EARTHQUAKE AND MULTIPLE HAZARD PROTECTION OF HIGHWAY BRIDGES
FHWA CONTRACT TEA-21 EXT

Multi-hazard-Resistant Bridge Wall Pier Concept (Task EXT-1C)
QUARTERLY REPORT (APRIL 2005 - SEPTEMBER 2005)

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Motivation and Objective

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.

A. Work performed during current calendar 2 quarters

Literature review and available analysis tools

Very little information is available on the performance of civil infrastructure systems under blast loading, particular regarding bridge component and details. The existing literature focuses on the performance of building structures (e.g., structural and non-structural components, walls and glazing panels). The complex distribution in time and space of blast pressures on bridge columns located at a short distance from the blast source has not been thoroughly investigated. It is also ascertained that this information does not exist in the classified literature.

There exist simplified methods of analysis to assess the response of structural members to blast loads. These methods are based on fundamental principles and are in most cases accurate enough for design purposes. These simplified methods allow the expeditious conduct of parametric studies and are not computationally intensive. In addition, there exist several computer programs to calculate blast parameters (pressure and impulse). Although some of the most sophisticated codes (such as BlastX) are not in the public domain, the program BEL (Bridge Explosive Loading), developed by the USAE Engineer Research and Development Center for the Federal Highway Administration is available on a limited distribution basis and was used for this research program. This program incorporates important components of the program BlastX, but is tailored to address the special case of blast loading and structural response of bridge components, including effects such as breaching and spalling on reinforced concrete members.

Design of multi-hazard bridge piers

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.

Various concepts of wall systems were first investigated. This included steel plate walls, as well as steel plate walls consisting of RC pre-cast panels sandwiching a thin steel plate. A drawback of this scenario was that the RC panels captured substantial pressures, and preliminary models suggested that wall of substantial thickness were required to resist the blast without losing their ability to carry gravity loads. These walls also introduced substantial overstrength in resisting earthquakes, which was contrary to the objective of an optimal multi-hazard design.

A pier-bent design concept consisting of concrete-filled circular steel columns (CFCSC) linked by a cap-beam proved to be more satisfactory, and was found possible using available tube sections. It was found that material effectiveness was highest for piers having the highest diameter-to-thickness (D/t) ratio. CFCSC with cross-sections of 16” diameter were found to provide adequate blast and seismic resistance during the design process. These CFCSC 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 (and incidentally is helpful in fulfilling the objective of accelerated construction). This structural configuration was therefore selected for experimental verification of its blast resistance.

Experiments on 1/4 scale multi-hazard bridge piers

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 concrete-filled circular steel columns (CFCSC) 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 steel beams embedded in the cap-beam and a foundation beam. Fiber 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; no reinforcement bars were used. Summary of the pier tests are presented in Table 1. In addition to the pier tests, a plate connected between two piers was also tested; results for this test are presented in Table 2.

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 2) were subjected to successive blast tests, as shown typically in Figure 3. Note that the cap-beams were not fixed to the reaction frames as it was intended to allow rotation to replicate actual conditions in bridges.

B. Preliminary results

Experiments on 1/4 scale multi-hazard bridge piers

Maximum residual plastic deformations of each pier after testing, and maximum residual plastic elongation of the plate after its test, are shown in Tables 1 and 2 respectively. Figure 4 shows Column 5 of Bent 1 after the test as an example. The CFCSC 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.

While it would have been desirable to test a reinforced concrete column for comparison purposes, budget did not allow it at this time. However, expert opinion and results from the BEL software indicate that a comparable reinforced concrete pier would have exhibited significant lower ductility and breaching of the concrete.

C. Work expected to be performed during the next calendar quarter

Detailed analysis is underway using data collected as part of this test program, to develop design recommendations and to calibrate and investigate the effectiveness of more advanced analytical models.

