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Bridge Failure

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Alternative ABC Methods and Funding Justification

Mohiuddin Ali Khan Ph.D., M.Phil., DIC, P.E., in Accelerated Bridge Construction, 2015

10.9.23 Precautions to prevent construction failures

A study on bridge failures carried out by the author concluded that most failures occur during construction or erection. The ABC system must avoid such failures through carefully considering issues such as the following:

- Failure of connections: Overstress from bolt tightening, failure of formwork, local buckling of scaffolding, crane collapse, and overload are some of the causes.
- The stability of girders during stage construction and the deck placement sequence need to be investigated and temporary bracing provided.
- Expansion bearings need to be temporarily restrained during erection.
- Some flexibility in selecting bolt splice locations may be permitted with the approval of the designer.
- Curved and skew bridges require special considerations, such as uplift at supports, achieving cambers, and reducing differential deflections between girders during erection.

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Mechanisms of Damage to Coastal Structures due to the 2011 Great East Japan Tsunami

Mechanisms of Damage to Coastal Structures due to the 2011 Great East Japan Tsunami

Jeremy D. Bricker, Tomohiro Miki, in Handbook of Coastal Disaster Mitigation for Engineers and Planners, 2015

3.1 Introduction

Another type of bridge failure is the damage of low-clearance reinforced concrete girder bridges located near the mouths of rivers. The beam bridge of Noda-Mura in Iwate Prefecture is shown in Figure 17 above, positioned very low with only 2.4 m clearance above the river. Unlike the Utatsu highway bridge, the deck was not overturned but moved horizontally several meters inland without severely damaging the anchor bars that restrained horizontal motion of the decks. This suggests that the deck was lifted up on the seaward side before or at the same time as it was pushed horizontally. Previous studies of tsunami wave forces on structures and bridges (Kosa et al., 2011; Shoji et al., 2010; Hiraki et al., 2011) indicate that the wave forces are mainly horizontal, and the vertical uplift force acts only for a short period when plunging waves impinge on the structure. The tsunami waves near Noda-Mura may have taken the form of few-meter-high bores, but there are no reports of plunging waves. In order to find out what kinds of water flows could cause this type of failure, numerical simulations of tsunami flows under various scenarios were conducted.

Figure 17. Damaged Hirouchibashi Bridge in Noda-Mura, Iwate Prefecture. Top photo is looking inland. The bottom left photo shows the bridge deck displaced inland (left). The bottom right shows the anchor bars bent inland.

Figure 17. Damaged Hirouchibashi Bridge in Noda-Mura, Iwate Prefecture. Top photo is looking inland. The bottom left photo shows the bridge deck displaced inland (left). The bottom right shows the anchor bars bent inland.

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ABC Planning and Resolving ABC Issues

Mohiuddin Ali Khan PhD, M.Phil, DIC, P.E., in Accelerated Bridge Construction, 2015

7.1.4 Bridge failures due to extreme events

An analysis of bridge failures due to construction difficulties and other common types of failures were addressed in Chapter 6. This chapter extends the analysis to extreme events and natural disasters, which are to a large extent outside of the control of human beings.

New Zealand and Haiti earthquakes: The recent earthquakes of 2011 in Christchurch, New Zealand and in Haiti presented an unprecedented opportunity to study their effects on communities and potential exposure to earthquakes. Design practices need to be developed that are in line with current seismic design criteria that some areas in the United States have begun to implement.

Calamities from tsunamis: An earthquake is more likely to become a disaster if it occurs in a populated area and generates a tsunami. The Tohoku, Japan earthquake of March 11, 2011 combined with the tsunami and damage to the Fukushima Daichi Nuclear Power Plant resulted in perhaps one of the worst natural disasters. The tsunami waves were estimated to range from 9 to 37.9 m in height, causing the majority of infrastructure destruction (with nearly 14,000 confirmed deaths, 5000 injuries, and 15,000 missing). Structures built to meet current design criteria performed overall very well. Damage has been primarily to infrastructure that was built with much less stringent seismic design criteria, especially in those areas with structures that did not have tsunami resistance incorporated in the design codes.

