MAINTAINING BRIDGE SAFETY AND SERVICEABILITY UNDER INCREASING TRUCK LOADS

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Abstract

Though bridges compose a small percentage of total highway mileage, their costs, construction time, and traffic disruption upon failure or temporary closing significantly impact highway system performance. Bridge deterioration analysis shows bridge damages increase significantly with incremental weights. Competitive modern commerce is continuously demanding loads well in excess of the current standards Bridge owners need to control the loading on the bridges to limit the deterioration of the existing bridge infrastructure. Several truck weight studies have highlighted the problem of increasing truck weights and their impacts on infrastructure. Bridge design codes, which were once primarily focused on design for strength and stability, have evolved to incorporate consideration of bridge serviceability and durability. In this regard, understanding increasing traffic loads holds the key to our understanding of bridge serviceability and durability. This paper discusses the impact of increasing truck loads on bridge decks and supporting members, including the likely deterioration mechanisms and long term durability.

Introduction

The truck industry is faced with the demand of increasing truck weight in order to get more carrying capacity. The modern freight industry has been pushing the limits of traditional standards for truck size and weight. Competitive modern commerce is continuously demanding loads well in excess of the current standards established by various federal and state departments of transportation. On the other hand, bridge owners need to control the loading on the bridges to limit the deterioration of the existing bridge infrastructure in the United States and to keep the structures in a safe condition. Freight loads that exceed design standards are accelerating the deterioration of the pavement and bridge infrastructure. Bridge deterioration analysis shows bridge damages increase significantly with incremental weights. Though bridges compose a small percentage of total highway mileage, their costs, construction time, and traffic disruption upon failure or temporary closing significantly impact highway system performance. Moreover, the catastrophic nature of bridge failures in terms of fatality, property loss, and traffic disruption necessitates maintaining the structural integrity and serviceability of bridges and merits substantial consideration.

Regulations are constituted to allow the truck weights to increase to a certain range while guaranteeing the safety and serviceability of the bridge system. Until the mid-1970's, the legal limit on trucks was 73,280 lbs (33.2 metric-tons). Today it is

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80,000 lbs (36.3 metric-tons). The axle group weights are regulated based on the federal bridge formula. This keeps the bridges designed with HS20-44 loading from being overstressed by more than 5 percent and the bridges designed with H15 loading from being overstressed by more than 30 percent. Most of the H15 bridges are built on low heavy-truck volume highways while the HS20-44 bridges are usually built on interstate highways. Most bridges in the United States were designed to accommodate either an H-15 or HS-20 loading. Recently the HL-93 loading has been introduced to model state legal loads heavier than the federal weight limits.

Many states have increased their legal loads above the federal standards. Based on a freezing index, Minnesota allows a winter increase in GVW of 10 percent during dates set by the transportation commissioner. Michigan allows loads up to 154,000 lbs (69.9 metric-tons), and some western states allow loads up to 131,000 lbs (59.4 metric-tons). Supporters of bigger trucks want to increase truck weights to 90,000 lbs (40.8 metric-tons) for single trailer trucks and over 100,000 lbs (45.4 metric-tons) for double and triple trailer trucks. Newly proposed legislation, states would allow carriers with weight limits up to 97,000 lbs (44.0 metric-tons) and with six-axles. Maine and Vermont have conducted one-year pilot programs granting heavier six-axle trucks access to interstate highways within their borders. Maximum weight was set at 100,000 lbs (45.4 metric-tons) in Maine and 120,000 lbs (54.4 metric-tons) in Vermont. Pilot study was performed in Idaho to allow trailer trucks up to 129,000 lbs (58.5 metric-tons) on Interstates.

Increasing Truck Weights

There are many factors contributing to the deterioration rate of bridges. Increasing truck load is one of the major ones. Any increase in legal truck weight would shorten the time for repair or replacement of many bridges. A methodology to estimate the cost impacts of increasing truck weight on individual bridges and extrapolate these impacts to a network of bridges was proposed in National Cooperative Highway Research Program Project 12-51 (NCHRP Report 495).