Experimentally obtained pier plastic deformations will be compared with the one that can be calculated using simplified methods of analysis. These simplified analyses will integrate strength values obtained form tensile tests from coupon to be taken from the steel tubes and steel plates from which the specimens were constructed. Subsequently, time history analyses will be performed using a combination of pressure-time history obtained from the restricted computer software BEL (Bridge Explosive Loading) as well as obtained experimentally for various charges and stand-off distances.

D. Problems or concerns regarding the conduct of the task, research results, etc.

No problems or concerns regarding this task are reported at this time.

E. Labor expended

Dr. Michel Bruneau	P.I.	80 hours
Dr. Diego Lopez Garcia	Post-doc	480 hours
Shuichi Fujikura	R.A.	200 hours

Table 1. Summary of Column Test Cases and Results

#	Bent	Column	Charge Weight	X	Z (m)	Maximum Deformation (in)	Maximum Deformation (mm)
#1	B1	C4	0.1 W	3 X	0.250	0	0.0
#2	B1	C4	0.55 W	3 X	0.750	0	0.0
#3	B1	C4	W	2 X	0.750	1 3/16	30.2
#4	B1	C6	W	1.1 X	0.750	1 13/16	46.0
#5	B1	C5	W	1.3 X	0.750	3	76.2
#6	B2	C4	W	1.6 X	0.250	15/16	23.8
#7	B2	C4	W	0.6 X	0.250	5 8/16	139.7
#9	B2	C6	W	0.8 X	0.250	1 12/16	44.5
#10	B2	C5	W	0.8 X	0.250	3 15/16	100.0

Table 2. Summary of Plate Test Cases and Results

#	Bent	Column	Charge Weight	X	Z (m)	Plate size (in)	Maximum Elongation (%)
#8	B2	C5, C6	0.06W	5 X	0.25	68.5 X 48 X 0.03	9.2

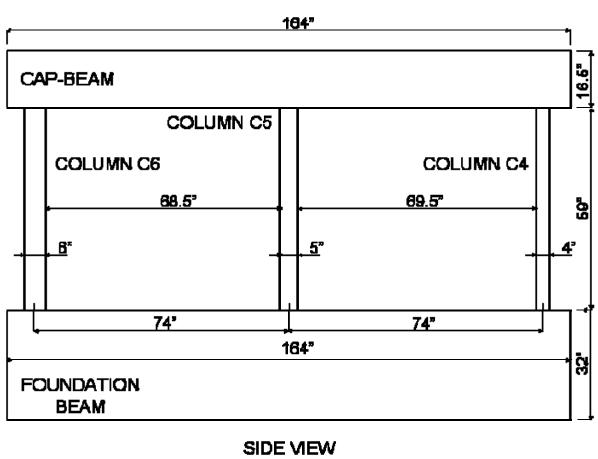

Figure 1. Experimental specimen

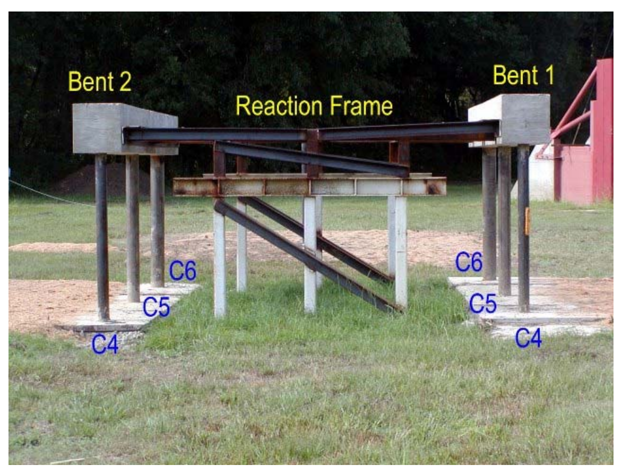

Figure 2. Test stetup

Figure 3. Blast fire ball

Figure 4. Bent 1-C5 (#5) after the test