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Multihazard-Resistant Highway Bridge Pier-Bent

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Summary

The terrorist threat on bridges, and on the transportation system as a whole, has been recognized by the engineering community and public officials since recent terrorist attacks. Since many bridges are (or will be) located in areas of moderate or high seismic activity, and because many bridges are potential terrorist targets, there is a need to develop structural systems capable of performing equally well under both events. This paper presents the development and experimental validation of a multi-hazard bridge pier concept, i.e., a bridge pier system capable of providing an adequate level of protection against collapse under both seismic and blast loading. A multi-column pier-bent with concrete-filled steel tube (CFST) columns is the proposed concept. The work presented here experimentally investigates the adequacy of such a system under blast loading.

Introduction

Recent terrorist attacks such as the one on the Alfred P. Murrah Federal Building in Oklahoma City (1995) and the one on the tallest towers of the World Trade Center in New York City (2001) are examples of the fact that the destruction of civil engineering structures has become one of the means employed by terrorists to achieve their objectives. There are some similarities between seismic and blast effects on bridge structures: both major earthquakes and terrorist attacks/accidental explosions are rare events that can induce large inelastic deformations in the key structural components of bridges. Since many bridges are (or will be) located in areas of moderate or high seismic activity, and because many bridges are potential terrorist targets, there is a need to develop structural systems capable of performing equally well under both events.

The objective of this research project is to develop a multi-hazard bridge pier concept capable of providing an adequate level of protection against collapse under both seismic and blast loading, and whose members' dimensions are not very different from those currently found in typical highway bridges. This paper describes design of the multi-hazard bridge pier-bent under blast and seismic loading, and experiments of 1/4 scale of the prototype bridge pier-bent. Additionally, the results from the blast experiments are compared with the ones from a simplified method of analysis considering an equivalent SDOF system having an elastic-perfectly-plastic behavior.

Design of Multihazard Bridge Pier-bent

Preliminary work included the examination of several different structural configurations of bridge piers and potential bridge bent systems, to identify some systems deemed most appropriate in meeting the objectives of this research. In all cases, bents were assumed part of a typical 3-span continuous highway bridge located in an area of moderate seismic activity.

A pier-bent design concept consisting of concrete-filled steel tube columns (CFST columns) linked by a cap-beam proved to be more satisfactory, and was found possible using available tube sections (Bruneau and Marson, 2004; Marson and Bruneau 2004). It was found that material effectiveness was highest for piers having the highest diameter-to-thickness (D/t) ratio. CFST columns with cross-sections of 16" diameter were found to provide adequate blast and seismic resistance during the design process. These CFST columns are smaller than the typical 3'-diameter reinforced concrete pier column, but expected to perform significantly better under blast loads. This type of structural member was deemed likely to be accepted in practice. This structural configuration was therefore selected for experimental verification of its blast resistance.

Experiments on 1/4 Scale Multihazard Bridge Pier-bent

A series of tests was performed at U.S. Army Corps of Engineers Research Facility in Vicksburg, Mississippi. Due to constraints in the maximum possible blast charge weight that could be used at the test site, test specimen dimensions were set to be 1/4 scale of the prototype bridge piers.

Piers were CFST columns linked by a cap-beam and at the footing level. As indicated above, preliminary analyses showed this type of piers capable of providing high resistance and ductility against both blast and seismic loads. Experimental specimen is shown in Figure 1 and two identical specimens (Bent 1 and Bent 2) were constructed to be tested. Each specimen consists of three piers with different diameters (D = 4", 5" and 6"), connected to a steel beams embedded in the cap-beam and a foundation beam. Fiber reinforced concrete was used for the cap-beam and the foundation beam to control cracking, which was deemed desirable against spalling of the concrete due to either earthquake or blast loading. Summary of the pier tests is presented in Table 1. Exact values of charge weights and stand off distances were omitted for security reason; instead these values were expressed by W and X, respectively in Table 1.

