The Truth Behind the Failure of the Francis Scott Key Bridge: Accidental Failure or Design Failure?

Divya Rai

Abstract

This review article delves into what exactly happened during the Francis Scott Key Bridge collapse. It explores the structure of the Francis Scott Key Bridge and whether the collapse happened because the structure was too weak or if it was solely the fault in the cargo ship which had an electrical failure, causing it to collide with the bridge. This article also explores ways the collapse could have been prevented ranging from evacuation methods to structural fixes and repairs that could have been performed ahead of time. The main purpose of this project is to raise awareness on how crucial bridge failures are especially since the collapse of the Francis Scott Key Bridge was one of the biggest events of 2024. There is always a possibility of such an event to repeat again on weaker bridges considering that the Francis Scott Key Bridge is one of the important structures in the United States.

Key Words

Baltimore Bridge Collapse, Francis Scott, Key Bridge, LiDar, SMS Messaging regarding bridge collapse

Introduction

On March 25, 2024, at around 1:30 AM, a cargo ship crashed into the Francis Scott Key Bridge, in Baltimore, Maryland due to an electrical failure.[1] The bridge was completely destroyed, and six construction workers were killed. While the bridge collapsed due to a direct impact, it is important to consider the structural condition of this bridge. Although during bridge inspections the bridge condition was deemed satisfactory, the Maritime Safety Committee flagged the Francis Scott Key Bridge as unsatisfactory.[2] The Maritime Safety Committee had been trying to raise awareness of the possibility of a bridge collision or any other disaster for the past two decades.

The Francis Scott Key Bridge was a vital transportation route in Baltimore and had very complicated construction. The bridge will take several years to rebuild. Although the fall of the Francis Scott Key Bridge was due to an accidental collision, it is possible that the construction of the bridge played a role in its collapse.

The collapse of the Francis Scott Key Bridge is not the only catastrophic event that has occurred due to an accidental collision. Over the years, there have been a few bridges that have collapsed due to collisions with boats. This list includes the following:

[1] Lea Skene, Denise Lavoie, Adam Tuss, News4 Anchor & Transportation Reporter, “Cargo Ship That Caused Baltimore Bridge Collapse Had Power Blackouts Hours Before Leaving Port.”
[2] Thompson and Duncan, “Long Before Key Bridge Collapse, Baltimore Mariners Warned of ‘Ship Strikes.’”

- The I-40 Bridge in Webber Falls, Oklahoma: On May 26, 2002, a barge rammed into the bridge over the Arkansas River, taking out more than 500 feet of the four-lane structure, according to the Oklahoma Department of Transportation.[3]
- The Queen Isabella Causeway Bridge in Texas: In 2001, his bridge collapsed due to a collision with a tugboat and a barge. Only three people survived this accident.[4]
- Eads Bridge in St. Louis: The Anne Holly Towboad rammed into the bridge on April 4, 1998. This collapse left 50 people injured.[5]
- The Big Bayou Canot Collapse in Alabama: This bridge was known for transporting freight trains and passenger trains. On September 22, 1993, a six-part barge group carrying coal and iron crashed into the bridge. A train traveling eastbound Alabama went through the collapsed bridge and also fell into the water.[6]

These bridges collapsed many years ago but all due to accidental collisions which shows that this has been an ongoing problem for a long period of time.

The J.E. Greiner Company designed and constructed the Francis Scott Key Bridge. The construction was started in 1972, and by 1977, it was ready to be used. [7] The bridge was constructed using the deck arch structure. An arch structure consists of an arch as its load-carrying system with abutments at each end, such as arches or bridges, that directly receive thrust or pressure.[8]

Figure 1: *Image of the Francis Scott Key Bridge built across the Patapsco River*
(Wikipedia contributors, "Francis Scott Key Bridge (Baltimore).")

This structure typically works by transferring the self-weight and other external loads in vertical directions partially into a horizontal thrust restrained by the abutments or piers at both sides.[9] A deck arch structure has arches below the deck instead of a regular arch bridge, which consists

[3] Sharfman, "Baltimore Bridge Collapse Highlights Deadly I-40 Bridge Collapse in Oklahoma From 2002."
[4] Moreno, "Key Bridge Collapse Brings Haunting Memories of Queen Isabella Causeway Tragedy in Texas."
[5] "April 4, 1998: Anne Holly Tow Rams Eads Bridge, Injuring 50 People."
[6] S, "A Bridge Too Far: The 1993 Big Bayou Canot Bridge Derailment."
[7] Intern, "This Day in Maryland History: Francis Scott Key Bridge Opens in 1977 - Preservation Maryland."
[8] Lin and Yoda, "Arch Bridges."
[9] Ibid.

