FULL-SCALE LATERAL IMPACT TESTING OF PRESTRESSED CONCRETE BEAM

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ABSTRACT

Over-height vehicle collision with bridges has increasingly occurred in the United States. Not only were severe damages observed on the bridges, but the collision caused injuries and fatality as well. In the meantime, the lack of knowledge in bridge specifications on lateral impact raises the concern of the existing bridges when subjected to lateral impact loading. A growing number of studies have been performed with respect to the impact of structures. Finite element method has largely been used to analyze the complicated collision mechanism and to do parametric studies. Also, small-scale tests were conducted to provide a more realistic behavior of the structure when subjected to impact load. This paper provides an opportunity of full-scale impact testing of a prestressed concrete beam, which leads to a realistic level of damage and mechanism analysis. A full-scale lateral impact testing facility was designed and built on a construction site in Knoxville, Tennessee. The over-height vehicle impact was simulated by impacting the bottom flange of an AASHTO Type-I prestressed concrete beam with an impact cart. This paper describes the details of the impact testing facility as well as the response of the prestressed concrete beam after impact.

Keywords: Over-height vehicle, Collision, Impact Testing, Full-scale facility.

Introduction

A growing number of bridge collisions caused by over-height vehicles occurred in the United States (Fu et al.[1]). The lack of knowledge in bridge specifications raises the concern of bridge safety when subjected to lateral impact. AASHTO LRFD Bridge Design Specifications[2] specifies that Extreme Event II include vehicle collision force.

Previous research have studied the performance of the structures to impact and impulsive load by experiments and analysis. Simms[3] studied the impact resistance of reinforced concrete units failing in bending by doing mass falling impact tests. Bate[4] carried out a large number of tests as an extension of the investigation by Simms[3]. The test specimens consisted of prestressed and reinforced concrete beams. The failure behaviors of prestressed beams under impact loading were presented in Ishikawa et al.[5], high speed loading analysis and impact failure analysis were also developed in their study. In above studies, the impact and impulsive loading were applied by falling mass from a certain height. Steel plates were used in some of the specimens to prevent the local failure. Different types of failure modes were considered, impact force and maximum deflection were estimated. Nonetheless, these dropping weight tests cannot accurately address the lateral impact problems caused by vehicles, in the meantime, the specimens used in the tests are small scale compared to the real bridge beams.

As for the increasing number of accidents caused by over-height vehicles, more studies have focused on the analysis of the dynamic behavior of structures to lateral impact. Finite element method (FEM) has been largely used to analyze the complicated collision process due to the less possibility of full-scale impact crash test in the field. Abendroth et al.[6] studied the effect of steel diaphragms on prestressed concrete bridges when subjected to over-height vehicle impact by using FEM. A magnitude of 120 kips impact loading applied at an intermediate diaphragm was selected such that the maximum principle-tensile strain that is induced in the impacted girder would not appreciably exceed the modulus of rupture of concrete for the girder. Xu et al.[7] studied the failure modes of different types of bridges when subjected to over-height truck impact via FEM, and a simplified model was proposed to calculate the impact force under different truck speeds.

In our study, a decision was made to build an outdoor full-scale impact testing facility to simulate the actual bridge beam behavior during impact. This paper summarizes the design and construction of this facility as well as an impact test of a prestressed concrete beam.

Design and Construction of Impact Testing Facility

Background

Zaouk et al.[8] described the results of a computer simulation using a Chevrolet C-1500 pick-up truck model for a frontal impact with a rigid wall at an initial velocity of 35 mph with 0 degree impact angle. The non-linear finite element simulation was validated by the data obtained from the impact testing. The energy absorption was analyzed in the simulation by computing the material internal energies and the energy absorbed by the whole vehicle was determined to be 158 kip-ft. Based on their study, the total initial impact energy of 74 kip-ft, which is almost half of 158 kip-ft, was chosen in our study to design the full-scale impact testing facility in order to simulate a relative severe situation during vehicle impact.

Multiple factors were considered in the design of the testing apparatus. The impact cart with an elevated track was selected after evaluating the cost and safety.

