Numerical Simulation on Dynamic Response of Prestressed Concrete Slab Subjected to Blast Loading

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Abstract. In order to obtain the dynamic response of prestressed concrete slab subjected to blast loading, the numerical modeling method for the dynamic response analysis of this kind of member subjected to blast loading was introduced, and the numerical model was established based on the ANSYS/LS-DYNA program. By comparing the numerical simulation results of the dynamic response of reinforced concrete slab with the experimental data subjected to blast loading, the accuracy of the numerical model was verified. So the numerical simulation method can be used in dynamic response analysis of prestressed concrete flexural members subjected to blast loading, with a certain precision.

1. Introduction
In recent years, a series of emergencies such as terrorist attacks and explosion accidents not only caused significant casualties and property losses, but also caused serious damage to surrounding buildings. The anti-blast design issues for building structures have received widespread attention. By the experimental research and the finite element simulation, the domestic and foreign scholars have studied the dynamic response characteristics and anti explosion reinforcement measures on block wall, door and window, steel plate, reinforced concrete slab and column subjected to blast loading in detail [1].

The dynamic response of reinforced concrete members subjected to impulsive loads and transient loads was analyzed by Krauthammer, and a simplified analytical model of reinforced concrete members was presented based on equivalent single degree of freedom system [2]. A finite difference program on dynamic response of reinforced concrete simply supported slab subjected to blast loading was compiled by Jones based on strain rate effect of the material, taking into account the change of the section geometric dimensions of member and loads along the length [3]. Dynamic response of reinforced concrete slab and high-strength steel fiber reinforced concrete slab subjected to blast loading was obtained by Zhou, by simulating the concrete material with the dynamic plastic damage model [4]. Shear failure and flexural failure of reinforced concrete one-way slab subjected to blast loading was simulated by Yan Shi [5]. Based on LS-DYNA, the dynamic response of reinforced slabs subjected to 3 kinds of impact loads, including triangular, rectangular and exponential, was simulated by Yang Chao [6].

Numerical simulation technology was a good supplement to the model test research, it not only can save a lot of cost, but also can significantly improve the work efficiency. The softwares of ABAQUS, AUTODYNA, LS-DYNA were usually used to analyze explosion and impact of the structure response, and the most widely used software was ANSYS/LS-DYNA which was launched in 1996 by LSTC company and ANSYS company. Therefore, it was of great practical significance to carry out the...
numerical simulation study on the anti-blast performance of the prestressed concrete slab based on LS-DYNA.

2. Numerical modeling method

2.1. Common node separate model
There were three kinds of modeling methods for concrete structures: integral, combined and separated. Insulated by a large number of literatures, the reinforcement element and concrete element mesh size was 10–50mm for analysis of reinforced concrete structure mechanical performance with the common node separate model, which can meet the requirements of accuracy, and the computing efficiency was improved.

2.2. Element type
The concrete was simulated using the SOLID164 3-D solid element, as shown in figure 1. The SOLID164 element had 8 nodes, and each node contained 9 degrees of freedom. The BEAM161 element was used to simulate the reinforcement and prestressing tendons, as shown in figure 2. The BEAM161 element contained 3 nodes, and the axial direction of beam was determined by end nodes I and J, and the principal axis orientation was determined by node K.

2.3. Material model
The Mat 72R3 model can simulate the mechanical properties of concrete subjected to high strain rate and large deformation effectively. The remaining model parameters can be generated by inputting the density, Poisson’s ratio, compressive strength, strain rate -DIF curve and unit conversion coefficient of the concrete. The strain rate effect, which was usually reflected by the increase coefficient of dynamic load, should be taken into account when analyzing the dynamic response of concrete structures subjected to blast loading.

MAT_PLASTIC_KINEMATIC (Mat 3) was used to simulate non prestressed and prestressed tendons, which was the plastic kinematic model. The failure of the material was determined by setting the effective plastic strain FS, and the strain rate was considered by the Comper-Symonds model.

