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Deficient Bridges and Safety Information

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Background

Structural Failures

When thinking of bridge safety, the public would often limit this to structural failures of bridges. And, there were over 500 failures of bridge structures in the United States (US) between 1989 and 2000 alone according to Wardhana and Hadipriono (2003). The age of the failed bridges ranged from one year to 157 years, with an average of 52.5 years. The most frequent causes of bridge failures were attributed to floods and collisions according to this study. In most of these cases, no people were killed but they all caused delays to travelers and costly repairs.

The deadliest bridge collapse in the US in the last 50 years did not involve motor-vehicle traffic. It occurred in 1993, when a passenger train was crossing the Big Bayou Canot Bridge hitting a kink in the tracks and derailed. The locomotive slammed into a bridge span and initiated the structure's collapse bringing the train into the river and killing 47 people onboard (Jenkins, 2017).

The second deadliest bridge failure was the 1967 Silver Bridge collapse between Point Pleasant, W.V. and Gallipolis, Ohio. The aluminum suspension bridge collapsed, plunging 32 vehicles into the Ohio River, killing 46 people, including two whose bodies were never found.

The third deadliest collapse was the 1989 Cypress Street Viaduct failure in Oakland, California. A 6.9 magnitude earthquake caused a number of structures to collapse — including a portion of the upper tier of Cypress Street Viaduct, a section of Interstate 880. And 42 of the quake's total 67 deaths occurred as a result of the viaduct's collapse.

The fourth deadliest collapse was the 1980 failure of the Sunshine Skyway over Tampa Bay in Florida. The bridge was struck by a ship during a thunderstorm causing the structure to collapse, sending six cars, a truck and a Greyhound bus plummeting 150 ft. into Tampa Bay with a total of 35 people killed.

In more recent time, the I-35 westbound bridge over the Mississippi River in Minneapolis collapsed on August 1, 2007, during the evening rush hour, killing 13 people.

Another highly publicized bridge collapse occurred in 1983 when the Mianus Bridge on the Connecticut Turnpike in Greenwich, Connecticut collapsed after one of the pins used in its construction had been sheared, killing 3 people.

Adding up these six most deadly bridge collapses gives a total of 186 fatalities in the 50-year period 1967 to 2016. In other words, these crashes by themselves, caused, on average, 3.7 fatalities per year. If we add other less deadly bridge collapses to these, we may get to an average of around five (5) fatalities per year over the last 50 years.

Bridge failures continue to happen. The collapse of a bridge on Interstate 85 in Atlanta in March 2017 meant that 250,000 commuters who travel the highway daily had to find new routes to work and school. But the good news was that no deaths (or even injuries) were reported.

Accidents not Related to Structural failures

It is much harder to find information on accidents related to bridges that do not include structural failures. A literature review came up with a bridge crash study from Kansas. Its findings include, “In 2005, there were 1,919 crashes on bridges in Kansas, including 26 fatal crashes. While overall these accounted for less than 3% of all traffic crashes, they accounted for almost 7% of the total number of fatal crashes." (Hurt et al, 2009). And, that percentage refers to crashes on bridges rather than under or near bridges.

Functional obsolescence or imperfect geometric design does not directly cause crashes. Non-optimal designs may increase the chance of a crash and aggravate injuries once a crash has occurred but it is almost always road user behavior that is the primary factor behind a crash. Therefore, the intent of this project is to initiate studies of how driver and pedestrian behavior can be influenced with information technology as well as how behavior can be influenced by changes to the geometric design.

A substantial subset of fatal injuries on bridges is made up of pedestrians and bicyclists—road user groups that often have no realistic alternative to using a functionally deficient bridge when they cross a river or an Interstate highway. However, there is not much literature in the area of pedestrian and bicycle safety on bridges. One exceptions with respect to pedestrian safety is a Korean study (Tay et al, 2011), which states that "fatal [pedestrian-vehicle crashes in South Korea] and serious crashes were associated with collisions involving pedestrians who were … on bridges…." However, the study does not go into the influence of detailed geometrical features. With respect to bicyclist safety, a Belgian study (Vandenbulcke et al, 2014) can be mentioned, which investigated risk factors for bicyclists limited to infrastructure, traffic and environmental characteristics. The results suggest that a high risk is statistically associated with the presence of bridges without cycling facilities such as bike tracks.

ASCE states in its 2013 Report Card for America's infrastructure, "In total, one in nine of the nation's bridges are rated as structurally deficient, while the average age of the nation's 607,380 bridges is currently 42 years. The Federal Highway Administration (FHWA) estimates that to eliminate the nation's bridge deficient backlog by 2028, we would need to invest $20.5 billion annually, while only $12.8 billion is being spent currently" (ASCE 2013). These sums do not include the greater safety issue of automobile drivers, bicyclists and pedestrians being injured or killed on or at bridges that are not structurally deficient but functionally obsolete or unsafe in some other way.

