Research Results

UMR Node

March, 2006

repair of buildings & bridges with composites

UPGRADE OF STRUCTURES WITH SRP AND CFRP COMPOSITES AGAINST EXPLOSIVE DEVICES PLACED VERY NEAR OR IN CONTACT WITH RC MEMBERS

PROJECT NO. II.3

SUMMARY

This project examines the feasibility of improving the blast-resistant capacity of reinforced concrete slabs by using innovative composite materials. In order to achieve this objective, five phases of testing were conceived. In the first phase of testing, four control reinforced concrete slabs were tested under real blast loads in order to establish a baseline for comparison for the other phases of testing. The explosive charge weight and stand-off distance required to impose a given damage level were predicted by using a modified displacement based methodology. Test results showed that the blast loads were effectively estimated using this method and the damage levels observed from the field tests correlated well with the predicted levels. In addition, test results corroborated that the blast-resistant capacity of RC slabs can be effectively increased by strengthening using composites. The main conclusion that can be drawn from these tests using explosives is that RC slabs retrofitted on both sides have a higher blast resistance capacity than those slabs retrofitted only on one side. This research summary discusses these experimental results along with the analysis steps used to predict the blast charge and standoff distance to impose a given damage level.

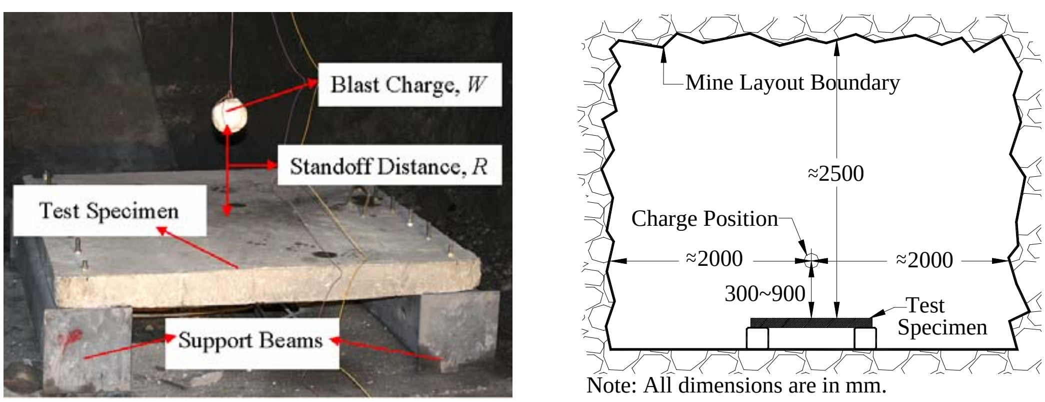


Figure 1. Test Setup

BACKGROUND

Explosive effects can impart a level of damage that can range from minor damage to completely structural failure and considerable losses of life. As such, in blast design one must also determine an acceptable level of damage that a structure can tolerate. In order to correlate different damage levels to specific stand off distances and charge weights, which are often used to quantify blast loads, the displacement based design (DBD) method typically used for the seismic design and assessment of structures was customized in this research for blast resistant design and assessment of structure.

In order to implement the DBD method, it can be learned that the equivalent viscous damping (EVD) ratio as a function of the displacement ductility is a crucial parameter in the application of the DBD method for seismic loads; and, in the context of the DBD method the loads are considered static. In this research program a set of generalized expressions were developed for estimating the EVD ratio under blast loads and as a function of the displacement ductility. Although, much information exists in the literature that clearly indicates that damping is usually ignored in blast resistant design; it is important to emphasize that in this research program the EVD ratio was primarily used as a mathematical tool to obtain the dynamic magnification factor necessary to correlate the design static loads to the dynamics of blast loads. Graphical correlation between the EVD ratio and displacement ductility to the DMF are presented in this paper.

Since the EVD ratio and the DMF are directly dependent on the moment curvature relations of structural members, a moment curvature analysis for the slabs was carried out before computing the EVD ratio and the DMF. Extensive research exits in the literature that clearly indicates that the response of reinforced concrete structures is significantly affected by high strain rate loads. Since, strain rates as high as 5000 per second have been registered under blast loads, accounting for the proper effects of the loading rate was also considered in this research program. In this research program strain rate effects were considered in the moment curvature analysis of RC members using well established dynamic increase factors (DIF). These factors consider the apparent increase in strength that concrete and reinforcing steel can achieve under blast loads. As such, models for reinforcing steel and concrete proposed in these references was also used in this research program to include the strain rate effects in the material models.

OBJECTIVES

1. To predict the charge weight and stand-off distance that a RC member can sustain for a given displacement ductility or damage level using the displacement based method.

2. To evaluate the blast resistance capacity of strengthened slabs with composites, and its application for the retrofit of RC slabs.