Planning for tsunami resistance: It is likely that future structures including highways and bridges located close to the coastal areas will take into account the huge tsunami impact force. The extensive instrumentation placed by Japan before the earthquake to some extent has provided a wealth of new information that may help in planning for the future.

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A Sibly and Walker study (1977) is referred to as a point for discussion. Fitting the trend, two bridge failures are considered consistent by H. Petroski (1993). Petroski points to anecdotal evidence that suggests the theory has predictive merit. Also, the managing director of Brady Heywood, Sean Brady, has looked at the technical and human aspects of this unfortunate trend. Refer to http://bradyheywood.com.au/uploads/129.pdf.

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It may be pointed out that many failures that occur during construction or demolition do not get reported. The present total number of bridges located in the U.S. highway system is extremely high. Lack of adequate maintenance and accidental failure can cause failures to occur sooner than 30 years, as recent failures in Minnesota and Washington State have shown. ABC prefabrication methods with better quality control should help in reducing the frequency of failures.

6.2.2 Importance of deck stiffening in suspension cable bridges

The importance of deck stiffness in suspension bridge design was recognized as far back as the 1850s. As a consequence, Roebling's generation utilized stiffening trusses and auxiliary ties to ensure deck stability, elements that are evident on the Brooklyn Bridge today. The gradual elimination of stiffening trusses and ties culminated in their absence from the Tacoma Narrows Bridge. Failure ensued, and the Tacoma Narrows Bridge was rebuilt with stiffening trusses included. These failures provide some insight into negligence and also the importance of innovative structural design.

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Bridge collapse

A.E. Schultz, A.J. Gastineau, in Innovative Bridge Design Handbook, 2016

3.4 Maintenance

Of all causes of bridge failure, lack of maintenance is the most preventable. Initial design assumptions usually hold true for bridge connections. As bridges degrade from environmental exposure, aging, and exposure to deicing chemicals, connections that were meant to move longitudinally can become fixed and alter the expected transfer of internal forces and reactions, which causes damage and in some cases failure. In addition, corrosion can cause section loss in steel members and steel reinforcement, which leads to strength degradation and increases the likelihood of bridge failure.

For example, the Sgt. Aubrey Cosens VC Memorial Bridge in Ontario, Canada, a steel-tied arch bridge built in 1960, partially collapsed in 2003 (Figure 31.14) when a large truck was crossing (Biezma and Schanack, 2007; Åkesson, 2008). Previously, some components of the bridge had failed but the problem had gone unnoticed and, when the truck crossed, the first three vertical hangers connecting the girder to the arch failed in rapid succession. When the first two hangers failed, the next few were able to redistribute and carry the load; however, when the third hanger fractured, a large portion of the deck displaced. The hangers were designed with the ends free to rotate, but these ends had seized up over time with rust and become fixed. When fixed, they were subjected to bending, which caused fracturing to occur on the portions of the hangers tucked inside the arch. Fortunately, no lives were lost in this partial collapse, but this failure highlighted the necessity for understanding initial bridge design assumptions and ensuring that these original design assumptions continue to hold true through a program of maintenance and regular inspections.

