Attachment C

Other Bridge Examples

1) The **I-520 Bridge** in Washington State had concrete leaks due to prestress related spalling. The solution was to detension prestressing and add reinforcement to concrete before re-tensioning[1].

2) **Boston "Big Dig" Central Artery/Tunnel Project** had tunnel ceiling panels fail, which resulted in 26 tons falling onto traffic resulting in death and injuries to citizens. There were massive leaks through concrete tunnel sections, which caused light fixture corrosion and the collapse. The solution was to evaluate epoxy adhesives and initiate new guidelines for overhead sustained tension applications. The concrete placement errors were found to be due to improper preparation and corrosion of dissimilar metals led to collapse of light fixtures and future replacement of 25,000 similar fixtures[2].

3) **State Route 93 Hoover Dam Bridge** (Mike O'Callaghan-Pat Tillman Memorial Bridge) in Arizona had a permit problem regarding the operation of a concrete-batch plant. Construction required hoisting workers and materials 890 feet above the Colorado River but high winds caused a cable failure resulting in a further two-year delay[3].

4) **Stonecutters Bridge** (Rambler Channel, Hong Kong, China) had problems with constructing foundations and with steel deliveries. This delayed the project by 4 years with unspecified costs in arbitration[4].

5) **Millennium Bridge** (Thames River, London, England) had excessive vibration from pedestrians walking across bridge. This caused the bridge to be closed for two years to the cost of 5 million British pounds[5].

6) The **Benicia Bridge** (Martinez, California) did not open until seven years after anticipated opening date, and the cost increase to nearly $1.3 billion. Part of the construction challenges consisted of noise and vibration from pile driving operations that impacted fish populations negatively in the Carquinez Strait, which caused a construction delay until an engineering solution was erected to project the firsts. Further, the

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[1] http://www.komonews.com/news/local/Inside-the-investigation-into-the-520-Bridge-pontoon-problems.html
http://seattletimes.com/html/localnews/2020769747_pontoonsdemotionsxml.html
http://www.wsdot.wa.gov/NR/rdonlyres/1F8F3AB5-0E04-46B5-A04D-C097AAACDE54/0/2013_0226_InternalReport.pdf
http://www.wsdot.wa.gov/News/2012/05/18_SR520PontoonFloatoutDelay.htm

[2] http://www.boston.com/news/specials/big_dig_problems/ (news articles)
http://en.wikipedia.org/wiki/Big_Dig (wiki article describing problems and mitigation efforts)
http://www.roadtraffic-technology.com/projects/big_dig/ (engineering article)

[3] http://www.tenfourmagazine.com/2013/05/trucker-talk/bridging-the-gap/ (magazine article)

[4] http://www.construction-post.com/stonecutters-bridge/ (industry website)

[5] http://www2.eng.cam.ac.uk/~den/ICSV9_06.htm (research paper)

contractors then had challenges with unexpected soft rock at the base of the piling used to support the bridge's piers.

7) The **String Bridge** in Jerusalem was postponed from opening for a year due to various planning and coordination problems. In March 2008, it was reported that a series of cracks had been discovered in the welding on base sections of the bridge under construction which delayed the project's opening.

8) The **Golden Gate Bridge** (San Francisco, California) opened in 1937 and has remained undamaged through multiple seismic events. In 1933, there were concerns raised that there could be large cavern in the vicinity that could weaken the pier foundation. By 1934, a full-fledged review over the safety of the south pier was under way within the board of directors and the press, the third since 1929[6]. Divers inspected the site and submitted a report giving a clean bill of health for the foundation. Nevertheless, some local engineers and scientists continued to criticize the bridge foundation. Baily Willis, emeritus professor of geology at Standard unleashed a sweeping denunciation of the entire bridge project, with special emphasis on the south pier. In a letter to the federal Public Works Administration officials, Willis said the pier was being constructed in an area where slides were common and in time would seriously affect the future of the city and bridge safety. The Public Works Administration officials told local officials that Willis's concerns had to be addressed before any loan could be approved. Senator Hiram Johnson then said he had serious doubts as to the future safety of the bridge and could not wholeheartedly support the financial requests. That summer Willis called for a halt to all construction. In view of the persistent efforts to kill the project, the directors held an open hearing in October 1934 and asked Willis to present his analysis of the pier foundation. He repeated his claim that the pier was being built on a slippery incline. But he also admitted had never made a personal inspection of the site and had not availed himself to the recent engineering studies made by the district or outside companies. Further, in the 1970s, builders started replacing corroded rivets on the Bridge with high-strength bolts dipped in organic zinc primer. Year after year, those bridge bolts have been slowly replaced and repaired as part of routine bridge maintenance.

