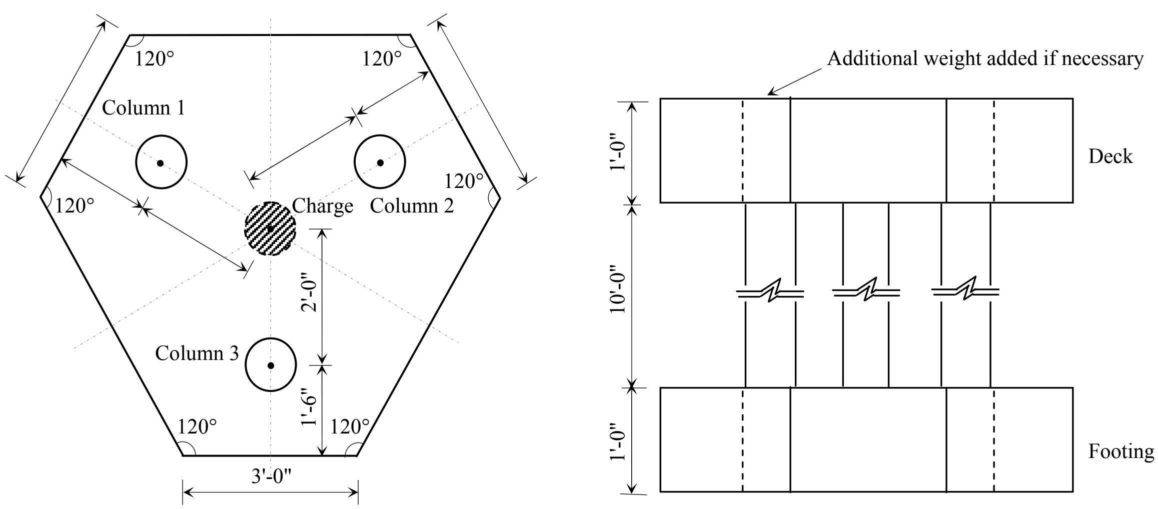
BLAST RESISTANCE ENHANCEMENT WITH AN INTEGRATED HARDENING, DAMPING, AND WAVE MODULATING SYSTEM USING 1/3 SCALE RC COLUMNS

SUMMARY
In recent years, issues related to the hardening of transportation structures have been steadily brought to the forefront of the structural engineering community. Due to their proximity to traffic flow and open access to the public, bridge structures are vulnerable to terrorisms' threats with close-in explosions near the main load-carrying members - columns. Under such loading conditions, how columns behave is currently not well known. Much more is to be learnt to mitigate blast effects.



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

Figure 1. Schematics a self-supported three-column specimen

In general, a contact charge will 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.

This project will introduce a cost-effective, integrated retrofit system, as shown in Figure 2, to improve the blast resistance of RC columns. Carbon fiber reinforced polymers (CFRP) sheets will be 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. This project will be executed over a period of 12 months in three tasks, including design, cast, test, and analysis of three RC columns.

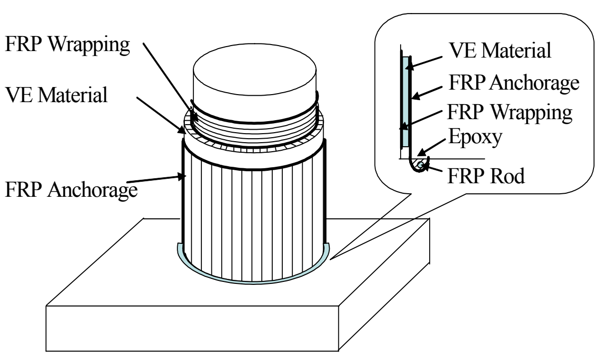


Figure 2. An integrated retrofit system

BACKGROUND

Under the support of the National Science Foundation (Award CMS9733123) and the Federal Highway Administration (Contract Agreement DTFH61-02-X-00009), an integrated damping and strengthening system was introduced for seismic retrofitting of RC columns. The proof-of-concept tests conducted on the UMR shake table 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.

In the FY2005, RB²C sponsored a project to apply FRP grid sheets and spray-up saturant in the proposed retrofitting system. The main goal was to characterize the above materials with coupon and concrete ring tests. Concrete ring specimens have been prepared and they are currently waiting for retrofit with spray-on equipment. Although there are currently no test results on the FRP grid sheets, coupon tests on CFRP sheets and VE layers have been conducted instead. The two critical design issues with these tests include the bond strength between CFRP sheets and VE layers, and CFRP sheets anchorage into the RC column footing.

Bonding tests were conducted under both static and dynamic loading. It was observed that all specimens failed in tearing of the VE layers and there were no indication of bonding detects. This indicated that the simple bonding between a CFRP sheet and a VE layer with Mbrace saturant resins was sufficiently strong. A VE coupon specimen is shown in Figure 3. Its shear stress and strain curve is presented in Figure 4. The area enclosed by the hysteresis loop in Figure 4 represents the damping of VE layers. Anchorage tests resulted in the development of an anchorage design equation.