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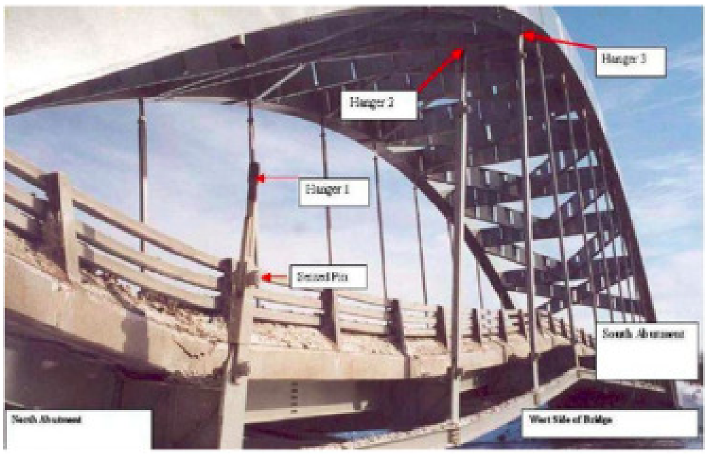
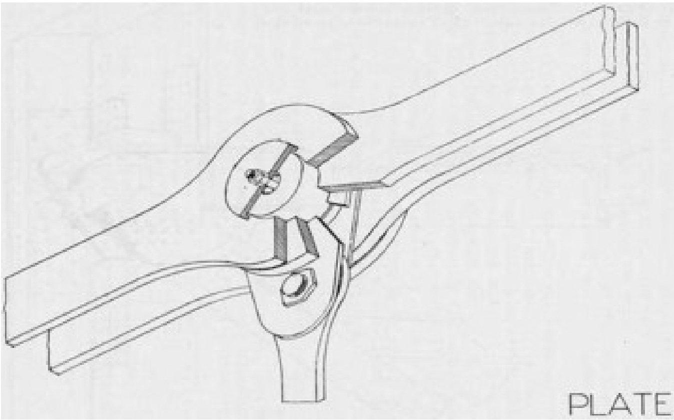


Figure 31.14. Partial collapse of the Sgt. Cosens Memorial Bridge. (*Bagnariol 2003*.)

Constructed in the late 1920s, the Silver Bridge, connecting Ohio and West Virginia was the first suspension bridge in the United States to use high-strength, heat-treated steel eyebars as tension members connecting the stringers to the suspension cable. During rush hour in 1967, an eyebar (Figure 31.15) fractured at its head and caused a complete collapse of the bridge, killing 46 people. Corrosion, fatigue, and nonredundant design of the eyebars were the major reasons for failure (Lichtenstein, 1993; Subramani, 2008). This tragedy led the US Congress to adopt systematic inspections of all bridges in the country and made engineers aware of the consequences of questionable choices in design specifications made to save money.



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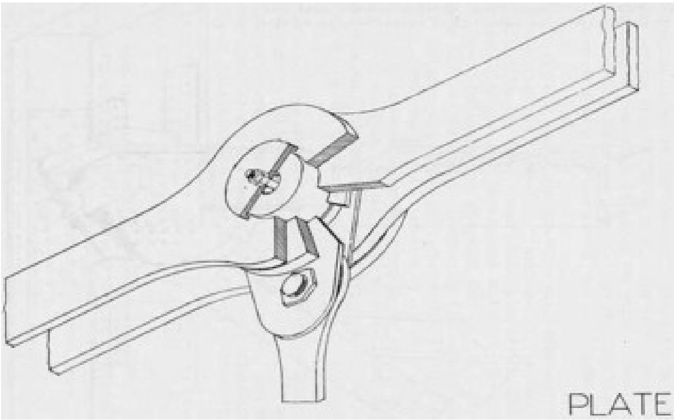

Figure 31.15. Silver Bridge typical eyebar connection detail.(*NTSB 1970*).

The Hintze Ribeiro Bridge in Portugal, built in 1887, collapsed in 2001 (Figure 31.16), claiming the lives of 59 people travelling in a bus and three cars. The steel truss bridge with superimposed concrete deck was supported by granite piers on timber piles, spanning 336 m over the Douro River in northwestern Portugal. The stability of one of the piers was undermined by the lowering of the river depth due to a combination of sand mining and dam operations (Sousa and Bastos, 2013; Antunes do Carmo, 2014). The lower water depth led to scour of the foundation of the pier and the eventual collapse of the bridge. The collapse led to immediate inspections and repair of bridges around Portugal.

Figure 31.16. Hintze Ribeiro Bridge post collapse (*Photo Credit: Enciclofurgo*).