Impact cart

A track with the change of height in 10 ft was constructed. In order to reach the required initial energy, the weight of the impact cart was determined to be 8000 lbs. The impact cart is a 50 cubic foot concrete block with a 10 inch x 10 inch x 10 inch impactor supported by a steel frame, as shown in Figure 1. Eight casters are also attached to the steel frame, four of which are used to support the weight of impact cart, and the other four act as side wheels to provide straight tracking. The dimension of the concrete block turned out to be 5 ft x 5 ft x 2 ft, and the actual weight of impact cart is 9000 lb. A pull hitch was also fabricated on the steel frame in order to pull the impact cart up the track.

Fig. 1 Impact cart

Track system

Framework that is capable of withstanding both gravity and lateral loads is required for the track system for this testing setup. The track system consists of posts, bracing, work platforms and a rail system. The bottom of the track is set at a height of one foot, and the height at the top of the track is 11 ft. The impact cart needs to roll down a smooth surface to create an impact with the specimen and the surface was provided by rails that were placed on top of the post line. Figure 2 illustrates the track system used in the impact testing.

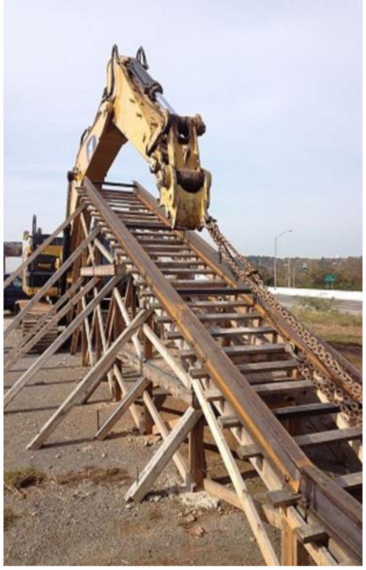


Fig. 2 Track system

Backstop

The backstop was designed to provide lateral support that prevents the specimen from sliding horizontally during the impact. The backstop consists of two wide flange steel beams that are set in concrete footings. HSS tubes were used to transfer the loads from the specimen to the wide flange steel beams. The HSS tubes are removable so that multiple specimens can be tested using the facility. Figure 3 displays the backstop system.

Fig. 3 Backstop system

Support system

The center of the impactor was designed to impact the bottom flange of the specimen where the -prestressing strands are located. The specimen needs to be elevated to where the bottom of the bottom flange is lined up with the center of the impactor. The support system consists of New Jersey Barriers and HSS tubes beneath the barriers, which are readily available at the testing site for other purposes. The support system is illustrated in Figure 4.

Fig. 4 Support system

Impact Testing

Specimen

The specimen used in the impact test was an AASHTO Type I prestressed concrete beam with 0.7-inch strands. The compressive strength of concrete girder is 14100 psi, and the compressive strength of concrete deck is 10631 psi. The deck concrete strength was higher than that of a typical deck in order to use a much narrower width of the deck for testing, yet still maintain the deck equivalency. The length of the beam is 56 ft and this beam was statically tested at both ends according to Cabage [9]. After the static test was completed, the beam was shipped to the impact testing site. This prestressed concrete beam was set up so that the middle portion of the beam can be tested by impact while leaving the failed beam ends from the static testing cantilevered out from the supports. The cross section view is shown in Figure 5. The track system, impact cart and concrete beam setup is indicated in Figure 6.

