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Load Distribution and Fatigue Cost Estimates of Heavy Truck Loads on Louisiana State Bridges

INTRODUCTION

TEA 21 (Transportation Equity Act 21) of 1998 allows heavy sugarcane truck loads on Louisiana interstate highways. These heavier loads are currently being applied to state and parish roads through trucks traveling from and to the processing plants. Generally, commercial vehicle weights and dimensions laws are enforced by highway agencies to ensure that excessive damage (and subsequent losses of pavement life) is not imposed on highway infrastructures like bridges. The axle loads and total loads of heavy trucks, which are considered primarily responsible for decreasing the service life of bridges, are significant parameters of highway traffic. TEA 21 is allowing sugarcane trucks to haul loads up to 100,000 lb. Because highways and bridges have traditionally been designed for the legal load of 80,000 lb., permitted trucks of 100,000 lb. or more decrease the expected service life of the infrastructure. During the 2009 regular session, the Louisiana Senate passed a Concurrent Resolution (SCR-35), which urged the Louisiana Department of Transportation and Development (DOTD) to conduct a pilot study on alternative truck-trailer configurations to support the bio-fuels industry. The senate concurrent resolution SCR-35 specifically requested that the study include vehicles hauling sugarcane biomass for alternative fuel and electricity generation. During the course of the work, the American Sugar Cane League indicated that their members requested that the bridge monitoring system be installed around the New Iberia area and the response to SCR-35 to be limited to theoretical evaluations.

OBJECTIVE

The objective of this research was to develop an integrated system for monitoring live load and verify the carrying capacity of highway bridges in Louisiana where heavy truck loads may have caused significant damage to state bridges. This study developed a monitoring system for synchronous measurement of live load and structural response of bridge components. The monitoring system integrated a distributed network of advanced strain and displacement sensors (continuous and peak). The anticipated major contributions include accumulated fatigue load spectra, strain measurements to determine in-service conditions, and adverse loading conditions on the bridge superstructure assessments.

SCOPE

The scope of the investigation on the impact of heavy truck loads on non-interstate bridges can be stated as follows:

- To study the effects of heavy truck loads (100,000 lb. and 148,000 lb.) on distribution of forces and moments on slab-girder bridges.
- To develop a long-term monitoring system that can assess the impact of heavy truck loads on safety, serviceability, and durability of non-interstate bridges.
- To determine the cost of the fatigue damage per heavy truck load (100,000 lb. and 148,000 lb.) per year.
- To investigate the use of strain measurements from the monitoring system to predict the gross vehicle weight of a truck.

METHODOLOGY

The bridge in this study was evaluated and a monitoring system was installed to investigate the effects of heavy loads and cost of fatigue for bridges on state highways in Louisiana. The superstructure of the bridge in this study was evaluated for safety and reliability under four different kinds of truck configuration and loads hauling sugarcane. The bridge model was verified by performing live load tests on the structure. The bridge finite element model was analyzed under the different kinds of loading and the effects were listed and compared. In response to the SCR-35, the alternative truck-trailer configuration will use extra axles under the load to reduce the impact on Louisiana roads. Ideally, the alternative truck-trailer design, when compared to the traditional truck-trailer, will simultaneously decrease the number of trucks and increase the total number of tons of sugarcane that travel on Louisiana roads. The two new truck configurations recommended are GVW-148 Opt-1 and GVW-148 Opt-2. Both truck weights will be limited to 100,000 lb. with a dolly weight to be limited to 48,000 lb. for a total gross vehicle weight (GVW) of 148,000 lb.

The bridge used in this study is located in south Louisiana in Iberia Parish along US 90 at LA 675, that is used repeatedly by heavy sugarcane trucks. The monitoring system installed consisted of strain transducers, data loggers, a high-speed digital camera to capture images of overloaded vehicles as they crossed the bridge, along with a solar panel and battery backup system. The overall system was designed to capture "events" based on a trigger limit, strain magnitude, on two mid-span bottom strain transducers, which includes a predefined amount of data before a trigger occurs and then a predefined amount of data after the trigger occurs. Along with saving the block of data, the camera mounted on the bridge also takes a photo of the passing truck with a time stamp on it. Photos are automatically saved with the strain data and gives researchers some idea about the axle orientation of the vehicle passing over the bridge.

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The user can configure the trigger limit and the size of the data block at any time. In order to support the data handling process, a live data monitoring website that manages the structural monitoring project was developed, which can be accessed from anywhere in the world. It provides access to up-to-date data and automatically alerts the appropriate personnel if data exceeds any predefined limits. This entails everything from alerting a field technician that a data logger battery voltage is low to informing an analysis engineer if a sensor is outside the predefined limits. The website's time-based graphing utility facilitates easy data analysis and comparison along with allowing the user to view anywhere from five minutes to one year's worth of data in a given plot. The website also allows the user to view desired data in a table form as well as save the data to a text file for their own records and use. Usernames and passwords have also been provided so that the engineers can begin the data handling procedures from their offices.

Field Test

A field test was done to verify the finite element model simulated in GTSTRUDL. A test truck fully loaded with sugarcane was weighed in a weighing station and the 100-kip gross vehicular weight was confirmed and matched with the theoretical load distribution for 3S3 truck. The distance between the axles and the wheel spacing was also measured. According to theoretical analysis, the driving path of the truck on each lane for the test was determined beforehand. The truck was driven over the bridge on different lanes and with different speeds in order to understand the effect of the impact of truck speed on the strain transducers. The bridge was closed to normal traffic for the duration of the test.