Traffic load data that are central to the design and evaluation of bridge structures include truck volumes, classifications, and load spectra for those volumes. In recent years weigh-in-motion (WIM) systems have been used to continuously collect unbiased data on truck weights, speeds, time of travel, axle weights and configurations, and volumes. WIM systems can also help to identify the likelihood of illegally overloaded trucks that may be causing the premature deterioration of the infrastructure. WIM systems can provide valuable traffic data for better planning and management of operations, maintenance and new design activities. A combination of WIM data collection equipment and simple vehicle classification equipment is used to provide the traffic data required.

Several truck weight studies using WIM data have highlighted the problem of increasing truck weights and their impacts on infrastructure. A study of trucks on Wisconsin highways using WIM records in 2007 indicated that 1.3 million out of 6 million recorded trucks weighed more than the legal limit of 80,000 lbs (36.3 metric-tons). Thousands of these trucks had an axle load beyond 40,000 lbs (18.1 metric-tons) and hundreds of them had an axle load beyond 50,000 lbs (22.7 metric-tons). A study was commissioned by the Indiana Department of Transportation to study the effects of overweight trucks transporting steel from Indiana to Michigan on Indiana's northwest road network. The State allows permit truckloads of up to 134,000 lbs (60.8 metric-tons). to cross this corridor. The study collected truck data over a four-month period and focused on Class 9 trucks (80,000 lbs (36.3 metric-tons)) which are typical five axle trucks, and Class 13 trucks (134,000 lbs (60.8 metric-tons)) which have seven or more axles and are generally used for the Michigan Train configuration. The WIM data indicated that 15% of the Class 9 trucks weighed over the 80,000 lbs (36.3 metric-tons) limit, while 26% of the Class 13 trucks weighed over their 134,000 lbs (60.8 metric-tons) limit.

Lack of compliance with truck weight regulations has added to the infrastructure degradation. A study performed to estimate the percentage of overweight trucks in Virginia, focused on trucks that were suspected of avoiding weighing by travelling on secondary arteries in the vicinity of the weigh stations. The results show that 11 to 14 percent of the trucks on routes used to bypass the weigh stations were overweight. Truck weights collected by mainline WIM systems when no enforcement operations are taking place are found to be 30 to 60 percent higher than weights collected using static scales in conjunction with enforcement operations. Generally, fixed Scale enforcement has not been very effective at promoting weight compliance. For example, in Minnesota, nearly 90% of all the >10,000 lbs (4.5 metric-tons) citations were issued by mobile enforcement. When enforcement is visible, the overweight violation rate is maintained at a low percentage.

Updating Bridge Design Loads

Bridge engineers often focus on enhancing the knowledge of member and system resistances with less effort expended on understanding the true live load demand on bridge elements and systems. From the inception of bridge design, engineers have been attempting to ascertain the proper design live loads for bridges. The AASHTO bridge design load does not change very frequently at the national level, not because there have been no needs to change rather because of the lengthy process of developing and implementing the change. Updating bridge live load models needs representative samples of unbiased truck weight data that meet accepted quality standards. The implementation of WIM systems in recent years has led to improving the quality and quantity of traffic data, which can be used to update the bridge design loads. The goal of NCHRP Project 12-76 completed in 2009 was to develop a set of protocols and methodologies for using available recent WIM data collected at different US sites and recommend a step-by-step procedure that can be followed to obtain live load models for LRFD bridge design. Results of this study have been applied to develop site or state specific design and rating load models for bridges in a number of states.

