundary conditions [15]. Zhikharev (2016) deals with the spherical testing and numerical modeling problems of fragment pavement of glass fabric/epoxy phenolic (GFRP) laminates [16]. Chen (2018) used LS-DYNA to conduct numerical simulation analysis on wall surface reinforcement with sprayed glass fibre material (GFRP) in view of the limitations of masonry structure [17].

In this paper, a new type of reinforced concrete slab wrapped with GFRP is proposed, which is composed of GFRP profile slab wrapped with reinforced concrete slab. Using the explicit dynamic finite element program ANSYS/LS DYNA, the overall structural dynamic analysis model of reinforced concrete slab and ordinary concrete slab with wrapped GFRP slab is established, and the anti-explosion performance of reinforced concrete slab with wrapped GFRP slab is studied by comparing and analysing the stress, displacement and velocity time history curves of the key points of the two different slabs under explosion. It provides technical support for the application of GFRP in structural anti explosion.

2. Reinforced Concrete Slab Wrapped with GFRP Slab

Wrapped GFRP slab reinforced concrete slab is a slab structure composed of GFRP slab and reinforced concrete. As shown in figure 1, GFRP profile slab is provided with ribbed slab, and the ribbed side is in contact with reinforced concrete. At the same time, epoxy sand blasting treatment is carried out on the inner surface, and sand bonding treatment on the rib and inner surface is carried out to closely combine GFRP slab with concrete, so as to give full play to the bearing capacity of GFRP reinforced concrete composite structure. GFRP plate has high tensile strength, small structural weight and strong explosion impact resistance. As a permanent formwork, it bears the force together with the later poured reinforced concrete and works together to bear the explosion impact load. The reinforced concrete slab wrapped with GFRP slab can give full play to the high strength and explosion impact resistance of GFRP. The new composite slab structure can be used as a tunnel and civil air defence channel to resist explosion. At the same time, GFRP slab can be used as a permanent formwork to save formwork construction time and can be used for emergency repair and construction projects.

![Figure 1](image1.png)

**Figure 1.** Schematic diagram of reinforced concrete slab wrapped with GFRP slab.

3. Calculation Model and Parameters

The general explicit nonlinear dynamic analysis finite element program ANSYS/dyna is used for calculation and analysis. The simulation model is composed of four materials: explosive, soil, air and reinforced concrete structure. According to the charging parameters of Russian aviation bomb, the depth of 25cm*25cm*25cm cube explosive is approximately determined for simulation research. The depth of soil invasion is 5m, the bottom of explosive is 5m away from the concrete slab, and the central initiation is adopted. The buried depth of concrete slab is 10m. The thickness of the slab is 600mm,
surrounded by fixed boundaries, with a length of 6m and a width of 3M. At the same time, monitoring point a is set at the centre of the plate bottom to monitor the dynamic response of the plate under the action of explosion impact. The calculation in this paper is a comparative study on the explosion resistance of ordinary concrete and reinforced concrete slab with wrapped GFRP slab under the same conditions. Therefore, the calculation conditions of the two models are the same, except that the top plate adopts ordinary concrete slab and reinforced concrete slab with wrapped GFRP slab respectively.

According to Saint Venant’s theorem and considering the calculation efficiency, the total width of the model is set as 30m. Due to the influence of the structure, the soil at the bottom of the structure is less affected by the explosion load, and the overall height is taken as 35m. The cross section of the model is shown in figure 2. The boundary condition of reinforced concrete slab wrapped with GFRP slab is that all sides are fixed boundaries, which is shown in figure 3. The outside of air, explosive and lining is assumed to be isotropic uniform rock mass, the surrounding and bottom boundaries are non-reflective boundaries, and the upper boundary is free boundary. The underground structure will be deformed due to the upper self-weight pressure and the lateral pressure of the surrounding soil, but the deformation is stable. The effect of explosion load is much greater than that of self-weight load, so the influence of gravity is ignored [18]. It is approximately assumed that there is a reliable bond between materials without bond slip. GFRP element and adjacent concrete elements share a node, so as to ensure the displacement coordination and force transmission between them.

![Figure 2](image1.png)

Figure 2. The calculation diagram of explosion model (unit: m).

![Figure 3](image2.png)

Figure 3. The calculation model of reinforced concrete slab wrapped with GFRP slab.

The air, explosive, rock and structure in the model adopt solid164 three-dimensional solid unit, and the cm-g-us unit system is adopted uniformly. Arbitrary Lagrange Euler (ALE) algorithm is used for
explosive, soil and air elements, Lagrange algorithm is used for structure, and fluid structure coupling algorithm is used for the interaction between rock, air and structure. Material model for air medium selection*mat_Null and equation of state*EOS_LINEAR_P0lynomial is described, and the material parameters are shown in table 1. Explosive*mat_ HIGH_EXPLOSIVE_Burn and equation of state*EOS_JWL is described, and the material parameters are shown in table 2. The medium in the model is moderately weathered sandstone, and *mat is selected_PLASTIC_Kinematic is described, and the material parameters are shown in table 3. Reinforced concrete structure, through the keyword*mat_BRITTLE_Damage to simulate, concrete strength grade C40, GFRP material through*mat_ENHANCED_COMPOSITE_Damage material model (table 4 for material parameters).