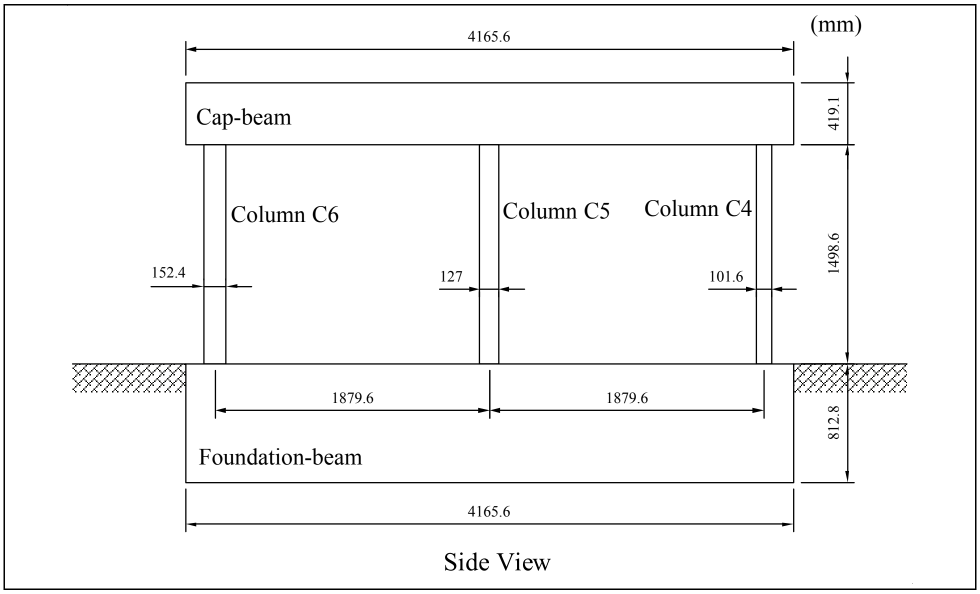

Figure 1. Experimental Specimen

Table 1. Summary of Column Test Cases, Test Results and Shape Factors

Test No.	Bent	Column	Charge Weight	X	Z[m]	Maximum Deformation [mm]
Test 1	B1	C4	0.1 W	3 X	0.250	0.0
Test 2	B1	C4	0.55 W	3 X	0.750	0.0
Test 3	B1	C4	W	2 X	0.750	30
Test 4	B1	C6	W	1.1 X	0.750	46
Test 5	B1	C5	W	1.3 X	0.750	76
Test 6	B2	C4	W	1.6 X	0.250	24
Test 9	B2	C6	W	0.8 X	0.250	45
Test 10	B2	C5	W	0.8 X	0.250	100

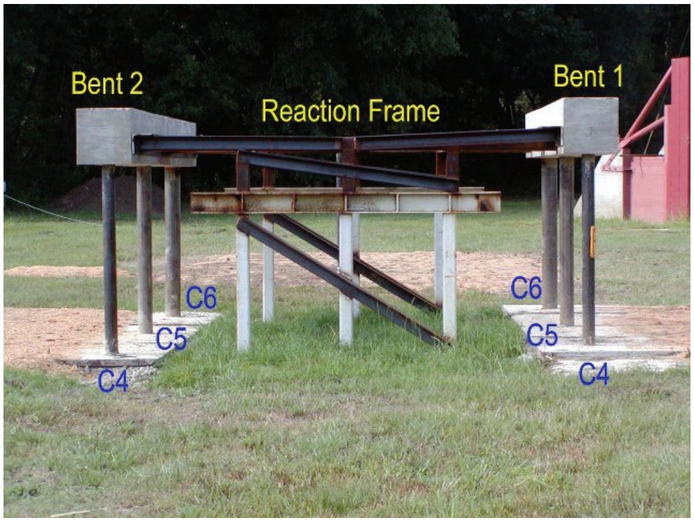

Figure 2. Test Setup

Figure 3. Column B1-C5 after Test 5

The experimental setup is shown in Figure 2. It consists of identical Bent 1 and Bent 2, and reaction frames between the two bents. Individual piers in each bent (Figure 1) were subjected to successive blast tests. Note that the cap-beams were not fixed to the reaction frames as it was intended to allow rotating to replicate actual conditions in bridges.

Maximum residual plastic deformations of each pier after testing are shown in Table 1. Figure 3 shows Column 5 of Bent 1 after the test as an example. The CFST column exhibited a ductile behavior under blast load. Note that no significant damage was suffered by the fiber reinforced concrete cap-beam as a result of the blast pressures.