of arches above the deck that are generally tied.[10] A structural difficulty can be found in the minimization of the misalignment of the arch axis and the line of thrust, as well as a sufficient bending and buckling resistance. [11]

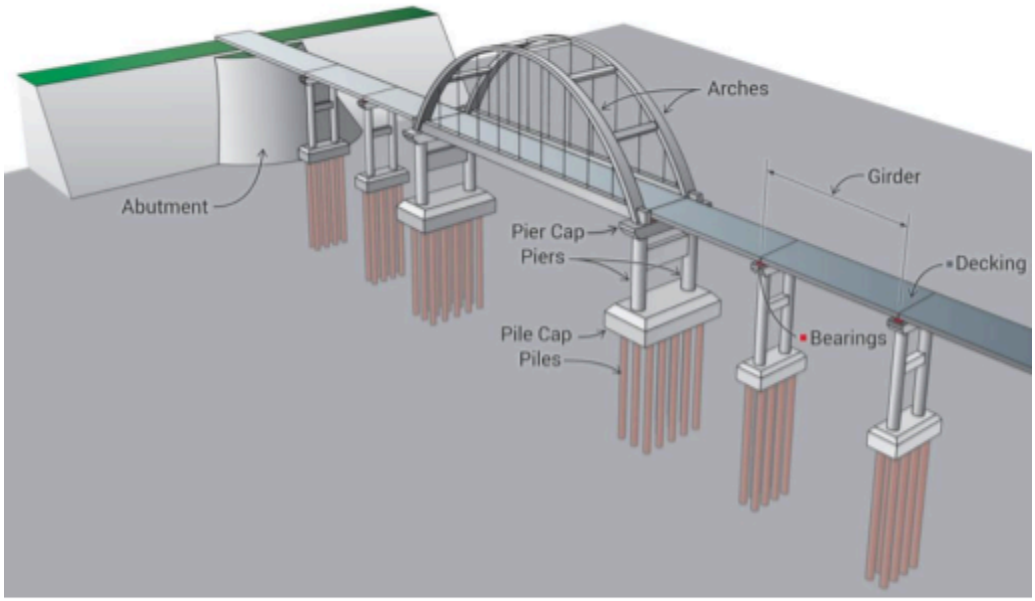

Figure 2: *Schematic diagram of an Arch Bridge*
(McDonald, "Vessel Bridge Impacts: A Structural Engineering Perspective.")

It is important for a bridge to be designed to withstand a head-on impact while preventing it from collapsing, but it may not always be practical.[12] A bridge is designed by first determining the nature of the loads likely to be imposed on a structure during its design life as quantified in the applicable design codes and other standards.[13] Examples of the nature of the loads include self-weight, wind, and contents.[14] Then, a system of structural elements, such as beams, columns, and braces, are arranged to carry those loads.[15] Finally, the elements are sized and detailed so they can safely carry the loads while recognizing the uncertainties in both the material strength and the load magnitudes as prescribed by building codes and standards.[16] Usually, this design is acceptably safe, but there are always drawbacks.

[10] Ibid.
[11] Ibid.
[12] McDonald, "Vessel Bridge Impacts: A Structural Engineering Perspective."
[13] Ibid.
[14] Ibid.
[15] Ibid.
[16] Ibid.

Key Bridge Timeline

On March 25, 2024 at 1:25 AM., when the ship was a little over half a mile away from the bridge, a primary electrical breaker that fed most of the ship's equipment and lighting unexpectedly tripped. This caused the ship to lose electrical power and experience a blackout.[17] The main propulsion diesel engine shut down after the pumps lost electrical power. The ship's crew was able to restore power, then called for assistance from tug boats, and the senior pilot ordered the ship's anchor to be dropped. However, it was too late to anchor the ship or for tug boats to reach it. [18] A second blackout also happened when the cargo ship was only a few hundred yards away from the bridge. The ship then struck a main support pier on the bridge, which caused it to immediately collapse at around 1:30 AM. [19]

Solutions

SMS messaging

There are specific safety procedures used when a bridge is deteriorating. Usually, when a bridge fails, there are damage inspections that help ensure the safety of passengers in vehicles.[20] When there is a mild collapse, traffic control is set up to secure the scene and safely help evacuate passengers traveling in vehicles.[21] Immediate repairs and restrictions are put into place. Restrictions will stay in place until a thorough inspection is done to ensure the damage is fixed.[22] However, in the case of the collapse of the Key Bridge, no evacuation procedure was put in place. This caused the death of six people. Carlo Ratti, an exceptional Italian engineer and architect has proposed a new smartphone system that can help detect bridge deterioration.[23] While in a vehicle, smartphones can capture the vibrations a bridge makes that can capture the structural health of a bridge.[24] This method gives bridge designers and construction workers a good sense of the quality of the bridge so necessary repairs can be done. Ratti's method is a collapse prevention method, not an evacuation procedure.[25] This method would not prevent a collapse similar to the fall of the Key Bridge because of how sudden it was.