Regression Analysis for the Truck Weights

One of the current methods of measuring truck weights in the state of Louisiana is the weigh-in-motion system. This system weighs a semi-truck while it is traveling along the interstate system. The system is only implemented in certain areas of the state, mainly on interstate sections on level ground. The areas that do not have weigh-in-motion still use the weigh stations along the interstate. Unfortunately, this type of system has limited applications and cannot be used on overpasses and bridges. The installed monitoring system provided the opportunity to explore the use of a strain gauge measurement system to determine truck weights and possibly be used as a means to help replace the expensive weight measuring systems. For this experiment to be proven plausible, a regression analysis was performed on several data sets, including controlled tests and live field data.

CONCLUSIONS

In this study, four different load cases for the truck loading were considered according to their location on the bridge deck. Case I is when the truck is on left lane (inside lane) of the span 14E producing maximum positive moment in the girders then call it. Case II deals with trucks located on the left lane but producing maximum negative moments in the girders. Similarly for Case III, the truck is on the right lane (outside lane), creating maximum positive moment in the girders; for Case IV, the truck is on the right lane creating maximum negative moment in the girders. Finite Element Analysis of the bridge was done under four different load cases and four different truck loadings. Under each load case, the effects (girder stress, girder deflections, and deck stresses) of the four different heavy trucks are listed and compared.

The results of the analyses show that the pattern of response of the bridge under the four different cases follows the same trend. Among the four different cases of loading configurations, Case 4 which was GVW = 148,000 lb. and vehicle length of 92 ft., produced the largest tensile and compressive stresses in the members. The results from the bridge deck analyses indicated that the ratio of tensile stresses at the top surface is of the same magnitude as the ratio of compressive stresses at the bottom surface. Also, the ratio of compressive stresses at the top surface is of the same magnitude as the ratio of tensile stresses at the bottom surface. These similarities confirm that the bridge deck is under a stable stress state, whether the stresses are in the tension zone or the compression zone. The heavy load as indicated in SCR-35 will cause damage to bridges, specifically with spans longer than 90 ft. During the live load tests, the strain readings were reviewed to determine the contribution of each girder to the behavior of the bridge as a system. The strains in the girders indicate that all the girders are in the same state of strain, tension, or compression, and the magnitude of the strain in each girder is related to its distance from the axle of the truck. This confirms to the design specifications, that the load applied to the bridge is distributed between the girders based on their location and spacing. The results of the linear regression analyses used to determine the truck gross vehicle weight from the strains recorded by the monitoring system were not conclusive.

The monitoring system also records strains every hour and strain cycles that occurred within the range during the hour period. The data provide the relative magnitude of strain ranges for the various gauge locations. It also provides the strain reversals in the girders, which is an important factor for fatigue analysis. The recorded data indicate that the bridge girders are subject to low cycles of high strain values, above 33-microstrains, and high cycles of low strain values. The girder performance under such conditions can be explained as follows: the high strain values exceed the serviceability criteria and can lead to cracks in the girders then the high cycles of low strain will lead to fatigue in the prestressed strands. Consequently the girders will deteriorate and the life span of the bridge will be reduced. The data from the monitoring system indicates that the average number of heavy load during October, November, and December is 3.5 times higher than the rest of the year. The bridges are exposed to a high cycle of repetition of heavy loads that will reduce the life span of the bridges by about 50%. The bridges that are built to last 75 years will be replaced after about 40 years in service. This seasonal impact is due to the sugar cane harvest, and these results confirm the cost of fatigue, as determined in the previous studies, LTRC report numbers 418 and 425.

RECOMMENDATIONS

Based on the results of the studies presented in this report, it is not recommended to increase the gross vehicle weight of sugarcane trucks. The heavy loads indicated in SCR-35 will cause premature fatigue damage to the main structural members and could cause their eventual structural failure. In addition, the majority of the Louisiana in service bridges were designed to accommodate lower loads than the bridge tested on this project. Therefore, based on the test results, one should expect that the proposed trucks to shorten significantly the remaining life span of Louisiana bridges. All these bridges should be rehabilitated prior to implementing SCR-35. The data from the monitoring system will provide a good source of information to review the current serviceability criteria used by DOTD for design of prestressed concrete bridge girders.

This research delivered a field-verified model for analyzing and determining the effects due to applied loads. The monitoring system records strains and strain cycles that occurred within the range during the hour period. The data provide the relative magnitude of strain ranges for the various gage locations. It also provides the strain reversals in the girders which is important factor for analysis.

DOTD should implement the data from the monitoring system to review the current serviceability criteria used by DOTD for design of prestressed concrete bridge girders.

DOTD should not increase the gross vehicle weight of sugarcane trucks from the current vehicle FHWA Type 10 (3S3) GVW 100,000 lb. The heavy loads indicated in Louisiana Senate Concurrent Resolution 35 (SCR-35) will cause premature fatigue damage to the main structural members and could cause their eventual structural failure. In addition, the majority of the Louisiana in-service bridges were designed to accommodate lower loads than the bridge tested on this project. Therefore, based on the test results, one should expect that the proposed trucks to shorten significantly the remaining life span of Louisiana bridges. All these bridges should be rehabilitated prior to implementing SCR-35.

The DOTD should implement this bridge for their live-load testing needs.

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