TEST SETUP

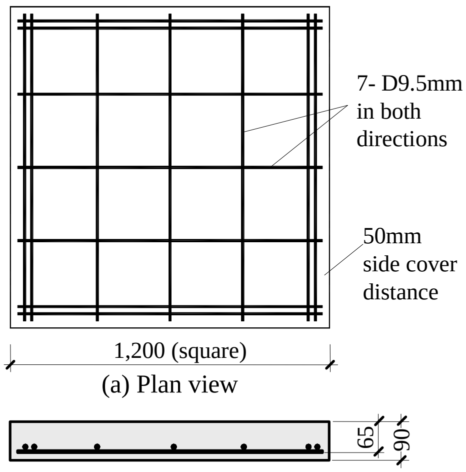
The slabs were tested at the UMR experimental mine center under real blast loads. Two steel box beams were used as the supports (see Figure 1). The desired charge was suspended above the exact distance by a wire, which was also the circuit to flame the charge. Each charge was composed of desensitized RDX high explosive, which correlates to an equivalent charge of TNT at a conversion rate of 1.185. All RC slabs were built with nominal dimensions of 1200 x 1200 x 90mm.

As shown in Figure 1, the distance from the test specimen to the mine boundaries were far enough that free-air burst design methods for blast loads were applicable within a reasonable degree of accuracy.

The slabs were reinforced with 7- D9.5mm steel bars in each direction, which leads to a reinforcement ratio of 0.50% (see Figure 2). This reinforcement ratio was selected because the capacity of the slabs needed to be controlled to within the maximum feasible charge weight that could be use inside the UMR experimental mine.

TEST MATRIX AND MATERIAL PROPERTIES

This research program consisted of five phases, which are described next.



Note: All dimensions are in mm.

(b) X-cross section

Figure 2. RC Slabs

Phase I:

In the first phase four control reinforced concrete slabs were test under real blast loads to establish a baseline for comparison for the retrofitted slabs. The predicted charge weights and standoff distances for the control slabs are shown in Table 1.

All the specimens were cast with 27.6MPa concrete and the internal reinforcing yield strength was 414MPa with an elastic modulus of 200GPa.

Table 1. Phase I: Charges and Distances

Slab No.	Damage Level	Charge (kg)	Distance (mm)
1A	I	0.10	910
1B	II	0.50	910
1C	III	1.16	300
1D	IV	1.71	200

Phase II:

In the second phase four RC slabs were built and strengthened with different schemes and different composite materials such as carbon fibers reinforced polymers (CFRP) and steel reinforced polymers (SRP). Two of the slabs, 2A-1 and 2B-1, were strengthened with CFRP sheets, and the other two, 2A-2 and 2B-2, were strengthened with SRP sheets, see Table 2. The thickness of the CFRP sheets and the SRP sheets were 0.165mm and 1.32mm, respectively. The sheets were installed along the entire width of the slabs and in the other direction they were terminated 152mm from the ends of the slabs.

The CFRP and SRP sheets demonstrated an elastic behavior up to its ultimate tensile strength, which was 3792MPa and 514MPa, and the elastic modulus was 228GPa and 36GPa.

Table 2. Phase II: Charges and Distances

Slab No.	Strengthening scheme	Charges (kg)	Distance (mm)
2A-1	CFRP (1 side)	1.35	300
2B-1	CFRP (2 sides)	1.35	300
2A-2	SRP(1 side)	1.35	300
2B-2	SRP(2 sides)	1.35	300

Phase III:

In the third phase two types of panels (Types I and II) were pre-manufactured by Strongwell and then investigated under static loads tests, see Figure 3. These tests were necessary in order obtain the required section properties. Referring to Figure 4 the initial stiffness for panels Type I and II were 5.5 and 2.2 kN/mm, respectively. These properties along with the maximum registered static loads and deflections were used to estimate the charge weights and standoff distances for the phase IV of testing.

(a) Panel Type I (b) Panel Type II

Figure 3. Strongwell Panel Types

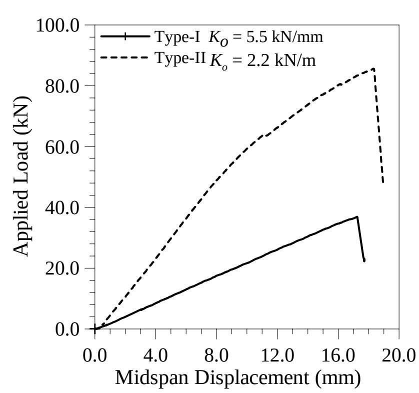


Figure 4. Strongwell Panels – Static Load Tests

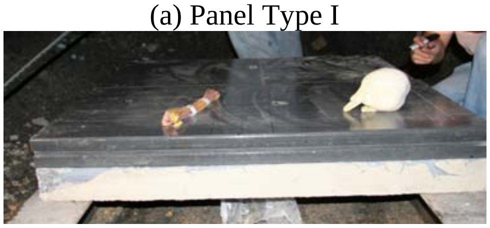
Phase IV:

In the forth phase a total of four tests were performed. The first two tests consisted of testing the two Strongwell panel types under real blast loads. In the remaining two tests two slabs were retrofitted with these panels' types, as shown in Figure 5, and then tested under blast loads, according to the charges and standoff distances depicted in Table 3.