Scour, the removal of backfill around the piers by river flow, caused the collapse of the Schoharie Creek Bridge (Figure 31.17) in 1987 in the United States (Storey and Delatte, 2003). The two-girder steel bridge was supported by closely spaced floor beams and longitudinal stringers on concrete piers. The scour, estimated to have been 8.5 m to 13.5 m, undermined the support of one of the piers introducing unexpected stress, which led to unstable cracking and the ultimate failure (Swenson and Ingraffea, 1991). Additionally, scour from ice flows is suspected to have contributed to the failure (Hains and Zabilansky, 2006). Two spans fell into the river, killing 10 people. The collapse highlighted the importance of postflood pier inspections and the vulnerability of shallow footings in riverbeds.

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Figure 31.17. Schoharie Creek Bridge collapse due to pier scour.(*USGS*, 1997).

A combination of corrosion, lateral motion, bridge skew, and fatigue cracking caused the Mianus River Bridge to fail (Figure 31.18) in 1983, killing several people (Fisher et al., 1998; Gordon, 1984). Corrosion in this steel plate girder bridge led to geometric changes in the joint and generated unanticipated forces. The joint failure led to increased inspection standards on fracture-critical bridges, as well as new nondestructive testing (NDT) methods to observe internal changes.

Figure 31.18. Mianus Bridge collapse.(*NTSB 1984*).

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Repair, Strengthening, and Replacement

Weiwei Lin, Teruhiko Yoda, in Bridge Engineering, 2017

14.1 Introduction

14.1 Introduction

The most common causes of bridge failures are structural and design deficiencies, corrosion, construction and supervision mistakes, accidental overload and impact, scour, and lack of maintenance or inspection (Biezma and Schanack, 2007). To overcome the adverse effects caused by the deterioration of structures, repair and rehabilitation work needs to be carried out during a bridge's service life.

In recent years, the rapid deterioration of steel bridge structures has become a serious technical and economic problem in many countries, including both developed and developing countries. As shown in Fig. 14.1(A), the bridges built in the United States between the 1920s and 1940s exhibited severe deterioration by the 1980s and resulted in the publications such as "America in Ruins: The Decaying Infrastructure" (Choate and Walter, 1983). In Japan, bridges built during the rapid economic growth period between the 1950s and 1980s began to exhibit deterioration in the 2010s, as can be found in Fig. 14.1(B). Since then, "Japan in ruins" has also become a concern. Taking the bridges older than 50 years (the bridge design service life) in Japan as an example, the ratio has increased remarkably from 6% in 2006 to 20% in 2016, and it is predicted to be around 47% in 2026, as shown in Fig. 14.2.