Table 1. Air material parameters.

| Density (g/cm³) | Pressure cutoff | Dynamic viscosity coefficient |
|----------------|----------------|-------------------------------|
| 0.8            | 0              | 0                             |

Table 2. Explosive material parameters.

| Density (g/cm³) | Detonation velocity (m/s) | Dynamic viscosity coefficient |
|----------------|---------------------------|-----------------------------|
| 1.367          | 4200                      | 2.4×1010                   |

Table 3. Rock material parameters.

| Density (g/cm³) | Elastic modulus (GPa) | Poisson’s ratio | Yield stress (MPa) | Strengthening coefficient |
|----------------|-----------------------|----------------|-------------------|--------------------------|
| Rock           | 2.2                   | 80             | 0.3               | 50                       | 0.5                      |

Table 4. Structural material parameters.

| Density (g/cm³) | Elastic modulus (GPa) | Poisson’s ratio | Compressive strength (MPa) | Tensile strength (MPa) | Failure strain |
|----------------|-----------------------|----------------|---------------------------|-----------------------|----------------|
| Reinforced concrete | 2.5                   | 100            | 0.25                      | 26.8                  | 2.39           | 0.02           |
| GFRP board           | 2.0                   | 45             | 0.3                       | 150                   | 20             | 0.1            |

4. Analysis of Numerical Simulation Results

Figure 4 shows the time history curve of vertical stress at measuring point a of two model slab top structures. It can be seen from figure 4 that the time history curve of pressure at the top of ordinary concrete slab structure shows that the maximum vertical compressive stress at monitoring point a is 5.2MPa and the maximum vertical tensile stress is 2.8MPa: The maximum vertical compressive stress and maximum vertical tensile stress of point a of GFRP reinforced concrete slab are 2MPa and 1.3MPa respectively. Compared with the common concrete model, the compressive stress of the roof monitoring point of the GFRP steel reinforced concrete slab model decreases by 61% and the tensile stress decreases by 53%.

Figure 5 shows the equivalent stress time history curve of measuring point a of two model slab top structures. From figure 4, it can be seen that the equivalent stress time history curve of ordinary concrete slab top structure shows that the equivalent stress of monitoring point a is 5.1MPa, while the equivalent stress of monitoring point a of GFRP reinforced concrete slab is 2.3MPa. Under the same explosion action, the equivalent stress of GFRP steel reinforced concrete slab model is 55% lower than that of ordinary concrete model.
Figure 4. Time history curve of vertical stress at measuring point a of model structure.

Figure 5. Time history curve of equivalent stress at measuring points of model structure (pa).

Figure 6 shows the displacement time history curves of measuring points of two model structures. It can be seen from the figure that there is a large displacement change at point a on the top of ordinary concrete slab structure, and the vibration is intense in the whole calculation time, and the maximum amplitude of point a is 0.082cm; The displacement of monitoring point a of GFRP reinforced concrete slab top model changes slightly, and the maximum amplitude is 0.024cm. It shows that the impact vibration of the new GFRP reinforced concrete composite slab structure under explosion is less due to the restraint of the wrapped GFRP slab, because it has better anti explosion performance.

Figure 7 shows the velocity time history curves of the measuring points of the two model structures. It can be seen from the figure that the velocity at the top of the ordinary concrete slab structure changes greatly, and the peak velocity at point a of the monitoring point is 0.08cm/us, equivalent to 0.8m/s; The displacement curve of monitoring point a of GFRP reinforced concrete slab model changes slightly, with the maximum amplitude of 0.04cm/us, equivalent to 0.4m/s, which is about 50% lower than that of ordinary concrete slab structure.

The above comparative analysis shows that under the same explosion action, the explosion resistance of GFRP reinforced concrete slab structure is better than that of ordinary concrete slab structure, and the indexes such as stress, velocity and displacement response are reduced by more than 50%.

5. Conclusion
The numerical simulation is carried out by using the explicit dynamic finite element program ANSYS/LS DYNA, and the explosion resistance of a new type of GFRP reinforced concrete composite slab structure is discussed. The following conclusions are obtained:

(a) The new type of wrapped GFRP reinforced concrete composite slab structure closely combines the GFRP slab with the concrete through the sand bonding treatment of the GFRP rib slab and the inner
surface, and gives full play to the superposition effect of the anti-explosion impact performance of GFRP and concrete. The numerical analysis results show that the anti-explosion impact performance of the new type of composite structure is superior.

(b) Due to the restraint effect of wrapped GFRP slab, the impact vibration of the new wrapped GFRP reinforced concrete slab structure under explosion is less, because it has better explosion resistance.

(c) Under the same explosion action, the explosion resistance of GFRP reinforced concrete slab structure is better than that of ordinary concrete slab structure, and the indexes in stress, velocity, displacement response and so on are reduced by more than 50%.

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