A primary goal of finding that bridges are unsafe may not be to recommend how to redesign existing bridges but how to use ITS and other information technology to, at first, inform (warn) road users of upcoming real-time safety issues. Such a system has been sketched and presented by researchers at the University of Montana, as shown in Figure 1 referenced by Amadeo Vazquez (2014). At a later development stage, ITS technologies can and should be used to take over control from drivers if they approach a bridge in an unsafe manner, such as at too high speeds for conditions or when they are getting too close to pedestrians or bicyclists.

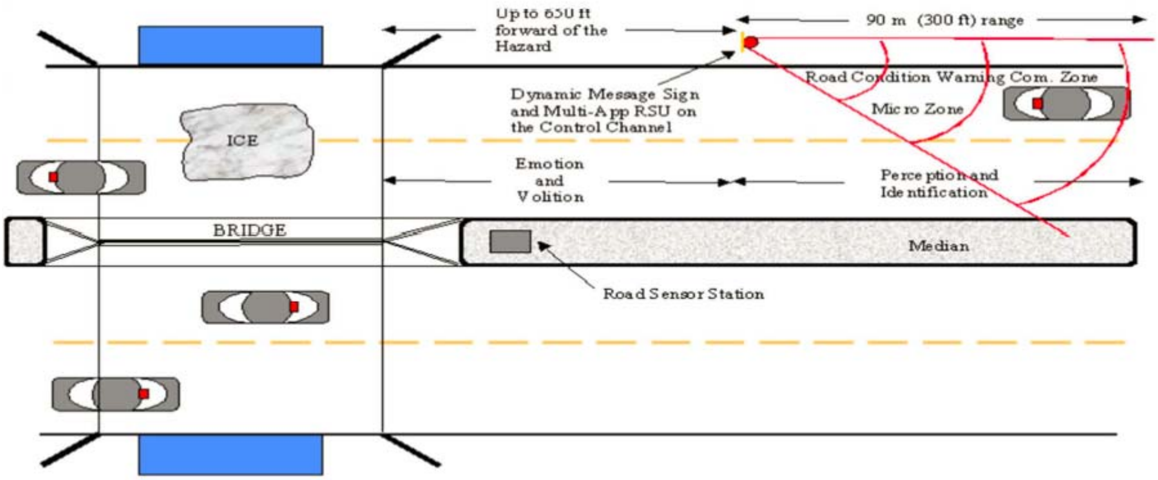

Figure 1 Potential ITS warning system for dangerous situations on or near bridge

There is a wealth of literature on guardrail and bridge rail design, and crash test results of different designs. And, there is a study of motorcycle fatalities from 2003 to 2008 in the state of Indiana showing that a major correlate of death was bridge-guardrails (Nunn, 2011). A specific issue with bridge piers, besides being unforgiving, is that they often cut the vision field ahead. That has been identified as a crash contributor for bicyclists in particular (Jordan & Leso, 2000). Another specific safety issues relates to passing under low-clearance bridges with commercial vehicles. An experiment using 'old-fashioned' ITS technology for reducing such crashes in Maine was presented by Belz & Garder (2009).

Objective

The ultimate goal of this project is to reduce human suffering and death caused by unsafe behavior at or near bridges in combination with less-than-optimal geometric design of said bridges. In other words, the emphasis should probably be to look at human factors and their interaction with geometric design and environmental factors including winter maintenance practices. Initial studies, presented in this report, pinpoints to what extent bicyclists, pedestrians and other road-user groups are the victims. It is very clear that many bridges—at least in the state of Maine—lack sidewalks as well as wide shoulders and therefore cause a special threat to vulnerable road users. The analysis will exclude suicides and homicides and focus on transportation-related crashes.

This project is primarily a safety project. However, badly designed bridges are frequently the Achilles heel in urban and suburban pedestrian and bicycle networks. Therefore, this project certainly has important implications in the creation of livable communities.

Methodology

For analysis of fatal crashes in the US, the Fatal Analysis Reporting System (FARS) database is a reliable source, but only for accidents that involve motor vehicles in traffic on public roads and streets. This database is maintained by the National Highway Traffic Safety Administration (NHTSA) and covers all public roads in the United States, including bridges, and data from several years back (from 1994 on) can be analyzed. However, FARS does not have a field (category) for bridge segments and it is therefore difficult to identify if a crash occurred on or under a bridge or somewhere away from bridges without going through each individual crash and using GPS coordinates and locating the crash that way.