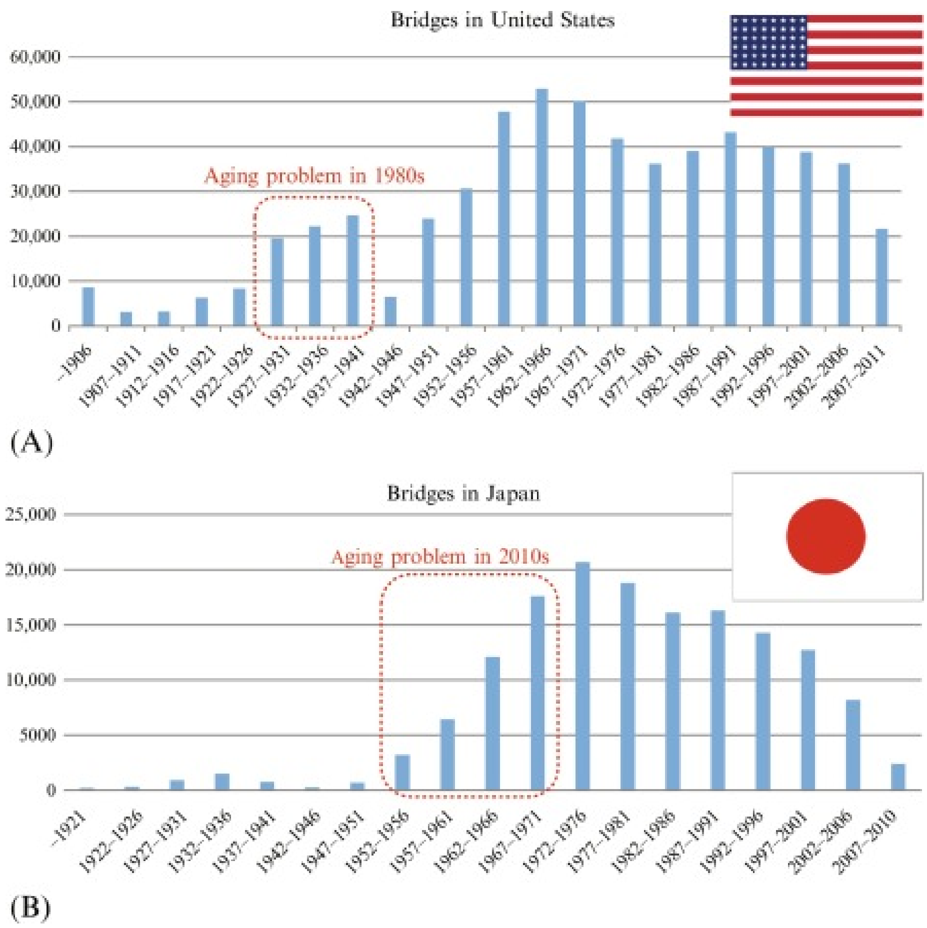

Fig. 14.1. Bridge inventory in the United States and Japan. (A) Bridge stock in the United States. (B) Bridge stock in Japan.(Courtesy of MLIT.)

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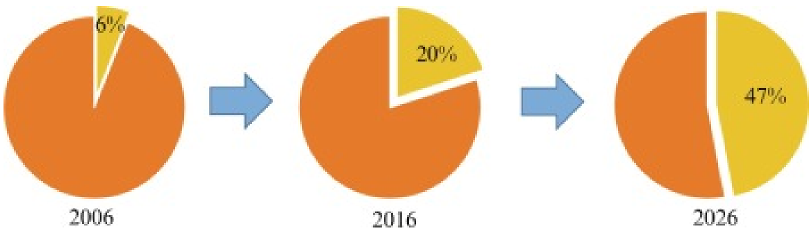

Fig. 14.2. Bridges older than 50 years in Japan.(Courtesy of MLIT.)

With aging, deterioration of bridges becomes a serious problem and seriously affects the serviceability and durability of bridges. Therefore, appropriate repair, strengthening, or replacement work should be performed on aged bridge structures to ensure their good performance in service condition. After tens of years' service, these old bridges need to be strengthened integrally for the whole bridges or repaired locally for certain steel members, or replaced. Therefore, bridge inspection, maintenance, rehabilitation, retrofitting, resilience, sustainability has also become a very essential factor in contemporary bridge engineering.

The repair, strengthening, and replacement are close alternative options for bridge engineers. The decision should be made according to the current condition, predicted deterioration, and consequence, and the cost of remedial measures at different stages. The purpose of maintenance and repair activities is to keep bridge structures in functional and safe conditions as the situation permits. In general, the deterioration or destruction can proceed very rapidly once started, and postponed maintenance can result in the development of major repair jobs. Thus, prompt and adequate maintenance is important for aged bridge structures. Considering the relatively high cost for replacing as well as the great impact on the public transportation, repair and strengthening the aged bridges is generally more preferable (both environmentally and economically) than to demolish and replace them by building new bridges. Nevertheless, bridge replacement is an option in case of severe damages of whole structures and higher cost of repair or strengthening work than replacement or reconstruction. It is generally a hard decision to choose among repair, strengthening, and replacement, but the option could be simplified as: repair now, repair later, strengthen later, or ultimately replace (Ryall et al., 2000).

In this chapter, the commonly used repair and strengthening techniques for steel bridges and concrete bridge will be described.

