II.1 & III.2

Research Results

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RETROFIT OF BLAST RESISTANT RC MEMBERS WITH CFRP AND SRP

SUMMARY

It can be learned that the equivalent viscous damping ratio is a crucial parameter in the application of the displacement based (DBD) method. Analytical studies presented here and elsewhere indicate that the equivalent viscous damping ratio is highly dependent on the axial load level. Furthermore, the same can apply for the loading type; namely, seismic and blast loads. Based on research findings, a generalized expression was developed that can be used to design or assess the blast resistance capacity of reinforced concrete members. Furthermore, successful implementation of the DBD method also requires the use of an inelastic shock spectrum to estimate the design displacement. A detailed analytical formulation was used to develop an inelastic shock spectrum for the design of blast resistant structures using the DBD method.

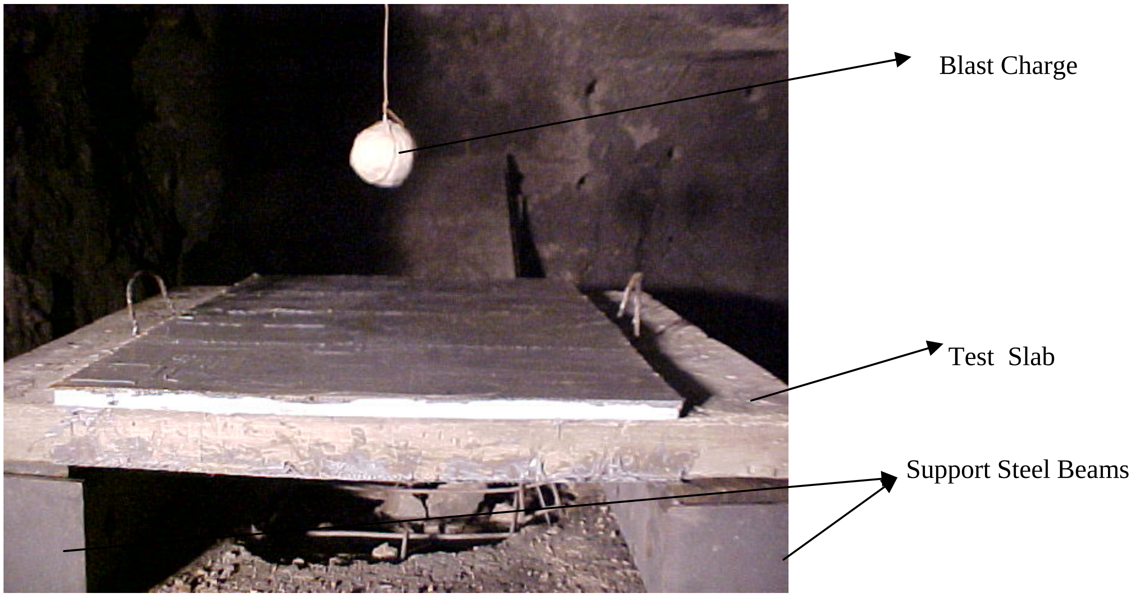

Figure 1. Test Setup

To demonstrate the viability of the suggested formulas, five RC slabs were tested under real blast loads in the out-of-plane direction. One of the slabs was used as the control unit to establish a baseline for comparison in terms of performance for the other four slabs, which were strengthened with fiber reinforced polymers (FRP). These retrofit schemes included using steel reinforced polymers (SRP) or carbon fiber reinforced polymers (CFRP). Test results showed that the blast loads were effectively estimated 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 FRP composites. The main conclusion that can be withdrawn from these tests using real life improvised explosive devices (IDE) is that RC slabs retrofitted on both sides have a higher blast resistance capacity than those slabs retrofitted only on one side. In addition, it is envisioned that once this retrofit technique is fully developed it can be applied also to RC columns.

BACKGROUND

One of the crucial parameters in applying the displacement based design (DBD) method is the equivalent viscous damping (EVD) ratio. The hysteretic response of RC members was expressed in terms of variables that are correlated to the axial load applied on the member and the achieved displacement ductility. Several researchers have concluded that the loading pattern, numbers of cycles, and loading rate affect the ultimate displacement and load capacity of a reinforced concrete member. Since the loading characteristics of seismic loads are significantly different than blast loads, the EVD ratio for blast loads proposed herein should also be different than those used in seismic design. Based on the hysteretic response of a RC member under different loading conditions, generalized expressions are proposed for estimating the EVD ratio as a function of the displacement ductility level for individual members. Analytical results indicate that the EVD ratio for seismic loads can be significantly lower than for blast loads.

Successful implementation of the DBD method requires the use of inelastic design response or shock spectra to estimate the design displacement. Nowadays elastic shock spectra are readily available as design charts in the literature that can provide for a reasonable estimate of the response of a structure under a blast loading using these charts. However, inelastic shock spectra for the design of blast resistant structures using the DBD method are not available. Based on the EVD ratios obtained above, the inelastic shock spectra can be equivalent to a substitute structure with the corresponding EVD ratio.

Recent terrorist attacks on non-military structures in the U.S. and around the world have increased the level of interest in research related to the design or assessment of structural members to resist blast loads. It has shown significant promise to estimate the charge weight and stand-off distance that a reinforced concrete column can sustain for a given displacement ductility.

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 columns.

TEST MATRIX

Five slabs were built with nominal dimensions of 48 x 48 x 3 ½ in. With the exception of the control (Slab 1), two slabs were strengthened with CFRP and the other two or were strengthened with SRP. The different strengthening schemes along with the predicted charge weights and standoff distances are shown in Table 1.

The material properties are presented as follows:

The slabs were poured with a specified 4,000psi concrete and reinforced with 0.8% longitudinal reinforcement ratio. The grade of steel reinforcement was 60ksi with an elastic modulus of 29,000ksi.