Simplified Analysis for Blast Loading

The simplified procedure adopted is described in USDA (1990). The method considers an equivalent SDOF system having an elastic-perfectly-plastic behavior, and assumes that all the energy imparted to the system by the blast loading is converted into internal strain energy. Under these conditions, the maximum deformation due to impulsive-type blast loading is given by:

$$X_m = \frac{1}{2}\left(\frac{I_{eq}^2}{K_{LM}\ m\ R_u} + X_E \right) \tag{1}$$

where I_{eq} is equivalent uniform impulse per unit length, K_{LM} is load-mass factor, m is the mass per unit length of the column, R_u is the strength per unit length of the column and X_E is the displacement at the onset of plastic behavior. In this analysis, I_{eq} was calculated by:

$$I_{eq} = \beta\ D\ i_{eq} \tag{2}$$

where i_{eq} is equivalent uniform impulse per unit area, D is column diameter and β is factor to account for the reduction of pressures on the column due to its circular shape. The values of i_{eq} were calculated using the program BEL (USACE-ERDC, 2004). BEL is a shock-wave propagation program using analytical/empirical models.

Comparison with Simplified Analysis for Tests

Experimentally obtained maximum plastic deformations of the piers were compared with the ones that can be calculated using simplified method of analysis. These simplified analyses were conducted using the strength values obtained from the compression tests of concrete cylinders and the tensile tests for the steel tubes from which the specimens were constructed. Note that the maximum deformations measured after the tests were obtained without loading on the structure (i.e. after the blast load) and are actually residual plastic deformations, X_{test}. Therefore, the test results had to be compared with the calculated residual deformations whose values were $X_m - X_E$, where X_E and X_m respectively represent the elastic maximum deformations and the maximum deformations under blast loading.

Following this approach by calibrating analysis with the test results, values for β for each test were calculated using the above equations. The resulting values for β are presented in Table 1 for the six test cases for which residual plastic deformation were obtained, along with the calculated elastic maximum deformations, the calculated maximum deformations under blast loadings, and the residual plastic deformations from the tests. It was found that the value of β for this type of circular columns is 0.45 (i.e. mean value of 0.450 and standard deviation of 0.020 from the six samples considered).

Table 2. Summary of Column Test and Analysis Results and Shape Factors

Test Num	Column	Shape Factor, β	Calculation			Test
			Maximum Elastic Deformation, X_E [mm]	Maximum Deformation, X_m [mm]	Maximum Residual Deformation, $X_m - X_E$ [mm]	Maximum Residual Deformation X_{test} [mm]
Test 3	B1-C4	0.472	6	36	30	30
Test 4	B1-C6	0.458	4	50	46	46
Test 5	B1-C5	0.447	3	79	76	76
Test 6	B2-C4	0.465	10	34	24	24
Test 9	B2-C6	0.440	6	51	45	45
Test 10	B2-C5	0.417	5	105	100	100

Conclusions

This paper has presented the findings of research to establish a multi-hazard bridge pier concept capable of providing an adequate level of protection against collapse under both seismic and blast loading. A series of experiments on 1/4 scale multi-hazard bridge piers was performed. The CFST column exhibited a ductile behavior under blast load, and no significant damage was suffered by the fiber reinforced concrete cap-beam as a result of the blast pressures. The results of the blast experiments were compared with the results from simplified method of analysis considering an equivalent SDOF system. Comparison of the results of these blast tests with this simplified analysis showed that a reduction factor accounting for the reduction of pressures on the circular column resulted in a value of 0.45.

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References

Bruneau M, Marson J. (2004): Seismic design of concrete-filled circular steel bridge piers. *Journal of Bridge Engineering*, 9(1), 24-34.

Marson J, Bruneau M. (2004): Cyclic testing of concrete-filled circular steel bridge piers having encased fixed-based detail. *Journal of Bridge Engineering*, 9(1), 14-23.

USACE-ERDC (2004): *Bridge Explosive Loading (BEL) version 1.1.0.3*. US Army Corps of Engineers' Engineer Research and Development Center, Vicksburg, MS. (distribution limited to U.S. Government agencies and their contractors).

USDA (1990): Structures to Resist the Effects of Accidental Explosions. *Technical Manual TM 5-1300*, US Department of the Army, Washington, DC.