9) The **Sunrise Bridge** (Tampa, Florida) had challenges with corrosion of the steel in the precast concrete segmental columns on the high level approaches. Workers entered the bridge superstructure in 2003 and 2004 to reinforce the corroded sections of the bridge. Another challenge arose around 2005–2006 when newspapers reported paint discolorations on the bridge's cables. These paint splotches and patches were a result of touch-ups that were performed over the years but began to show through over recent years. In 2008, the Florida Department of Transportation began an overhaul including repainting the cables in their entirety (instead of touching up) and rehabilitating the lighting system at the summit of the bridge. Other problems that were overcome on the bridge included: Tendon Corrosion, Tendon Failures, Split/Crack PE Duct, Grout Voids, Contaminated Grout, Salt Water in Hollow, Segmental Joint Leaks, Concrete cracks, PE Duct Material Deficiency, Poor PE Duct, and Cracked Pourbacks[7].

[6] The History of the Building of the Golden Gate Bridge, Richard Thomas Loomis (1959).
[7] http://www.dot.state.fl.us/Structures/DesignConf2006/Presentations/session20/Final-20Garcia.pdf

10) Construction began on the **Deh Cho Bridge** (New Brunswick, Canada) in 2008 2008 and was expected to be completed in 2010 but faced delays due to technical and financial difficulties until November 2012 when it opened to traffic. The original construction budget was $169 million and final cost was $202 million. During the final approval of the bridge plans by the Government of the Northwest Territories and its outside technical advisors, inadequacies relating to the design of the superstructure were discovered. In 2009, the general contractor was terminated by the Deh Cho Bridge Corporation, which announced an agreement could not be reached on a price for the revised superstructure[8]. A delay was announced in the construction schedule to allow for an investigation of design changes, and the opening date pushed back by a year to late 2011. It ultimately opened in November 2012.

11) The **Twin Sails Bridge** (Poole, Dorset, England) faced challenges with the road surface which caused the bridge to remain closed although the opening ceremony and visit by Her Royal Highness The Princess Royal went ahead in early March 2012. The bridge opened to traffic in April 2012 after the road surface had been relaid. Problems with the bridge operation continued in the summer of 2012 with delays caused through the barrier operation and lifting mechanism as well as continuing defects in the road surface[9].

12) The **Derek S. Hines Memorial Bridge** (Massachusetts) was built in 1966 on the granite abutments, pivot pier, and rest piers of an earlier bridge, constructed in approximately 1882. Construction was scheduled after a barge hit the bridge in 2008. The reconstruction of the bridge is a design-build project being undertaken by MassDOT with federal funds. When the bridge closed in November 2010, officials projected it would be out of service for 18 months. However, delays occurred in obtaining necessary environmental permitting pushed the best-case scenario from a May opening to July. In July 2012 MassDOT said the bridge would remain closed through August 2012, adding a significant challenge to Yankee Homecoming organizers who had planned many of the events believing the bridge would reopen in time. MassDOT said independent testing and inspections of the completed bridge's mechanical and electrical operation system confirmed an alignment problem that resulted in a portion of the mechanical systems' operation being out of tolerance with contract specifications. The teeth in the gears that allow the bridge to swing open and allow boat traffic to pass were off by about 1,000th of an inch[10].

13) Work on the **Sand Creek Bridge** (Oklahoma) got under way in 2012 on the 3-mile project. Reinforced concrete piers for the bridge were installed in April 2012[11]. Oklahoma State officials predicted completion within 90 days. However, in 2012, settlement issues at the approaches to the bridge caused several months of delays in completing the $10 million improvement and realignment project. Decisions were expected in 2012 to enable corrections to begin. Experts had to analyze soil-test reports

[8] http://en.wikipedia.org/wiki/Deh_Cho_Bridge
[9] http://en.wikipedia.org/wiki/Twin_Sails_Bridge
[10] http://www.hinesbridgeproject.com/
[11] http://okbridges.wkinsler.com/osage_county/sandcreek3.html

to yield answers about the problem — which caused the north side of the bridge to settle more than three inches below where it should have tied in with the new roadway.