LiDAR

While the Key Bridge collapse was an accidental collision with a ship due to an electrical failure, the main reason most bridge collisions happen is due to flood season[26]. During flood season, the river's level fluctuates a lot, and the distance from the bridge to the water surface is

[17] Lea Skene, Denise Lavoie, Adam Tuss, News4 Anchor & Transportation Reporter, "Cargo Ship That Caused Baltimore Bridge Collapse Had Power Blackouts Hours Before Leaving Port."
[18] Ibid.
[19] Ibid.
[20] Dunne and Thorkildsen, "Case Study: Response to Bridge Impacts – an Overview of State Practices."
[21] Ibid.
[22] Ibid.
[23] Senseable City Lab and Ratti, "Good Vibrations."
[24] Ibid.
[25]Ibid.
[26] "Bridge Anti-Collision Solution - LS LiDAR.".

difficult to determine.[27] The distance above the waterline also changes when the ship is loaded or unloaded.[28] It can be difficult for the ship driver to determine if the ship can pass the bridge safely. Whenever the driver's judgment is incorrect, the ship ends up colliding with the bridge.[29]

One solution that can potentially prevent bridge collapses is the LS Bridge Anti-Collision System.[30] The system consists of a Light Detection and Radar (LiDAR), a camera, field alarm equipment such as acoustic-optic equipment and LED display equipment to monitor the warning software, and a terminal display platform.[31] The LiDAR is installed on both sides of the bridge pillars. The installation height of the LiDAR is the height limit of the bridge and the two LiDARs cross to detect the ship.[32] At least one of the LiDARS of the ship will detect when a ship is higher than the bridge limit and will output an alarm signal. It can know the position and distance of the vessel and can send a warning to the ultra-height vessel through the tweeter and large LED screen.[33] The early warning information also reaches the Water Administration/Police. After the early warning is received, the bridge personnel will be able to reach on time to to deal with the danger. This will effectively avoid the collision.[34] This system is not sensitive to external light, and the detection is good at night.[35] The early warning distance goes up to 2000 meters and has high sensitivity, which helps it recognize targets such as masts and tower cranes.[36] This system can also work without interruption during the day with high reliability.[37]

The New and "Improved" Key Bridge

After the collapse of the Francis Scott Key Bridge, Carlo Ratti, an exceptional Italian engineer and architect, had a plan for replacing the 3,500-foot bridge together with WeBuild, an Italian construction group, and Michel Virlogeux, a French structural engineer.[38] They have proposed to replace the Key Bridge, which was originally a deck-arch bridge, with a cable-stayed structure.[39] A cable-stayed structure is a bridge form in which the weight of the deck is supported by a number of nearly straight diagonal cables in tension running directly to one or more vertical towers. [40] The towers transfer the cable forces to the foundations through vertical compression.[41] The tensile forces (relating to tension) in the cables also put the deck into horizontal compression.[42]

---

[27] Ibid.
[28] Ibid.
[29] Ibid.
[30] Ibid.
[31] Ibid.
[32] Ibid.
[33] Ibid.
[34] Ibid.
[35] Ibid.
[36] Ibid.
[37] Ibid.
[38] Roche, "Carlo Ratti Associati Proposes Replacement Francis Scott Key Bridge."
[39] Ibid.
[40] The Editors of Encyclopaedia Britannica, "Cable-Stayed Bridge | Definition & Facts."
[41] Ibid.
[42] Ibid.

Figure 3: *An example of the new proposed structure that would replace the Francis Scott Key Bridge*
(Roche, "Carlo Ratti Associati Proposes Replacement Francis Scott Key Bridge.")

Cable-stayed bridges take a short time to build and are rigid and cost-effective[43]. However this structure has some disadvantages because it is only suitable for short to medium length distances, the cables could be prone to corrosion and high levels of fatigue, and the structure is not strong enough to withstand excessive climate conditions. [44]

Conclusion

Although the proposed structure is quite solid, building a new structure will not solve the issue of sudden collisions. The Key Bridge collapse happened solely due to the electrical failure in the ship and could not have been prevented by using a stronger structural design. The bridge design is typically not the issue when it comes to collisions. However, it is impractical to design a bridge that can fully withstand a collision. The main reasons for bridge collapses are either deterioration or impact strength of the collision on the bridge. Therefore, in order to prevent a bridge collapse, the collision should be avoided altogether. A solution is an early warning system, such as the LS Bridge Anti-Collision System, which sends a warning to the police and bridge personnel. The siren directs the ship away from the bridge, preventing the ship from colliding with the bridge altogether. With systems in place to prevent collision accidents, bridges would stay in good condition, and many deaths would be avoided.