Fatal crashes are typically written up in local newspapers and covered by television stations. But, information from the past is sometimes not archived in a way that makes it easy to retrieve. Therefore, only 2016 fatal crashes have been analyzed here. Newspapers and other media sources were searched on a more-or-less daily basis throughout 2016 and through August 2017 to get updated information on crashes that occurred in 2016. The news articles frequently show photos or videos from the crash site making it possible to identify exactly where it happened. This combined by the text of the news story gives a good picture of what happened, though the information may at times be biased or false, if witnesses lie to reporters.

Google satellite and street-view were used to get more detailed information about the geometry of the site of the crash. FARS for 2016 crashes will be online in September 2017, and the analysis will continue at that time, and be presented in a future paper. The information in FARS includes more-or-less all information gathered by police, including precise information about the latitude and longitude of the location of the crash. Using the latter information, in combination with other FARS information, Google satellite and street-view, it should be possible to determine the exact location of the crash relative to bridge structures in the few cases where the news story did not pinpoint it.

An analysis of non-fatal crashes was limited to the state of Maine. Maine Department of Transportation provided crash data and AADT information etc. The safety analysis here covered not just locations where crashes had occurred. Crash-free locations, in particular bridges, were also included. To get risk estimates, crash data is not enough, but estimates of exposure is also needed. Exposure for automobile traffic was gathered. However, exposure of pedestrian and bicycle flows were not gathered.

Results

As earlier mentioned, looking at recent history, bridge failures kill around five people per year in the United States, and that is not insignificant. But there are many more people killed in crashes on bridges, or going off bridges, or hitting abutments and piers on a road passing under a bridge. Many victims are pedestrians and bicyclists. Functional obsolescence or imperfect geometric design does not directly cause crashes but non-optimal designs may increase the chance of a crash and aggravate injuries once a crash has occurred. However, it is almost always road user behavior that is the primary factor behind a crash. Therefore, this project will continue with an analysis of crashes to look at how driver and pedestrian behavior—and thereby safety—can be influenced with information technology as well as how behavior can be influenced by changes to the geometric design.

Below are the results of an analysis of ‘all’ fatal crashes on or under bridges in the US in 2016 and a subset of non-fatal bridge accidents in Maine.

Fatalities on or under bridges in 2016 in the US

Fatal crashes on or under bridges were found through media publications in newspapers, television, etc. It was verified that the crash had not been deemed a suicide and that it physically occurred on or under the bridge/overpass. In September 2017, the National Highway Safety Administration will make FARS data available, and further verification of causation etcetera will be done. But so far, it can be concluded that the US in 2016 had at least 258 fatal crashes that were not suicides or planned homicides. These crashes killed 314 people on or under bridges. There were 244 car/truck occupants, 35 MC riders, 4 bicyclists and 31 pedestrians killed. Out of the 31 pedestrians killed, at least 7 were pedestrianized motorists who had gotten out of their motor-vehicles after their vehicle had stalled, been involved in a minor crash or other event.

Overall, 81 of the crashes happened under the bridge (with piers etc.) and 174 on top of bridges. In 84 of the 174 fatal crashes on bridges, the bridge was traversing water and in the remaining 90 cases, the bridge was passing over other highways, railroads or similar facilities.

Of the 81 crashes under bridges, 65 were single-vehicle strikes of piers or abutments and one was a truck having a raised bed strike the bridge structure. Two cases involved pedestrians being hit while walking through underpasses and one case was an MC rider having stopped to shelter from rain. In three cases, an occupant drowned when driving under a flooded underpass.

Of the 174 crashes on top of bridges, 84 were single-vehicle crashes. In 21 of them, the motorist was killed as a result of striking a bridge railing or guardrail without going off the bridge. Of the multi-vehicle crashes, 17 started out as rear-end crashes, 6 as sideswipe, and 27 as head-on crashes whereas 8 of them could not be determined based on media reports. Eight of the crashes on bridges involved a pedestrian or pedestrianized motorist. One fatality occurred as a result of a 'pedestrian' climbing a bridge and lost their balance and fell, so this is not a traffic accident but rather a climbing accident.

Out of the 174 fatal crashes on top of bridges, 89 had a vehicle or its occupants or other road-user being thrown down onto the highway or river below the bridge with 53 of them not being preceded by a multi-vehicle crash but rather were caused by a driver losing control and going through or over bridge railings showing the need to strengthen and/or raising these. In most of these cases, it was the occupants of the vehicle who were killed but in one case, a motorist survived whereas four 'pedestrians' were killed when the vehicle landed on top of them. In 14 crashes, there was a multi-vehicle (or multi-unit) crash preceding going off the bridge. Five of the crashes involved a pedestrianized motorist having exited their vehicle and being hit by a passing motorist and thrown down and in another two, a motorist got out of their car and, seemingly by mistake, fell down when they stepped over a low railing. These two could possibly have been suicides but were deemed by police as accidents.