AASHO published its first design specifications in 1931. In it, the magnitude of highway live load was a function of the traffic class. Depending on the loaded length, the live load consisted of either a truck train or equivalent distributed load. In 1944, AASHO published its fourth edition of the specifications in which the HS20 was adopted as design loading. In the late 70s and early 80s, a number of states started to design for HS25 loading, and for an increased alternate military vehicle. This was done to accommodate the increase in truck size and weight, and state-legislated truck loads. Although an increase in the design truck weight was justified, the HS-25 loading was still not adequate to cover the plethora of truck weights and sizes operating on highway bridges. In lieu of adopting the HS25 loading nationally, AASHTO adopted provisions in its 1982 Interim allowing operating agencies to analyze bridges for overload vehicles, which are consistent with their permit operating policies. In the LRFD Specifications first published in 1994, a new live load model was adopted. The model, referred to as HL-93, consists of a design truck (two trucks for negative moments and pier reaction) or a tandem combined with a lane load. Unlike the H and HS design loads, HL-93 was developed to accommodate state legal loads, unanalyzed permit loads, and trucks operating under the grandfather provisions. Inclusion of two 25,000 lbs (11.3 metric-tons) tandem axles in the HL-93 loading has enhanced the load effects on short span bridges. However, the live load modeling in LRFD did not specifically address the increasing load effects on bridge decks from the heavier and more complex axle configurations.

Bridge Decks

Reinforced concrete (RC) bridge decks provide the driving surface and also transfer wheel loads to the supporting beams or stringers. Research has demonstrated that the axle weights have a more significant effect than the GVW in the deterioration of reinforced concrete bridge decks. States have placed a high priority on designing and building longer lasting decks. Bridge design has primarily focused on strength and stability while the new challenge of longer service life places additional requirements to bridge design: engineers need to equally consider concrete durability in the design. A 40 year service life has been common for RC decks. Use of stainless steel bars offers the promise of 100-year bridge decks through the elimination of salt induced corrosion.

Significant updates to the bridge deck design provisions have been recently introduced in the LRFD code. In combination with advanced materials, this could enhance deck performance in future years. Before the 1994 AASHTO LRFD Design Code provisions, concrete bridge decks were only orthotropically reinforced in the U.S. In this design approach, different reinforcement ratios are applied in the perpendicular and parallel directions to the traffic. Greater amount of reinforcement is required in the perpendicular direction to traffic, because the orthotropic reinforcement design does not take two-way slab action into account in the bridge deck; it assumes that the deck behaves as transverse strips along the length. Studies in Canada in the late 70’s developed isotropically reinforced bridge decks, which accommodated the two-way slab action by the requirement for equal amounts of reinforcement in both directions. The design procedure was first included in the Ontario Highway Bridge Design Code (OHBDC), 1991. It was adopted into the AASHTO LRFD Bridge Design Code as the "Empirical Bridge Deck Design Method."

A significant amount of resources has been used to perform deck renewal, including overlay and replacement. Fatigue of RC bridge decks due to truck loads has attracted research attention for over two decades. Until recently, this topic was investigated using a stationary load with varying magnitude, referred to as a stationary pulsating load. Such loading setup was used perhaps because steel fatigue testing was typically done this way. During 1990s studies were done using a simulated moving wheel load on deck models. Both groups found that a moving load is much more damaging than a stationary pulsating load. Resulting cracking very closely resembled that observed in real bridge decks in service. These test results also explained the mechanism of RC deck damage being that of shear fatigue.

Fatigue damage in decks originates from discontinuities such as very small cracks. Two likely causes of visible cracks are concrete shrinkage and truck overloads. They are considered the triggers of fatigue damage accumulation in RC decks. Cracks then grow because of load cycles and cause further deterioration. When a transverse crack is present, the shear force induced by the truck wheel introduces stress concentration at the crack tip. This stress concentration becomes the driving factor for fatigue damage accumulation. When a longitudinal crack is present due to an overload, the situation is similar although the stress range is not the same. The shear force at a transverse crack changes sign when a wheel crosses the transverse crack, while the shear force at a longitudinal crack does not change sign when a wheel moves along the crack. Wheel movements across cracks cause the rubbing of the cracks causing them to widen, and the fatigue accumulation at the crack tip causes crack extension over time. Cracks can link up with growing load cycles and cause spalling, with further aggravation from environmental factors and steel corrosion.