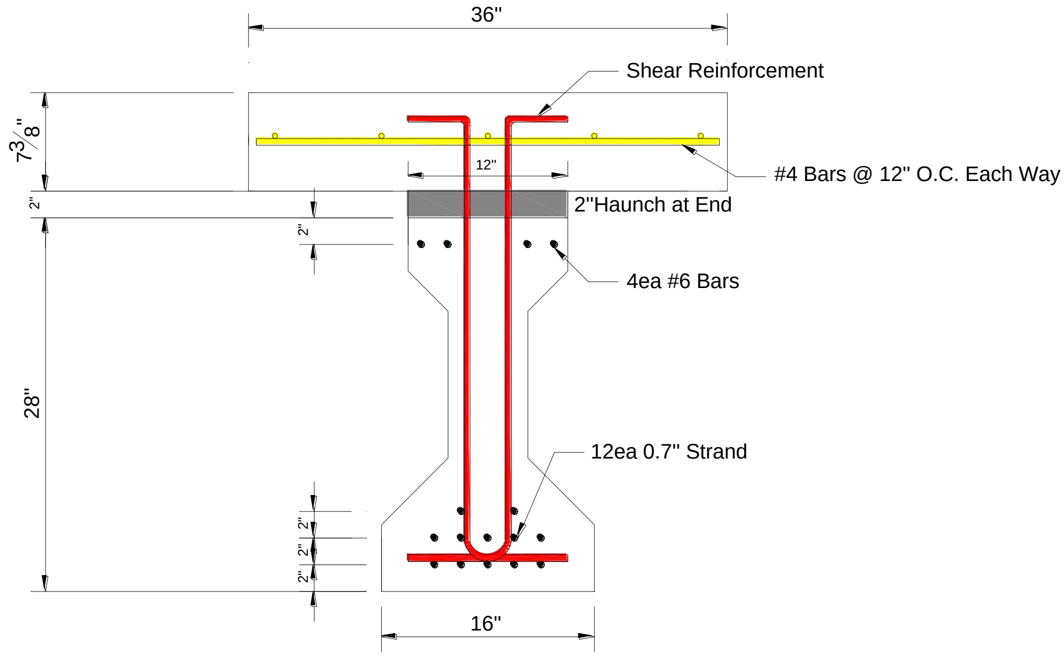
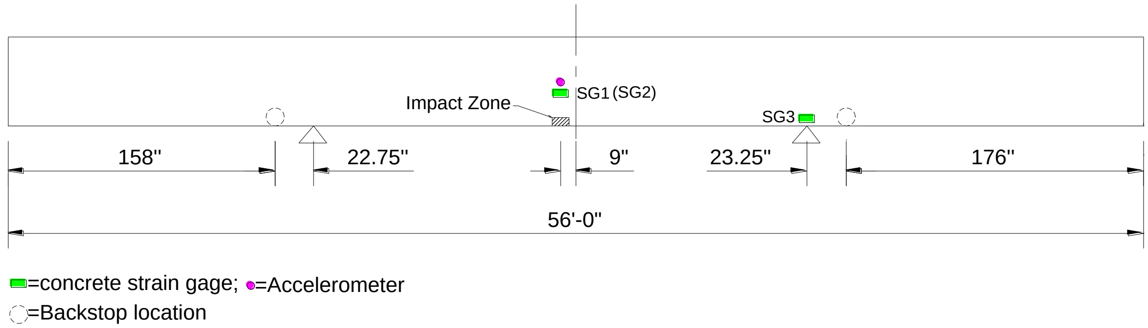


Fig. 5 Prestressed concrete beam cross section

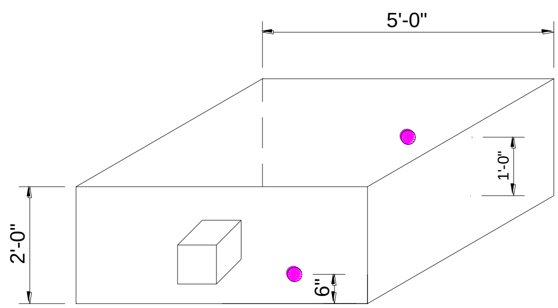
Fig. 6 Prestressed concrete beam setup

Instrumentation

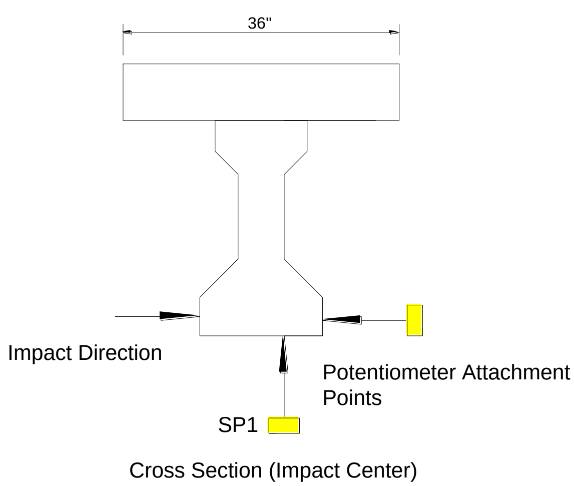
The data collection was accomplished by using National Instruments (NI) data acquisition hardwire and LabVIEW programming platform. The acceleration, displacement and strain were recorded by accelerometer, string potentiometer and strain gage with the sampling rate of 10-kHz during impact. Three concrete strain gages were put on the beam. Two accelerometers were attached to the impact cart, and the last one was above the impact zone on the beam. Two string potentiometers were attached to the bottom flange of the beam in order to get the horizontal and vertical movements, and the other two were clamped to the top of wide-flange steel beams. Five strain gages were applied to two wide-flange steel beams. Figure 7 shows the locations of all sensors used in the testing.