[43] Hillier, "7 Types of Bridges Every Engineer Should Know About."
[44] Ibid.

Works Cited

ksdk.com. “April 4, 1998: Anne Holly tow rams Eads Bridge, injuring 50 people,” n.d. https://www.ksdk.com/article/news/history/1998-anne-holly-rams-eads-bridge-injures-50-people-key-bridge-baltimore/63-8b7f6ea1-de7d-40ea-bdb4-b66a9b0d003b.

LS LiDAR. “Bridge Anti-Collision Solution - LS LiDAR,” October 30, 2021. https://www.leishenlidar.com/bridge-anti-collision-solution/.

Dunne, Richard, and Eric Thorkildsen. “Case Study: Response to Bridge Impacts – an Overview of State Practices.” Case Study. *Federal Highway Administration*. 2014. Reprint, Federal Highway Administration, September 2020. https://www.fhwa.dot.gov/bridge/preservation/docs/hif20087.pdf.

Hillier, Alan. “7 Types of Bridges Every Engineer Should Know About.” Enerpac Blog, August 23, 2024. https://blog.enerpac.com/7-types-of-bridges-every-engineer-should-know-about/.

Intern, Waxter. “This Day in Maryland History: Francis Scott Key Bridge Opens in 1977 - Preservation Maryland.” Preservation Maryland, March 26, 2024. https://preservationmaryland.org/francis-scott-key-bridge-opens/.

Lea Skene, Denise Lavoie, Adam Tuss, News4 Anchor & Transportation Reporter. “Cargo Ship That Caused Baltimore Bridge Collapse Had Power Blackouts Hours Before Leaving Port.” *NBC4 Washington*, May 14, 2024. https://www.nbcwashington.com/news/local/cargo-ship-that-caused-baltimore-bridge-collapse-had-power-blackouts-hours-before-leaving-port/3616015/#:~:text=According%20to%20the%20preliminary%20report,power%20and%20experience%20a%20blackout.

Lin, Weiwei, and Teruhiko Yoda. “Arch Bridges.” In *Elsevier eBooks*, 155–73, 2017. https://doi.org/10.1016/b978-0-12-804432-2.00009-8.

McDonald, Brian. “Vessel Bridge Impacts: A Structural Engineering Perspective.” Exponent, September 6, 2024. https://www.exponent.com/article/vessel-bridge-impacts-structural-engineering-perspective.

Meaney, Scott. “Surviving a Collapsing Bridge in Your Car.” Pool Fence DIY, March 27, 2024. https://www.poolfencediy.com/blogs/blog/surviving-a-collapsing-bridge-in-your-car#:~:text=Act%20Quickly%20to%20Escape,windows%20and%20exit%20the%20vehicle.

Moreno, Julie. “Key Bridge Collapse Brings Haunting Memories of Queen Isabella Causeway Tragedy in Texas.” *KSAT*, March 26, 2024. https://www.ksat.com/news/national/2024/03/26/key-bridge-collapse-brings-haunting-memories-of-queen-isabella-causeway-tragedy-in-texas/.

Roche, Daniel Jonas. “Carlo Ratti Associati proposes replacement Francis Scott Key Bridge.” The Architect’s Newspaper, May 7, 2024. https://www.archpaper.com/2024/05/carlo-ratti-associati-webuild-michel-virlogeux-francis-scott-key-bridge/.

S, Max. “A Bridge Too Far: The 1993 Big Bayou Canot Bridge Derailment.” *Medium*, January 7, 2022. https://mx-schroeder.medium.com/a-bridge-too-far-the-1993-big-bayou-canot-bridge-derailment-33c11278a4fe.

Senseable City Lab, and Carlo Ratti. “Good Vibrations.” Senseable City Lab., n.d. https://senseable.mit.edu/good_vibrations/.

Sharfman, Alexandra. “Baltimore Bridge Collapse Highlights Deadly I-40 Bridge Collapse in Oklahoma From 2002.” KTUL, March 26, 2024. https://ktul.com/news/local/baltimore-bridge-collapse-highlights-deadly-i-40-bridge-collapse-in-oklahoma-from-2002-webbers-falls-emergency-crews-dive-team-14-people-killed-memorial-structure.

The Editors of Encyclopaedia Britannica. “Cable-stayed Bridge | Definition & Facts.” Encyclopedia Britannica, July 1, 2020. https://www.britannica.com/technology/cable-stayed-bridge.

Thompson, Steve, and Ian Duncan. “Long Before Key Bridge Collapse, Baltimore Mariners Warned of ‘Ship Strikes.’” *Washington Post*, May 23, 2024. https://www.washingtonpost.com/investigations/2024/05/23/key-bridge-warnings-ship-strikes/.