Deck cracking is recognized as the initial trigger for deck deterioration. The first adverse phenomenon to occur in bridge decks due to increasing axle weights would be longitudinal flexural cracking. Cracking of bridge decks will increase the potential for corrosion. Transverse cracks are more common than longitudinal cracks in bridge decks. However, transverse cracks are primarily caused by shrinkage during or soon after construction and are not affected by increasing truck weight. Combinations of transverse and longitudinal cracking was the most detrimental as these often lead to surface spalls, potholes, or deck punching shear fractures. Punching shear is a highly localized failure mode and, while obviously not desirable, is good in the sense that it will not typically lead to catastrophic accidents and is relatively easy to repair. It has been observed that they occur in regions of relatively new and growing longitudinal deck cracking, in the presence of transverse deck cracking, which is quite prevalent at almost all locations. Thus, inspecting for significant longitudinal deck cracking and identifying effective and efficient repair schemes for such cracks is believed to be a key factor in avoiding deck punching shear failures.

Overloads, whether authorized or illegal, impact bridge safety and adversely affect the performance of bridge decks and supporting members and will also increase maintenance costs. The Newburgh-Beacon Bridge (NBB) in New York provides one example of the impact of heavy trucks on bridge decks. NBB carries Interstate-84 (I-84) across the Hudson River at Beacon and Newburgh, New York. The North span (Westbound) was opened in 1963 and the South span (Eastbound) in 1980. The NBB has the heaviest volume among the Hudson River spans, and is a major commercial corridor between the Midwest and northern New England. The Newburgh-Beacon bridges are subjected to steadily increasing truck volumes and truck loads, including overloads. There had been major deck problems at the NBB facility and the owner had capital improvements projects planned for this facility in following years. The owner had observed that the condition of the eastbound deck was experiencing greater deterioration than the westbound deck and instituted a WIM study to better ascertain the traffic loads. The objective of the study was to obtain and analyze recent truck traffic data collected at two permanent WIM sites on I-84 near the bridge site.

The WIM data was analyzed to determine the percentage of trucks that exceed the legal weight limit of 80,000 lbs (36.3 metric-tons) in each direction. It was found from the analysis of 2006 WIM data (over 1.5 million trucks) that 8.5% of the trucks traveling east bound and 5.5% of the trucks traveling west bound exceeded the 80,000 lbs (36.3 metric-tons) limit. Moreover, the percentage of trucks that exceed 100 kips was 1.9% for the eastbound lanes and 0.7% for the west bound lanes. Also revealing was that 37% of the six-axle dump trailer trucks that operate under a NYSDOT divisible load permit in the eastbound direction exceed 100,000 lbs (45.4 metric-tons) while only 10% of these trucks in the westbound direction were over 100,000 lbs (45.4 metric-tons). The WIM data showed that the eastbound trucks were significantly heavier than the westbound traffic, which also explained the greater deck deterioration observed in the eastbound direction. Site-specific load models representative of the actual trucks that routinely cross the NBB were also developed. The site-specific loads reflected the directional distribution of truck loads at the NBB (heavier loads in the eastbound direction). The WIM data analyses assisted the owner in the design decision making for upcoming projects and future maintenance.