Table 1. Predicted Charge Weight & Stand-off Distance

Unit	Strengthening scheme	Predicted Charges & Standoff Distances
1	None	2.0 lbs @ 1ft
2A	SRP (One side only)	2.8 lbs @ 1ft
2B	SRP (Both sides)	2.8 lbs @ 1ft
3A	CFRP (One side only)	3.0 lbs @ 1ft
3B	CFRP (Both sides)	3.0 lbs @ 1ft

The SRP laminate has a slight nonlinear behavior up to its ultimate strength, with an elastic modulus of 29,000ksi and a tensile strength of 170ksi. However, the CFRP laminate demonstrated elastic behavior up to approximately its ultimate strength, with an elastic modulus of 33,000ksi and a tensile strength of 550ksi. The material properties of the strengthening laminates are shown in Table 2.

Table 2. Material Properties

	Tensile strength (ksi)	Elastic modulus (ksi)	Ultimate strain (%)
SRP	170	29000	1.63
CRFP	550	33000	1.70

TEST SETUP

The specimens were tested at the UMR experimental mine center. 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 conduct circuit to flame the charge.

ANALYTICAL RESULTS

Figure 2 presents the analytical result of EVD ratio versus the displacement ductility under blast loads. Figure 3 presents the displacement spectra of a blast–resistant member subjects to blast loads. Based on these analytical results, the estimated blast charges are listed in Table 1.

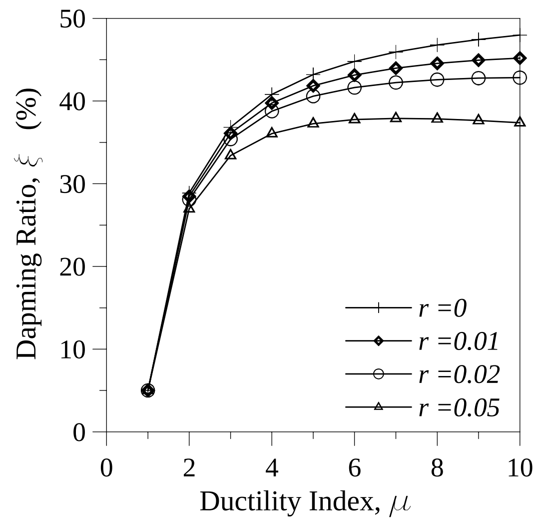

Figure 2. EVD Ratios vs. Ductility

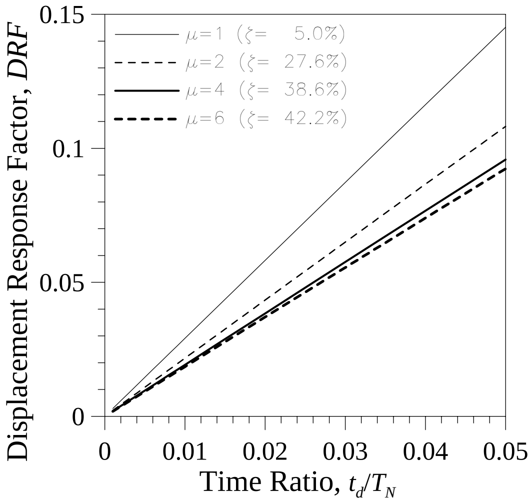

Figure 3. DRF for Blast Load

EXPERIMENTAL TEST RESULTS

The strengthening schemes and the corresponding experimental test charges for the slabs are summarized in Table 3.

As shown in Figure 4, the control slab failed due to a major flexural crack parallel to the supports at the mid-span, the residual displacement was 13/16 inches at the center of the slab and 7/16 inches at the edges. In addition, a second major crack also developed at mid span but perpendicular to the support beams.

For slabs 2A and 3A, significant damage was observed; however, slabs 2B and 3B, suffered damage very similar to the control slab but the charge weights were higher. The residual displacement for slabs 2B and 3B were nearly the same and registered 1 3/4 inches at the center of the slab, and the residual displacement was1 1/8 inches at the edges.

Table 3. Experimental Test Matrix

Unit	Charges & Standoff Distances
1	2.0 lbs @ 1ft
2A	3.0 lbs @ 1ft
2B	3.0 lbs @ 1ft
3A	3.0 lbs @ 1ft
3B	3.0 lbs @ 1ft

CONCLUSIONS

The following conclusions can be drawn from the current research:

1. The EVD ratio is not only directly related to the displacement ductility level, but also highly dependent on the axial load level. Furthermore, the EVD ratio is also affected by the subjected loading types such as seismic and blast loads.

2. The charge weight and stand-off distance of blast loads can be effectively estimated by the DBD method with the appropriate EVD ratios.

3. Placing retrofit only on one side of the slabs did not enhance the blast resistance capacity of RC slabs due to the negative pressure.

4. Blast-resistant slabs should be retrofitted on both directions in order to prevent the crack perpendicular to the support beams since the blast wave will be transmitted in all directions in the plane of the slab.

Figure 4. Experimental Test Results

FOR FURTHER RESEARCH

1. RC slabs strengthened with two way fibers.

2. Investigate energy dissipation system to enhance the blast resistance of the retrofitted slabs.

3. Application of these retrofit techniques into the blast protection of RC columns for charges placed very near or in contact with structural members.

CONTACT

Binggeng(Mike) Lu
Graduate Research Assistant
University of Missouri-Rolla
Tel: (573) 341-6852 Fax: (573) 341-6215
Email: bl2t9@umr.edu

Pedro Franco Silva, Ph.D., P.E.
Assistant Professor of Civil Engineering
University of Missouri-Rolla
Tel: (573) 341-6280 Fax: (573) 341-6215
Email: silvap@umr.edu