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Introduction to sediment transport in open channels

Introduction to sediment transport in open channels

Hubert Chanson, in Hydraulics of Open Channel Flow (Second Edition), 2004

Discussion

A spectacular accident was the Kaoping river bridge failure on 27 September 2002 in Taiwan. Located between Kaohsiung and Pingtung city, the 1 km long bridge failed because of scour around pier abutment. The bridge had been in operation for about 22 years. Illegal gravel dredging upstream was suspected to be one of the causes of failure. A 100 m long bridge section dropped taking 18 vehicles with it, but there were fortunately no fatalities. Witnesses described a rumbling sound as the four-lane bridge broke and fell into the river. Relevant references in bridge failures and scour include Hamill (1999) and Melville and Coleman (2000).

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Prefabrication of the Superstructure

Mohiuddin Ali Khan Ph.D., M.Phil., DIC, P.E., in Accelerated Bridge Construction, 2015

8.2.1 Examples of actual failure or near-failure conditions

There have been recent examples of actual bridge failures or near-failure conditions. A bridge in Washington State collapsed, sending three people to the hospital.[2] The I-35 Bridge in Minneapolis, Minnesota collapsed into the Mississippi River in 2007, killing 13 people and injuring 145.

The Maine Department of Transportation (MaineDOT) assembled a panel that released a report in 2007, "Keeping Our Bridges Safe."[3] That report found MaineDOT was responsible for 70% of known bridges in the state, 205 of which were more than 80 years old. Transportation officials estimated that 288 bridges would be at risk of closure or weight restrictions within a decade.

Transportation for America (a national safety advocacy group)[4] found Maine had the ninth highest percentage of structurally deficient bridges in the county. The University of Maine has been involved with load testing several Maine bridges. Recently, the I-95 Bridge that crosses Kenduskeag Stream was shut down for a few hours and heavily loaded dump trucks were used to test the effects the loads had on the bridge.

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Recent Developments in ABC Concepts

Mohiuddin Ali Khan Ph.D., M.Phil., DIC, P.E., in Accelerated Bridge Construction, 2015

2.7.10 Revisions to NBIS

The inspection and rating procedures have undergone further changes following subsequent bridge failures, such as:

- I-95 Mianus River Bridge in 1983
- Schoharie Creek Bridge in 1987 in New York and Cypress Viaduct due to the Loma Prieta earthquake in 1989 in California

In 1998, the FHWA estimated that nearly 30% of the nearly 600,000 bridges in the United States were considered structurally deficient. Over a quarter million bridges built between 1956 and 1975 would require major repairs or deck replacement in the near future. To ensure the best use of limited monies, wise engineering management is required. Bridge failures need to be avoided at a predetermined cost. Load posting requirements are a step in the right direction.

The following revisions were made to NBIS:

- *Inspection frequency*: Maintain inspection frequency of 2 years for bridges exceeding 20 ft in length.
- *Fracture critical members (FCM)* must be identified.
- *Underwater inspection* procedures are required.
- *Team leader certification* requirements were revised.
- *Inventory data for state bridges* are to be updated within 90 days with any changes in load restriction.

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Sterilisation considerations for implantable sensor systems

S. Martin, E. Duncan, in Implantable Sensor Systems for Medical Applications, 2013

Biomaterials and coatings

Biomaterials and coatings

Host response to implanted sensors is the primary cause of sensor failure (Bridges and Garcia, 2008). The available biomaterials able to withstand fluid egress while allowing the transfer of biochemical vectors represent the greatest challenge to the performance of implantable sensor systems. For example, hydrogel coatings have been explored as a potential surface modification to control the host reaction to the biomaterial, but hydrogels can be adversely affected by the conditions required for sterilisation, such as the heat and gases from EO and the oxidative effects from radiation sterilisation. Anti-fouling surface treatments often include active ingredients that provide anti-inflammatory agents to the surface as a means to counteract the host response, such as the use of nitric oxide (Wu and Meyerhoff 2008). As new materials and combinations of materials with coatings, drugs, biologics and mechanical treatments are developed, each must be evaluated as sterilised components within or on the surface of the device.

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