14) The **Zilwaukee Bridge** (Michigan) is an eight-lane structure that was completed in 1988. Construction began in 1979 with an expected completion date three years later; however, the bridge was not available to traffic for nine years. The initial budget of $79 million was exceeded by $48 million. In 1982, with the bridge two-thirds complete, a 150-foot long, 6,700-ton segment was not property counterbalanced and sank five feed out of alignment while rising 3.5 feet on the other end, cracking a pier footing the process. Once repairs were made, a new contractor was hired to complete the bridge once the initial contractor and the state agreed to terminate their contract in exchange for both sides dropping their lawsuits over the accident. The new contractor developed a method of heating the concrete to allow construction during the winter. However, on some cold days, these new sections could not be properly sealed against water infiltration, eventually leading to spalling as the water froze and expanded. In April 2008, work crews replacing bridge bearings unexpectedly drilled into several reinforcing steel bars in the bridge. The $3.3 million project was further hindered when crews determined that more than 30 new bearings were not designed property. In 2008, the bridge opened to traffic again. In December 2012, a $70 million construction project was launched to replace 154 bearings in question and rebuild 4 miles of the bridge by 2015[12].

15) In 2001, the **King Bridge** (Ohio) began a refurbishment project to widen the bridge's four lanes, add pedestrian walkways, and replacing the drawspans and the bridge's control towers. The drawspan replacement, the project's second phase, began in 2004. But with completion delayed a year by a design error and further complicated by construction problems, the costs rose from $43 million to over $50 million. Work began in January 2007 to replace the drawspans. Project officials determined that concrete work to modify the bridge structure to accommodate the replacement drawspans was taking longer than expected. In January 2007, workers found cracking concrete inside the drawspans' anchor piers that needed to be replaced. In March 2007, local papers reported more delays in the installation of the new drawspans that could result in $20,000 per day fines from the U.S. Coast Guard against the City of Toledo. In July 2007, the City sued National Engineering and Contractor Co., HNTB Corp., and Bergmann Associates Inc. for alleged engineering and design problems that caused the one-year delay in rebuilding the bridge[13].

16) The **Manhattan Bridge** (New York) crosses the East River in New York City, connecting Lower Manhattan with Brooklyn. The bridge was opened to traffic in 1909. In 1912, two streetcar companies began operations on the bridge's tracks. Since the tracks were on the outer part of the bridge, passing trains caused the structure to tilt and sway. Eventually, when one train moved over the bridge, on side would be 3 feet lower than the other side. In 1956, at a cost of $30 million, a repair program was begun. In 1984, another major repair program began. After an 18-month delay, the Department of

[12] http://en.wikipedia.org/wiki/Zilwaukee_Bridge
[13] http://en.wikipedia.org/wiki/Martin_Luther_King_Bridge_(Toledo,_Ohio)

Transportation resumed train service in 1990, despite warnings from engineers. In December 1990, state inspectors discovered corroded support beams and missing steel plates. Reopening was slated for 1995, but the south side did not reopen until 2001 and the north side did not reopen until 2004, allowing all four tracks to be used for the first time in 18 years[14].

17) In 2005, hairlines fractures were found on the **Wakota Bridge** (Minnesota) by a third-party inspector which delayed the westbound span's opening by a year. The fractures were not believed to be a safety hazard; however, it was thought that the degraded quality would diminish the expected 100-year effective life of the bridge by allowing salt and water to seep in. An investigation revealed that at the time the bridge was designed, there were no published standards for how much load the concrete components could support. Assumptions were made that turned out to be incorrect. The existing bridge was retrofitted by adding post-tensioned steel cables to transfer more of the load to the piers. The design firm took responsibility for the $14.8 million cost to fix the problem and redesigned the future eastbound span. The new westbound span bridge was finished and opened to two-way traffic in the summer of 2006. Meanwhile, negotiations began with the contractor about costs and scheduling related to the changes to the future eastbound span. In 2006, Lunda Construction Company was discharged from its contract due to disagreements about delays and cost overruns. The bid for the eastbound bridge was let on January 25, 2008. The winner was Lunda Construction, with a bid in excess of a million dollars over what their original offer was. In 2010, the eastbound span of the new Wakota Bridge opened[15].

18) Construction began on the **Flintshire Bridge** (North Wales) in September 1994, and it was hoped that the bridge would open to traffic in late summer 1997. The timetable slipped to December 1997 when spalling was noticed. When the contractors removed the scaffolding in 1997 to unveil the 118 meter high main tower, they saw concrete starting to fall off. Road surfacing work on the deck of the bridge had to be stopped in 1998 while an investigation was carried out. Because the spalling delayed surfacing of the deck, it meant that the bridge's opening date had again to be put back. The pre-cast elements were cast on site. The shell elements were joined together and it was their relationship with the in-situ core that caused the problems[16].

[14] http://en.wikipedia.org/wiki/Manhattan_Bridge
[15] http://en.wikipedia.org/wiki/Wakota_Bridge
[16] http://en.wikipedia.org/wiki/Flintshire_Bridge