As discussed, it has been observed that decks subjected to heavy traffic deteriorate at a faster rate than the supporting beams or stringers. This can be seen in the following condition history for two RC decks in California (ref: NCHRP Report 495). One of them (Bridge 33-198 on I-880) allows all truck traffic, the other (Bridge 33-324 on I-580) allows only trucks with GVW below 10,000 lbs (4.5 metric-tons). These two routes are parallel to each other. Essentially, I-580 is an alternative route to I-880 for lighter vehicles. The environmental conditions for these two bridges are virtually the same and no deicing chemicals have been used on these two routes. Both bridges have continuous spans of reinforced concrete box girders with an RC deck. The deck on Bridge 33-198 is 7.5 in. (19 cm) thick and that on 33-324 is 6.5 in. (16.5 cm) thick. The reinforcement is virtually the same in these two decks. The condition histories were directly taken from respective bridge inspection reports. Bridge 33-198 had a significant repair for potholes approximately at the age of 29 years. In contrast, Bridge 33-324 did not need repair at a similar age. More importantly, the former has shown more potholes since that repair, and the latter did not need such repairs although some cracking was observed. Note that the 33- 198 deck is about 15 percent thicker than the 33-324 deck. This provides significantly higher shear strength to resist wheel loads. It was concluded that the difference in the two decks' condition was due to the different truck loads carried. These two routes have had similar total annual average daily traffic (AADTs) over these years, but very much different truck traffic. Bridge 33-198 has carried 15 to 25 times more trucks. This comparison indicates that it is the load that is the major factor for RC deck deterioration, at least in areas where no or little salt is used. It should be noted that for many other areas in the country, a large amount of deicing chemicals is used for winter safety maintenance. RC bridge deck deterioration has also been found to be strongly correlated with steel reinforcement corrosion caused by deicing chemicals.

Steel Bridges

The governing deterioration mechanism for steel bridges, subjected to heavy traffic, is fatigue. Fatigue is insensitive to loading that occurs less frequently than 0.01% of all load cycles – such as a special permit loads. It should be noted that annual permits are issued in many states for an unlimited number of trips with up to twice the legal GVW An increase in the allowable weight of these annual permit vehicles could become significant for steel bridges if they exceed 0.01% of the truck traffic at a particular bridge.

The effect of increasing truck weight on steel girders depends on when the bridge was designed. Steel girders designed before improved fatigue design specifications were introduced in the 1980's often feature poor fatigue details such as welded cover plates. Unfortunately, most steel girder bridges in service today were designed before fatigue-design specifications were improved. As shown by an MNDOT study, steel girders designed since 1985 are typically not susceptible to fatigue at present truck weights and should be able to tolerate a modest increase in truck weight up to 20% without reducing the expected fatigue life to less than 75 years. For bridges with some remaining life before fatigue cracking begins to occur, the remaining life can be reliably calculated if the fatigue life is due to cracking from primary loads on poor fatigue details such as cover plates. For these bridges, an increase in legal GVW of 10% would lead to a reduction in the remaining fatigue life of about 25%.

A large number of the steel bridges built before 1985 are potentially susceptible to fatigue damage due to poor detailing. Web-gap cracking, or distortion-induced fatigue, was not addressed in the specifications until 1985. Most distortion-induced fatigue cracks occur where connection plates for diaphragms or floor beams are not welded to the tension flange due to unfounded reluctance to weld to the tension flange. Since 1985, it has been required that connection plates be rigidly attached to both flanges, eliminating this type of cracking in new bridges. Due to the complex and unexpected stress ranges that are experienced at these locations, it is currently extremely difficult to predict the life of web gap details without field measurements. Many bridges with these details are susceptible to cracking under current truck loads and more will be susceptible to cracking with increased allowable GVW. If the fatigue life is limited by distortion-induced cracking such as at web-gap details, the remaining life is not presently quantifiable. However, the treatment for this deficiently is typically a retrofit to eliminate the web distortion.

Calculations can be done to quantify load-induced fatigue in existing bridges or in new designs. The vehicular live load for checking fatigue in steel structures in the LRFD Specifications consists of a single 3-axle design truck with a gross weight of 54,000 lbs (24.5 metric-tons), which represents the truck weight spectrum from WIM studies done in the 1980's (NCHRP Report 299). New fatigue-life evaluation procedures are contained in the AASHTO manual for Bridge Evaluation. One of the features of the AASHTO manual is its ability to incorporate site-specific information (WIM data) in the fatigue analysis. Fatigue-life calculations can be more realistically determined through the gathering of site-specific data gathered by a WIM system.

