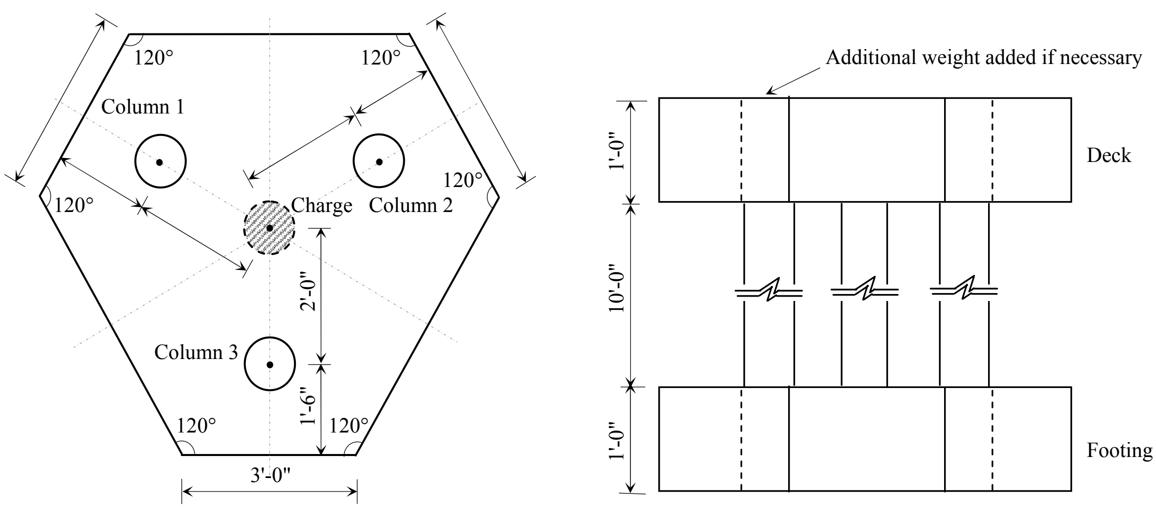
BLAST RESISTANCE ENHANCEMENT WITH AN INTEGRATED HARDENING, DAMPING, AND WAVE MODULATING SYSTEM USING 1/3-SCALE RC COLUMNS

SUMMARY

The blast test was determined to be performed at the Fort Leonard Wood Blast Test Range in January, 2006. Since then, the research team has been working on the pre-test analysis and the design of a three-column specimen. It is planned that the actual test will be carried out in summer, 2006. In this progress report, the design concept and instrumentation of three reinforced concrete (RC) column specimens as well as modeling of an unretrofitted column are discussed. Plan for the remaining tasks is briefly mentioned. To compare in an identical loading condition the blast performance of an unretrofitted column with those of two columns retrofitted with different techniques, a three-column specimen is being designed as shown in Figure 1 such that each column has the same distance from the charge placed in the middle of the test setup. To understand the behavior of the columns, each will be instrumented with strain gauges along one reinforcing bar in tension, pressure gauges on the front side of the column, and one distributed crack sensor on the tension face of the concrete.



(a) Plan view **(b) Elevation view**

Figure 1. A self-supported three-column specimen

INTRODUCTION

Hardening of transportation structures has recently been brought to the forefront of the structural engineering community. Due to their proximity to traffic flow and open access to the public, bridges structures are vulnerable to terrorisms' threats with close-in explosions near the main load-carrying members – columns. Under such loading conditions, how RC columns behave is currently not well known. Much more has to be learned to mitigate blast effects.

A contact charge can generally punch a hole on a RC column and cause spalling in the back side of the column as a result of the blast-induced tension stress wave. On the other hand, a far-field charge will mainly induce blast incident and possibly reflection waves traveling toward and around a column. It will generate pressure pulses and air blast (dynamic wind) effects on the column. In the standoff distance close to the charge size, both punching and blast-induced vibration effects will be important. Therefore, to enhance the column performance against close-in explosions, an integrated multi-layer approach with hardening, damping, and modulating (HDM) materials must be taken.

In this study, a cost-effective, integrated retrofit system, as shown in Figure 2, to improve the blast resistance of RC columns is introduced. Carbon fiber reinforced polymers (CFRP) sheets are used for column strengthening while viscoelastic (VE) layers are for damping of the blast-induced vibration effect on the column, and modulating the incoming blast waves by optimizing the impedance ratios among different materials. The inner FRP sheet is wrapped around the RC column with its fiber oriented along the perimeter to provide confinement to the concrete. The outer FRP sheet with its fiber oriented along the column is to anchor the VE layer into the connection element of the column such as footing or cap beam. In between the two FRP sheets, shear strain is applied on the VE layer and vibration energy is dissipated through the plastic property of the VE layer.

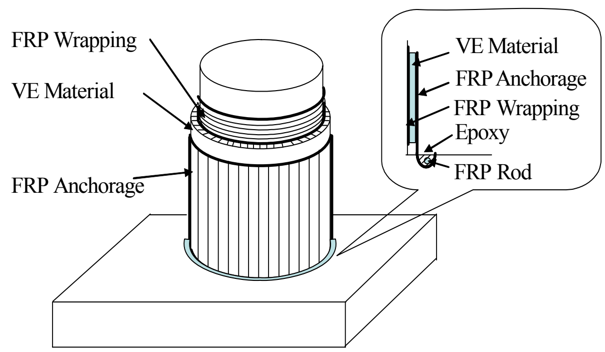


Figure 2. An integrated retrofit system

The proof-of-concept tests of the integrated retrofit system were conducted on the UMR shake table. The test results indicated that the damping component was effective in reducing the peak acceleration and displacement of 1/5-scale columns by 10~50% under sinusoidal and earthquake loading. Further reduction can be achieved for full-scale columns as shown by numerical simulations (Chen et al. 2006).