The media reports points towards at least 21 of the crashes involving alcohol or drugs but FARS analysis may add significantly to that number. In only eight of the cases, ice or snow was a definite contributor. In other words, nationwide, better snow or ice removal or real-time information about bridge friction coefficients, would not greatly influence the total number of fatalities.

Structural failures prior to the 'accident' did not contribute to any fatalities on bridges in 2016. Debris falling from a bridge as a result of a crash took one person's life.

Two of the fatalities involved workers doing reconstruction of bridges. One of these was a traffic accidents where one worker was killed in a 50-ft fall after a [non-construction] driver of a truck hit the boom lift which the worker was using. The other fatal accident was not a traffic accident but involved contractors painting a bridge. The person was standing on a platform tied to the bridge by a series of ropes and cables when one cable broke and the platform suddenly tilted, throwing five workers into the water, killing one of them.

Maine Data

Maine has around 2,515 bridges and overpasses that are longer than 20 feet. There are also 1,374 bridges with short spans of 10 to 20 feet. As of 2016, the State of Maine owns and manages 2,744 of these bridges. For the 3-year period 2011-2013, there were 765 reported crashes on, under or very near bridges in Maine with 79% of them occurring on top of the bridges and 8% under the bridges and the remaining 13% just off the bridge, but still classified as bridge related. Overall, 28% involved personal injury which is slightly lower than for crashes away from bridges. A significantly higher percentage of crashes occurred during ice and frost conditions on bridges (19.5%) than on other segments (5.1%). Adding snow to that, a total of 30% of the bridge crashes in Maine happened when the roadway was covered in snow or had icy conditions. So, even if snow and ice is not a nationwide issue with respect to fatalities, it seems to be a significant issue in Maine and probably in other northern states.

A detailed analysis of crash rates was done for two of the 16 counties in Maine. The crash rate per hundred million vehicle miles (HMVM) traveled for all bridges was 317 for Aroostook County and 244 for Kennebec County in Maine. This can be compared to the average statewide crash rate of around 195 for these three years. The injury crash rate, including possible injuries, was 52.9 per HMVM for Aroostook County and 58.8 per HMVM for Kennebec County. The average statewide injury crash rate for all public roads in Maine was around 59 per HMVM for these years so bridge crashes are not overrepresented when looking at injuries in these two counties.

If we look at different roadway categories in these two counties, we can see that the average crash rate on Interstate bridges was almost exactly double that of all Interstate segments (130 vs 64 per HMVM). For other principal arterials, the average crash rate on bridges was also double that of non-bridge segment (223 vs 114). For major collector roads, bridges also have higher rates than other segments (240 vs 154). The difference is even greater for local roads with bridges in these two counties having an average crash rate of 1,230 vs the average state rate being 247 for local roads in this 3-year period.

Discussion

Prior to this study, there was little recent overall knowledge of the quantity of the safety issue of bridges. People, including safety experts, have focused on structural concerns rather than functional ones. This study shows that mortality-wise, traffic safety is a problem roughly 60 times greater than structural issues. To focus on the 1.5% of fatalities that are caused by structural failures will not optimize safety.

Roughly one person dies every day on crashes on or under bridges. A majority of those killed were occupants of cars or trucks but MC riders and pedestrians are also often victims. About 32% of the crashes occur under the bridge, with a majority being single-vehicle strikes of piers. In other words, better protection of piers and abutments should be a priority. Of the crashes on top of bridges, almost exactly half are single-vehicle crashes, typically striking guardrails and then sometimes tumbling down from the bridge. In just over half of the crashes that start out on top of bridges, the fatality is a result of a road-user being thrown down onto the river or highway below the bridge. Stronger and higher guardrails should immediately be installed on ‘all’ bridges. Structural failures prior to the ‘accident’ did not contribute to any fatalities on bridges in 2016, but two of the fatalities involved workers doing reconstruction of bridges.

Within a few decades, we may have transitioned to highly automatic (HAV) vehicles when it comes to purchase of new vehicles. However, non-HAV vehicles will probably continue to travel across bridges for the foreseeable future, at least for several decades. And, even if non-HAVs eventually are prohibited in traffic, there will be pedestrians and bicyclists using urban bridges, so safety of non-HAVs will still be important. Therefore, this study will not be totally dated but its findings will remain relevant for decades with respect to many aspects.

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