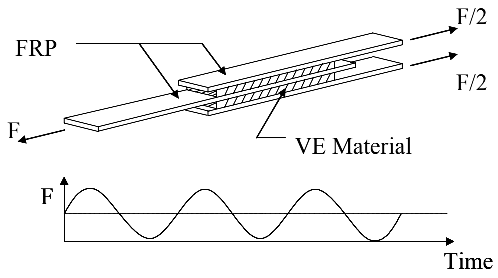


Figure 3. VE specimen and loading protocol

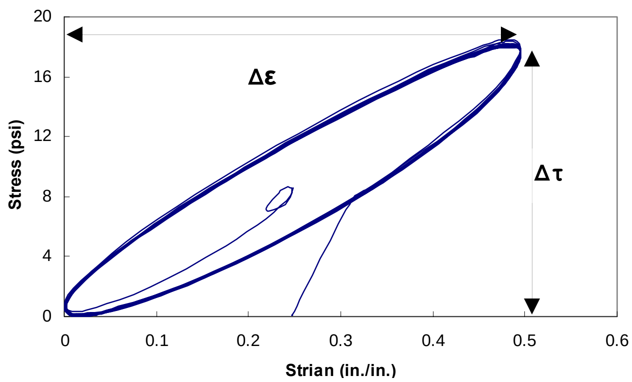


Figure 4. Stress-strain curve

The composite materials used in the FY2005 project consisted of CFRP sheets and Mbrace saturant resins. For the new project, CFRP will be used again. Both FRP grid sheets and spray-on saturant will be used to finish testing of the concrete rings that have already been cast.

OBJECTIVE

This proposed project is aimed to develop and demonstrate in field conditions a blast mitigation technique with a multiple layer system for hardening, damping, and modulating (HDM) of blast wave and penetrating effects, which is referred to as an HDM system. The effectiveness of the proposed strategy will be quantified by comparing the performance of retrofitted versus unretrofitted three columns so that the scale effect may be minimal.

WORK PLAN

To allow a fair comparison of performance, facilitate field tests, and ensure a manageable research project within the proposed budget and time, three identical RC columns will be cast on a mat foundation, as shown in Figure 1. The three columns will support a RC deck on which additional weights can be placed to ensure a uniform gravity load distribution on the columns. One column will serve as a benchmark member with no retrofitting, the second column will be strengthening with CFRP sheets only, and the last column will be retrofitted with the integrated HDM system. Such a self-supported, three-column specimen will be tested at an explosion range. It requires no setup expenses in field conditions. An explosive charge will be hanged from the center of the deck to ensure the same standoff distance to all columns.

Technically the possibility of testing a three-column specimen is due to the nature of an equal-lateral triangle. To obtain quality data from one blast test, the effect of the reflection wave from one column on the other columns must be either separated from the original incident wave or rapidly diminishing in a short time. Since the majority of the reflection waves from three columns are expected to cancel each other when they encounter at the center of the columns. The residual reflection wave from one column will likely propagate through the middle of other two columns, avoiding direct interference with them.

Three main tasks proposed in this project include design and casting of a three-column specimen, pre-test simulation and field testing of the specimen, and data cleansing and reduction. A final report will be provided to sponsoring companies of the proposed research work. Each task is detailed as follows.

Task 1: Design and casting of columns:
Each column will be designed as a 1/3-scale specimen to a prototype bridge column in Missouri. Preliminary design indicated that each column would be 12″ in diameter and reinforced with 6#4 deformed bars with #3 ties every 6″. The three-column specimen will be cast in three phases: footing, column, and deck. A few dozen strain gauges will be attached on longitudinal reinforcement rebar. Additional concrete blocks, if needed for extra dead loads, will be identified from the existing stocks in the Highbay Structures Laboratory.

One out of the three columns will be wrapped with CFRP sheets. The number of plies depends on the charge weight determined in Task 2 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 plies will be sufficient. Another column will be retrofitted with the CFRP strengthening, as used for the first 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	X	X
C2-CFRP	X	X
C3-HDM	X	X

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. Equally important, the shape and size of the columns must be reasonably accurate in their final position.

Task 2: Pre-test simulations and field testing:
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 Computational Structural Dynamics (CSD) and Computational Fluid Dynamics (CFD) software. These analyses may be coupled to include fluid-structure interaction effects, depending on the availability of software.

Since it is intended to have two explosions 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.

Task 3: Data cleansing and reduction:
The end goal of this one-year project is 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.

Very high and very low frequency contents of the measured signals will be filtered out to eliminate the noise contamination on the useful data. The parameters of interest as performance criteria will be extracted from the measurements and compared at two levels of charge. The experimental results will also be used to validate the simulated results obtained prior to field testing.

BUDGET

The deliverable of this project will be a final project report similar to this proposal in format. The budget for this project will cover support for one graduate student over a period of 12 months, and costs for materials and supplies, instrumentation, and necessary transportation. The total direct cost is $25,000.

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