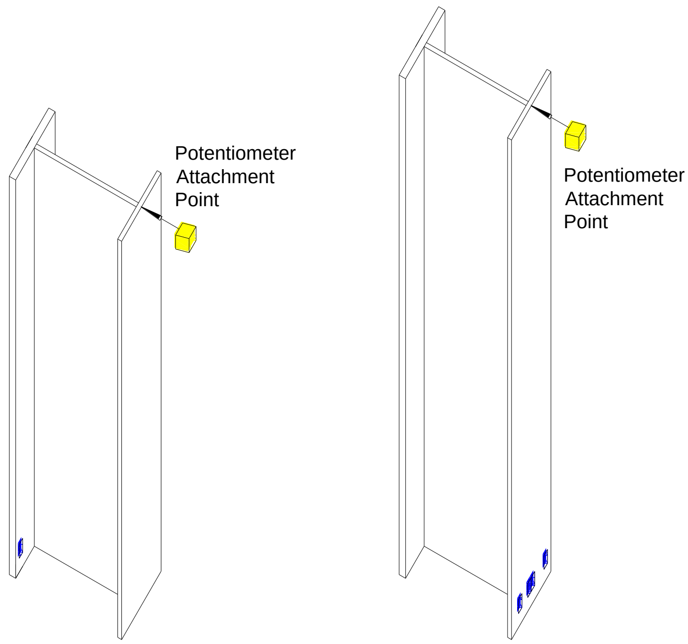
(a) Front View (“SG2” located on the back)



(b) Impact Cart with Two Accelerometers



(c) Two String Potentiometers on the Specimen



(d) String Potentiometers and Strain Gages on Wide-Flange Steel Beams
Fig. 7 Positions of sensors

Impact testing

The impact testing was conducted in November 2014. The purpose of the testing was to evaluate the testing facility and data acquisition system, as well as observe the response of the concrete beam during collision. Before the impact, the cart was connected to an excavator by a chain and a shackle that was connected to the pull hitch on the cart. Once the cart was pulled up the track, a second excavator was placed on the front side of the impact cart to prevent it from rolling down. Once the second excavator has secured the cart, the chain was slacked and shackle was unfastened. The bucket of the second excavator was raised to release the cart. Figure 8 shows the impact cart pulled up the track before impact. From the moment the impact cart was released, the whole collision took about 3 seconds and then the cart was completely stopped without a second hit.

Fig. 8 Impact cart at designed height

Testing Results

Figure 9 presents the process of the collision from side view of the beam and the first picture shows the beam just before impact. It can be seen from the side view that the impact forced the bottom flange of the prestressed girder to rotate and move upward, with concrete spalling near the point of impact. The beam crumbled and the cracking was observed all the way through the beam. The prestressing strands were all uncovered and the pre-tensioning forces were released from all of the strands. The prestressed concrete girder was totally destroyed after the impact. Figure 10 shows the beam after impact, in order to miss the prior damaged zones, the length of each overhang is relatively long. Due to the gravity of the overhangs, beam bow upwards after collision.

t=0 s

t=0.033 s

t=0.067 s

t=0.100 s

t=0.133 s

t=0.167 s

t= 0.200 s

Fig. 9 Collision process from side view

Fig. 10 Beam after impact

The supporting structure performed well, however when the impact cart hit the first angle change near the bottom of the ramp, a section of the track failed. The joists nearly sheared completely in two and the welds on the rails broke, as illustrated in Figure 11. The section that was damaged has been redesigned and repaired. Despite this damage to the track, the facility as a whole worked for the intended purpose.

Fig. 11 Damaged joists and welds

Summary and Conclusions

Multiple factors were considered during the design of the full-scale impact testing facility. An impact cart with an elevated track was selected over drop weight and pendulum tests because it is more cost-effective and a safer system, as well as less construction time is involved. The setup system consists of an impact cart, track system, backstop and supports. The impact cart rolls down the track and the center of the impactor impacts the bottom flange of the specimen. A backstop was constructed to prevent the specimen from sliding horizontally during the collision.

During the impact test, the whole system was proved to be working as expected except for the structure failure of one section of the track, which has been redesigned and fixed. All the data obtained from the data acquisition system are reasonable, which are currently being analyzed. The duration time of the lateral collision was found out to be 0.08 seconds.

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