When data on truck types and their weight distributions are available through WIM investigation at a site, the effective gross weights of representative truck configurations can be determined based on Miner's hypothesis, as follows:

$$W = (\sum \alpha_i W_i)^{1/3}$$

Where W is an effective gross weight, and α_i is the frequency of occurrence of trucks with a gross weight of W_i. The effective weight for a given truck configuration is selected so that the fatigue damage caused by a given number of passages of a truck of this weight is the same as the fatigue damage caused by an equal number of passages of trucks of similar trucks of different weights in the actual traffic.

There is great variability in truck traffic from site to site. Code specified fatigue loading may be unconservative or even unsafe when applied to major bridges on heavy truck corridors. Site-specific fatigue-life models were developed using WIM data from two long span bridge sites in New York City that are subject to heavy truck traffic. These models were developed as a point of comparison with the conventional AASHTO fatigue truck; the intent therefore was to provide a comparative assessment on the influence of load models on the fatigue-life of longitudinal members. A temporary WIM system was used to gather about two weeks of traffic load data at each bridge in 2005. Over 88,000 trucks were measured at Bridge 1 and over 128,000 trucks were measured at Bridge 2 during a two week period. WIM data was used to compute the effective gross weight of all trucks using the Miner's equation given above. The 3-axle fatigue truck has an effective gross weight of 67,600 lbs (30.7 metric-tons) for Bridge 1 and 69,700 lbs (31.6 metric-tons) for Bridge 2, well above the 54,000 lbs (24.5 metric-tons) gross weight for the AASHTO fatigue design truck. These statistics reflect the fact that a significant percentage of trucks on both bridges exceed the legal limit of 80,000 lbs (36.3 metric-tons). Fatigue damage will increase exponentially with increase in truck weights and associated live load stress range. Code specified fatigue loading may grossly underestimate the true fatigue damage, particularly in bridges on heavy truck routes, bridges in urban areas and bridges that serve as major river crossings.

The George Washington Bridge carries Interstate 95 from northern New Jersey across upper Manhattan. Over 300,000 vehicles per day cross the 82-year-old span. The bridge has two levels. Since Sept 2001, trucks have been restricted to the upper level, which has four lanes in each direction. In August 2013, repair crews began an $82-million effort to fix extensive cracking in the upper-deck structural steel caused by increased truck traffic on the upper deck, particularly heavy trucks. Crews will replace 6-foot (183 cm) portions of the existing orthotropic steel deck above every floor beam along the upper level roadway, and rehabilitate the remaining deck area.

The steel orthotropic deck on the upper deck was built in 1978. In the early 90's the deck began to experience fatigue cracking in the strap-plate fillet weld to the ribs. Cracks in the deck rib welds increased at an exponential rate due primarily to the increased heavy truck traffic that the deck has been carrying since Sept 2001, when all truck traffic was banned from the lower level and re-directed to the upper level. The trucks are also much heavier than those for which the deck was originally designed. The bridge is a major crossing and a significant number of trucks exceed the legal truck weight. A WIM study of trucks was performed at this site in 2009. Site-specific fatigue truck models were developed for the rehabilitation design using the traffic data. The overweight trucks produce fatigue stresses nearly 60% greater than that of the HS-20 truck, which has resulted in a shorter fatigue life of the deck.