2.4. Blast load model
According to the research in this paper, CONWEP model was used to simulate blast load [7]. The use of CONWEP blast model could greatly save the calculation time by imposing blast load directly on the
structure, without establishing a large number of explosives and air model. The input parameters included the weight of TNT explosive, the coordinates of the explosion center, the initiation time, the type of explosion and the unit conversion coefficient [8].

2.5. Stress initialization
Compared with reinforced concrete member, the key to the dynamic response analysis of prestressed concrete member was the simulation of prestressed tendons, so stress analysis of structural member should be done prior to transient analysis. The initial stress of prestress was taken into account by the explicit-implicit conversion method, that was, ANSYS or LS-DYNA was used as the implicit analysis, and then the transient analysis was carried out.

3. Numerical model validation

3.1. Experimental design
Blast experiment of two simply supported reinforced concrete slabs was done by Sun Wenbin [9]. The thickness of the slab was 120mm, and the test device was as shown in Figure 3.

Reinforcements were arranged by double-layer and two-way, and diameter of reinforcement was 10mm, which was as shown in Figure 4. The yield strength of reinforcement was 560MPa, and the compressive strength of concrete was 48MPa. The explosive was suspended above the center of the reinforced concrete slab at 600m. The TNT equivalent of explosion I was 0.079kg, and the TNT equivalent of explosion II was 2.09kg.

![Figure 3. Test equipment](image)

![Figure 4. Arrangement of reinforcement](image)

3.2. Comparison of results
According to the above numerical modeling method, the steel mesh division and the concrete mesh division were as shown in Figure 5.

![Figure 5. Meshing of test slab](image)
The comparison of experimental results of the peak displacement at mid-span of the slab and numerical results was as shown in Table 1. It can be seen from Table 1 that the numerical results of the peak displacement at mid-span of the test slab were close to the experimental results, and the error of the explosion I was less than the error of the explosion II. Because it was difficult to calculate the dynamic response of the member subjected to shock wave, the error as shown in Table 1 was acceptable. The above results indicated that the numerical model can be used to analyze the dynamic response of reinforced concrete members subjected to explosion.

Table 1. Comparison of the peak displacement

| Category   | Blast distance (m) | Wight of TNT (kg) | Scaled distance (m/kg^{1/3}) | Test value (mm) | Calculated value (mm) | Error (%) |
|------------|--------------------|-------------------|-------------------------------|----------------|-----------------------|-----------|
| Explosion I | 0.6                | 0.079             | 1.40                          | 1.12           | 1.25                  | 11.6      |
| Explosion II | 0.6                | 2.090             | 0.47                          | 50.00          | 33.60                 | 32.8      |

For the above two kinds of TNT weight, the relationship of the numerical vertical displacement at mid-span joint of test slab with time was as shown in Figure 6. It can be seen from Figure 6 that, the displacement response of the slab was small for explosion I, and there was a high frequency vibration. The displacement response of the slab was very obvious for explosion II, so the slab was in a plastic stage, and failure features has been presented.

The numerical overall vertical deformation of the slab for explosion II was larger than that for explosion I obviously at the time of displacement of the mid-span joint being maximal, which showed that the dynamic response of the slab increased obviously with the decrease of the equivalent distance.

In the case of explosion II, the plastic deformation occurred at the back of the test slab in a wide range, and the development of the plastic zone was in line with the tensile crack and the failure of the back of the slab in general.

![Figure 6. Vertical displacement time history curve of mid-span joint of test slab](image)

4. Conclusions

The numerical modeling method for the dynamic response of prestressed concrete slab subjected to blast loading was introduced.

Comparing the dynamic response of the numerical calculation results and model test results, this indicated that the numerical simulation method can be used in dynamic response analysis of prestressed concrete flexural members subjected to blast loading, with a certain precision.
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