The Ohio Department of Transportation
Office of Research & Development
Executive Summary Report

An Over-Height Collision Protection System of Sandwich Polymer Composites Integrated with Remote Monitoring for Concrete Bridge Girders

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Problem

One of the common damages in existing highway bridges is the damage at the bottom corners or edges of the reinforced concrete beams or box girders induced by an impact of trucks exceeding the allowable height clearance of the bridges. Due to collision impact of the trucks, the bottom or outer layers of concrete girders are usually peeled off (see Fig. 1) so that the steel reinforcements are exposed to the surrounding environment and subjected to corrosion, leading to the reduced load carrying capacity. An over-height collision protection or scarifying system can be used to protect the concrete girders from such impact damage, thus ensuring the integrity of the bridge structures.

Fig. 1. Impact damages in the concrete bridge girders by over-height trucks

A collision protection and scarifying system shown in Fig. 2 is developed in this study, and it utilizes advanced materials/structures to protect highway bridge girders. The proposed collision protection and scarifying system is in a new "I-Lam" (**I**mpact **Lam**inate) panel configuration and bolted and/or bonded to the bottom portions or edges of concrete girders. The proposed I-Lam panels are made of a composite sandwich construction with multi-layer aluminum honeycomb core and top and bottom thin face sheets, and they are developed/designed specifically for impact damage protection of bridge girders (e.g., concrete girders).

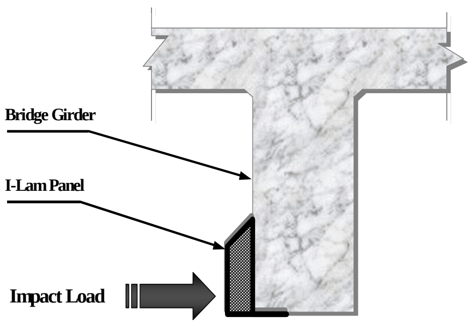

Fig. 2. Over-height collision protection (scarifying) system for concrete girders

Objectives

This study aims to develop a new collision protection/scarifying I-Lam system for concrete bridge girders using composite sandwich with crushable core, to integrate the system with smart sensors and actuators for remote sensing, triggering and monitoring, and to demonstrate the benefits of using the scarifying elements for protecting the bridge girders from the expected localized damages.

The major objectives of the study include: (1) To develop general design for the collision protection system based on the specified site conditions and construction requirements; (2) To conduct the analysis, optimal design, and quality control tests of the collision protection system and to develop design criteria and guideline for I-Lam; (3) To implement the developed collision protection system in identified damaged bridges or new constructed bridges, and to re-deploy the system if damage occurs over the duration of the project; and (4) To monitor the short- and long-term performance of the collision protection system using smart sensors and actuators and remote sensing technology. Due to some circumstance and modification in the I-Lam installation design, only the visual field inspection is considered to monitor the performance of collision protection system. A smart triggering and monitoring system using piezoelectric sensors and actuators is instead developed and tested at the lab, and it is ready for field implementation.

Description

In this study, an aluminum honeycomb collision protection system so called "I-Lam" (**I**mpact-**Lam**inate) sandwich (see Fig. 3) for concrete bridge girders is developed, designed, analyzed, fabricated, tested, and field-installed. Details of analysis procedures and engineering design criteria for collision protection system are proposed. The following research findings are briefly summarized:

Fig. 3. Double-layer I-Lam sandwich (12 x 12 x 8 in.)

- Three simple linear elastic impact models (i.e., discrete system, beams under concentrated load, and beams under distributed load) for I-Lam sandwich beams with inclusion of shear-off effect of the overheight material are developed. The models are capable of explicitly predicting the contact force, displacement and duration during the impact event.

- Three design criteria (i.e., contact force limit, contact displacement limit, and energy absorption limit) for I-Lam sandwich structures are proposed, and they are used as a guideline for designing impact mitigation and protection system.
- Energy analysis is established to calculate the energy partition among different components in an I-Lam sandwich system, and it provides a better design criterion for design analysis of impact energy absorption systems, such as I-Lam, and offers good predictability for energy absorption capacity of the system.
- Corresponding to the elastic and elastic-plastic impact analysis as well as the energy model, different design analysis stages are defined. They can be used to accurately and more realistically analyze the impact event of I-Lam under different loadings and magnitudes of impact.
- Based on the developed engineering design analysis protocol and the defined loading and impact speed requirements, a bi-layer aluminum sandwich design for I-Lam (see Fig. 3) is designed and finalized.
- Numerical simulations of plain and reinforced concrete beams with and without I-Lam protections indicate that with I-Lam protection, the transferred contact force is reduced dramatically, and as expected, about 60 to 70% of the kinetic energy is absorbed by crushing of the aluminum core in the I-Lam.
- Both the compressive crushing and indentation tests of I-Lam sandwich materials are also performed, from which the elastic-plastic indentation behavior and contact law are experimentally obtained. The refined analysis based on the experimental data from the crushing and indentation tests is performed, and it indicates that the proposed I-Lam structure meets the given design loading and impact requirements and behaves satisfactorily.
- Full-scale impact test are conducted to three reinforced concrete (RC) beams (i.e., two protected with I-Lam panels and one without I-Lam protection) at Transportation Research Center, Inc. (TRC), and the experimental evidence indicates that the I-Lam panels can be used to effectively protect the substrate structures and mitigate the impact damage by core crushing.
- An overheight imapct detection and evaluation system is developed for the concrete bridges based on smart piezoelectric material.

Conclusions & Recommendations

In summary, the developed smart bi-layer honeycomb I-Lam sandwich is capable of reducing the transferred contact force dramatically, absorbing/mitigating impact energy, protecting the underneath concrete structures by system scarifying and core crushing, and monitoring the impact incident with smart piezoelectric sensors, and it is applicable to protecting other structures (e.g., steel girders, columns) from accidental vehicle impact in the highways. The simplified analytical models and corresponding design criteria and guidelines developed have contributed to advancing engineering practice and design of impact protection/mitigation systems. The conducted experimental study of I-Lam under crushing and indentation is important for better understanding the contact behavior during the impact process and helps develop semi-empirical models. The full-scale lab impact tests of reinforced concrete beams with and without I-Lam protection demonstrate the effectiveness of the I-Lam panels in impact protection and mitigation and validate the proposed I-Lam concept at the lab-scale level.

Implementation Potential

The simplified design criteria (i.e., contact force limit, contact displacement limit, and energy absorption limit) and methodology developed for I-Lam sandwich structures can aid and guide practicing engineers to design similar impact mitigation and protection systems and to tackle the collision-related problems encountered in the field.

The potential of the over-height collision protection (scarifying) system for future implementation in protecting concrete bridge girders from impact is promising. This developed technology could also be adopted for bridge columns and signing structures as well as steel bridge girders for protection from possible impact loads.

The outcomes of this study provide guidance for developing acceptance test procedures for similar applications, observations and recommendations useful for updating current bridge repair procedures. Ultimately, potential pilot projects should be identified and implemented to demonstrate the effectiveness and usefulness of the proposed protection system.