Concrete Bridges

The service life of concrete bridges can be affected by material selection, construction process, environmental attacks, and traffic loading. The deterioration of well-constructed concrete bridges is mainly caused by traffic loads, especially heavy trucks and various environmental attacks. The environmental attacks on bridges in cold climates include chloride penetration and the subsequent corrosion of steel reinforcement; freeze-thaw cycles on concrete in saturated or near-saturated conditions

If the loads were increased on concrete girders, the first deterioration mechanism to occur that is significantly affected by increasing loads would be shear cracking. Shear cracking is a serviceability problem and there is significant additional capacity in shear before failure could occur. However, shear cracking could increase the rate at which water can penetrate the girders and increase the rate of corrosion of the prestressing strands and other reinforcement. Cracking in reinforced concrete bent caps is another impact that typically occurs during heavy truck loading. Smaller vertical flexural cracks usually occur over the supporting column and larger inclined flexure-shear cracks propagate from the girder loading region to the supporting column.

Cracking of concrete girders caused by overloaded trucks can have implications for bridge safety, serviceability and long-term durability. Shear cracking is a common phenomenon to occur with increasing truck weight that could significantly affect service life for prestressed concrete I-girder bridges and concrete girder bridges. Starting in the late 90's, there were over 500 cast-in-place reinforced concrete deck-girder (RCDG) bridges in the Oregon Department of Transportation (ODOT) inventory that were identified as exhibiting diagonal-tension cracking. Of these cracked bridges, nearly half were along the I-5 and I-84 corridors. The majority of the cracked bridges were built between the years 1947 and 1962. Weight restrictions on cracked bridges caused significant detours that were costly. Reinforced concrete bridges built at that time were designed by a method that resulted in less shear reinforcement than is required by current methods. It is considered likely that inclined cracking problems were also built into these girders by overly liberal Vc allowances in the code at the time and insufficient reinforcement anchorage. Since these bridges were designed, the volume of truck traffic in Oregon has grown several-fold, and the federally defined maximum allowable five-axle truck-trailer weight has increased from 72,000 (32.7 metric-tons) to 80,000 lbs (36.3 metric-tons). ODOT imposed truck and axle weight restrictions on these bridges while considering appropriate strategies to manage the situation.

In addition, ODOT commissioned a study by Oregon State University (OSU) to help the state's bridge engineers determine the load-carrying capacity of bridges with cracked girders. Research revealed that the calculations for the load and resistance factor rating (LRFR) accurately accommodate the effects of cracks. Presence of cracks did not necessarily indicate that a girder had lost load capacity. One key to load capacity was the detailing of the steel reinforcement, especially how well the longitudinal steel bars that run the length of the beam were anchored at the ends of the beams. The shift to LRFR and the incorporation of Oregon's WIM data improved the load rating values for many of the cracked RCDG bridges rated as insufficient under the previous method. As a result, 120 bridges were removed from the list of those to be replaced, and 80 bridges were shifted from the list of those to be repaired or replaced to the list of those that require no work.

Additionally, a critical issue leading to the fatigue of prestressed concrete girders has been identified as girder cracking. Studies have established a connection between fatigue related failures of reinforcement and cracks in prestressed girders. It was found that flexural cracks in prestressed concrete girders led to increased stress ranges in the strands, increasing the possibility of fatigue failure and decreasing the service life of the girders, and the bridge structure as a whole. In addition, the presence of cracks in prestressed concrete girders could lead to increased strand corrosion.

Closing Words

Several truck weight studies have highlighted the problem of increasing truck weights and their impacts on infrastructure. While, modern commerce is continuously demanding loads well in excess of the current standards, bridge owners need to control the loading on the bridges to limit the deterioration of the existing bridge infrastructure. Bridge design codes have not always kept up with changing traffic loads. If we are to design longer lasting bridges, bridge engineers need to expand their understanding of the true live load demand on bridges. The implementation of WIM systems in recent years has led to improving the quality and quantity of traffic data, which can be used to update the bridge design loads. Bridges on major truck corridors should be designed and/or evaluated using site-specific load models. Understanding increasing traffic loads holds the key to our understanding of bridge performance and durability. Maintenance strategies for bridges need to be calibrated to reflect live load exposure as traffic loads along with environmental factors are the leading causes of bridge deterioration.

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