The bond behavior between VE layer and FRP sheet as well as the anchorage behavior between FRP sheet and concrete were investigated in Huang and Chen (2005). Both the bond and the anchorage can be designed to a satisfactory performance. Bonding tests conducted under static and dynamic loading indicated that all specimens failed in tearing of the VE layers and there were no indication of bonding detects. Anchorage tests resulted in the development of an anchorage design equation.

OBJECTIVE

This study is aimed to develop and demonstrate in field conditions a multiple layer blast mitigation system for hardening, damping, and wave modulating (HDM) of columns. The effectiveness of the proposed strategy will be quantified by comparing the performance of retrofitted versus unretrofitted three columns in an identical test condition.

TEST MATRIX

One out of the three columns (C1) is unretrofitted, serving as a benchmark structure. Another column (C2-CFRP) will be wrapped with CFRP sheets. The number of pliers depends on the charge weight determined from numerical simulations to be completed later as well as the potential failure mechanism (punching for shear failure or pressure pulse induced vibration for flexural failure). It is expected that one or two pliers will be sufficient. The last column (C3-HDM) will be retrofitted with the CFRP strengthening, as used for the second column, and the VE damping and impedance modulating layer that is anchored into the footing of the column as illustrated in Figure 2. The test matrix of all columns is shown in Table 1.

Table 1 Test matrix of columns

Column	Low charge	High charge
C1	√	√
C2-CFRP	√	√
C3-HDM	√	√

Since the interference of reflection waves from the three columns could potentially affect the quality of test data, it is critical to ensure that the three columns are arranged in a symmetric configuration about the explosive charge that will be hung on the bottom face of the deck, as shown in Figure 1. Equally important, the shape and size of the columns must be reasonably accurate in their final position.

DESIGN OF COLUMN SPECIMENS

Each column was designed as a 1/3-scale specimen to a prototype bridge column in Missouri. It was 10 feet long and 12″ in diameter. The column was reinforced with 6#3 deformed bars and #3 hoops every 6″. A dozen strain gauges will be attached on one longitudinal reinforcement rebar.

Since only two explosions will be ignored to obtain the data for performance comparison among the three columns at low and high charges, it is vital to make sure all sensors and their associated instrumentation systems work appropriately prior to testing. Accelerometers and pressure transducers will be installed in field condition and tested with several trial measurements for the impact vibration induced by a rubber hammer. It is anticipated that the transient responses of strain, acceleration, and pressure will be acquired. One distributed crack sensor will be embedded near surface of the tension side of each column.

PRE-TEST SIMULATION OF COLUMNS

To determine the charge weight and standoff distance necessary to cause significant damage to the columns (high charge) and to prevent structural damage (low charge), pre-test analysis will be conducted with modeling of a quarter column portion in ABAQUS. As shown in Figure 3, the concrete and steel rebars were modeled separately. They were assumed to bond together perfectly in analysis.

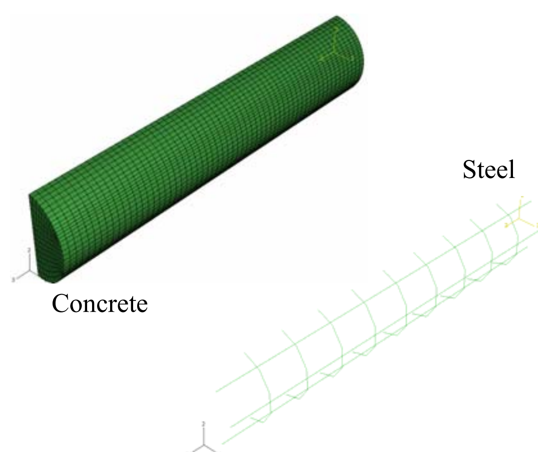


Figure 3. Model of one quarter of a column

FUTURE WORK

The three-column specimen will be finalized in the next two months. It will be then cast in stages in the test site. The field tests are expected to take place in summer of 2006. After testing, data will be cleansed and used to compare the relative merits of two retrofitting techniques: CFRP strengthening and the proposed integrated HDM system. The performance criteria for comparison include the extent of cracks, size of craters, extent of rebar yielding, peak pressure, peak acceleration, and damping ratio. The experimental results will also be used to validate the simulated results obtained prior to field testing.

CONTACTS

G.D. Chen, Ph.D., P.E.
Associate Professor of Civil Engineering
328 Butler-Carlton Hall
University of Missouri-Rolla
Tel: (573) 341-4462 Fax: (573) 341-4729
Email: gchen@umr.edu

Jason Baird, Ph.D.
Research Assistant Professor
114 Rock Mechanics
Rock Mechanics & Explosives
Tel: (573) 341-6648 Fax: (573) 341-4368
Email: jbaird@umr.edu

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