Table 3. Phase IV: Charges and Distances

Slab No.	Strengthening scheme	Charges (kg)	Distance (mm)
4A	Panel Type I	0.90	200
4B	Panel Type II	0.90	200
4C	Slab + Panel Type I	1.71	200
4D	Slab + Panel Type II	1.71	200

(a) Panel Type I



(b) Panel Type II

Figure 5. Slabs + Strongwell Panel Types

Phase V:

This phase has not yet been completed. In this phase a total of two tests will be performed and will be nearly the same as tests 4C and 4D to the exception that SRP sheets will also be installed on both sides of the RC slab. Then, on the top surface Strongwell panels will be installed and tested according to the charge weight and stand off distances shown in Table 4.

Table 4. Phase IV: Charges and Distances

Slab No.	Strengthening scheme	Charges (kg)	Distance (mm)
5A	Slab + Panel Type I + SRP both sides	1.71	200
5B	Slab + Panel Type II + SRP both sides	1.71	200

EXPERIMENTAL TEST RESULTS

Damage levels recorded during the real blast tests conducted at the UMR experimental mine are shown in Figure 6 for all phase of testing.

1A
1B
1C
1D
2A-1
2A-2
2B-1
2B-2
4A
4B
4C
4D

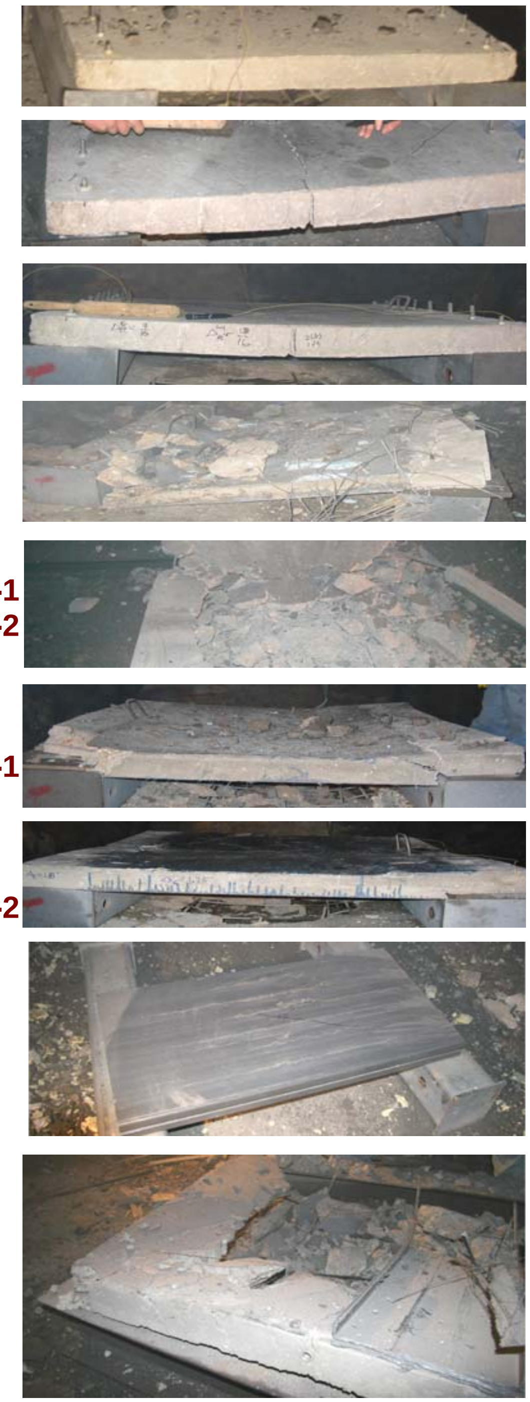


Figure 6. Summary of Experimental Test Results

CONCLUSIONS

The following conclusions can be drawn from the current research:

1. The charge weights and stand-off distances to impart a given damage level were reasonably estimated in this research program.

2. Results from Phase I indicate that the slabs were severely damaged for large ductility levels under blast loads. This can be attributed to the large dynamic magnification factors that are expected for close proximity charges. As such, in future research this should be considered by developing expressions for close proximity charges that can develop large pressure waves. However, for damage levels within low ductility levels the procedure lead to reasonable prediction of the charge weights and standoff distances.

3. Results from Phase II suggest that placing retrofit only on one side of the slabs did not enhance the blast resistance capacity of RC slabs due to the negative pressure. However, for those slabs retrofitted on both sides the damage levels were significantly reduced.

4. Results from Phase IV suggest that the charge weight and standoff distances predicted for the Strongwell panels alone were reasonably predicted. However, as before, significant damage was observed for panels 4C and 4D.

FURTHER RESEARCH

The next series of tests consists of completing Phase V of testing. It is expected that by installing the SRP sheets on both sides of the slabs in addition to installing the Strongwell panels will present an optimum blast resistance design solution.

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