609.pdf

A SunCam online continuing education course

Ethics Case Study on
Francis Scott Key Bridge Collapse

by

Mark Ludwigson, P.E.

Course Outline:

Professional Ethics

Ethics is concerned with moral principles and appropriate conduct. For example, doing the right thing, considering others before oneself, and behaving in accordance with agreed principles.

Professional ethics are standards of behavior for working professionals. For example, the Hippocratic Oath has been taken by physicians since the fourth century BCE. The oath established several principles of medical ethics still in use around the world, including medical confidentiality and non-maleficence (not harming a patient). Another historic example is the Teacher's Oath, which includes a commitment to respecting students, improving teaching skills, and teaching for the good of the students.

Today, professional behavior standards are set and enforced by:

- Employers, such as corporations,
- Professional organizations (NSPE, etc.), and
- Federal, state, or local regulations (government).

For example, Costco Wholesale Corporation promotes ethical capitalism and has the following Code of Ethics statement:

What is Costco's Mission Statement and Code of Ethics?

Here at Costco, we have a very straightforward, but important mission: to continually provide our members with quality goods and services at the lowest possible prices.

In order to achieve our mission, we will conduct our business with the following Code of Ethics in mind:

- Obey the law.
- Take care of our members.
- Take care of our employees.
- Respect our suppliers.

If we do these four things throughout our organization, then we will achieve our ultimate goal, which is to reward our shareholders.

Federal government employees are subject to the ethical standards in Code of Federal Regulations:

> *5 CFR 2635.101 Basic obligation of public service.*
> *(a) Public service is a public trust. Each employee has a responsibility to the United States Government and its citizens to place loyalty to the Constitution, laws, and ethical principles above private gain. To ensure that every citizen can have complete confidence in the integrity of the Federal Government, each employee must respect and adhere to the principles of ethical conduct set forth in this section, as well as the implementing standards contained in this part and in supplemental agency regulations.*

Engineering Ethics

For the engineering profession, there are several behavioral standards specific to engineers. In the United States, a popular standard is the "Code of Ethics for Engineers" by the National Society of Professional Engineers (NSPE).

The National Council of Examiners for Engineering (NCEES) manages "model law" and "model rules" which include behavioral standards (cover pages below). Most states have laws and rules that are based on these model documents. Each time the model documents are updated, the NCEES and NSPE encourage all states to adopt the new standards.

Each state has rules for professional conduct specific to engineers. These rules are usually located in the state administrative code in the chapter/section for engineering. These state rules are enforceable with disciplinary consequences. An example rule is that a person shall not offer or perform engineering services unless he or she is licensed as a professional engineer.

NSPE Code of Ethics for Engineers

This is the most widely accepted document for engineering ethics in the United States is the “Code of Ethics for Engineers” by the National Society of Professional Engineers (NSPE).

The main statements are copied here:

I. Fundamental Canons

Engineers, in the fulfillment of their professional duties, shall:

1. Hold paramount the safety, health, and welfare of the public.
2. Perform services only in areas of their competence.
3. Issue public statements only in an objective and truthful manner.
4. Act for each employer or client as faithful agents or trustees.
5. Avoid deceptive acts.
6. Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

II. Rules of Practice

1. Engineers shall hold paramount the safety, health, and welfare of the public.
2. Engineers shall perform services only in the areas of their competence.
3. Engineers shall issue public statements only in an objective and truthful manner.
4. Engineers shall act for each employer or client as faithful agents or trustees.
5. Engineers shall avoid deceptive acts.

III. Professional Obligations

1. Engineers shall be guided in all their relations by the highest standards of honesty and integrity.
2. Engineers shall at all times strive to serve the public interest.
3. Engineers shall avoid all conduct or practice that deceives the public.
4. Engineers shall not disclose, without consent, confidential information concerning the business affairs or technical processes of any present or former client or employer, or public body on which they serve.
5. Engineers shall not be influenced in their professional duties by conflicting interests.
6. Engineers shall not attempt to obtain employment or advancement or professional engagements by untruthfully criticizing other engineers, or by other improper or questionable methods.
7. Engineers shall not attempt to injure, maliciously or falsely, directly or indirectly, the professional reputation, prospects, practice, or employment of other engineers. Engineers who believe others are guilty of unethical or illegal practice shall present such information to the proper authority for action.
8. Engineers shall accept personal responsibility for their professional activities, provided, however, that engineers may seek indemnification for services arising out of their practice for other than gross negligence, where the engineer's interests cannot otherwise be protected.
9. Engineers shall give credit for engineering work to those to whom credit is due, and will recognize the proprietary interests of others.

Francis Scott Key Bridge Collapse Overview

The Francis Scott Key Bridge Collapse was a shocking disaster that impacted hundreds of thousands of people. The incident occurred on March 26, 2024, in the Baltimore metropolitan area in Maryland. The bridge spanned the Patapsco River, was part of interstate 695, and was the main southern beltway around Baltimore. The bridge collapsed after the container ship named "Dali" (MV Dali) lost power, veered off course, and struck a critical bridge pier.

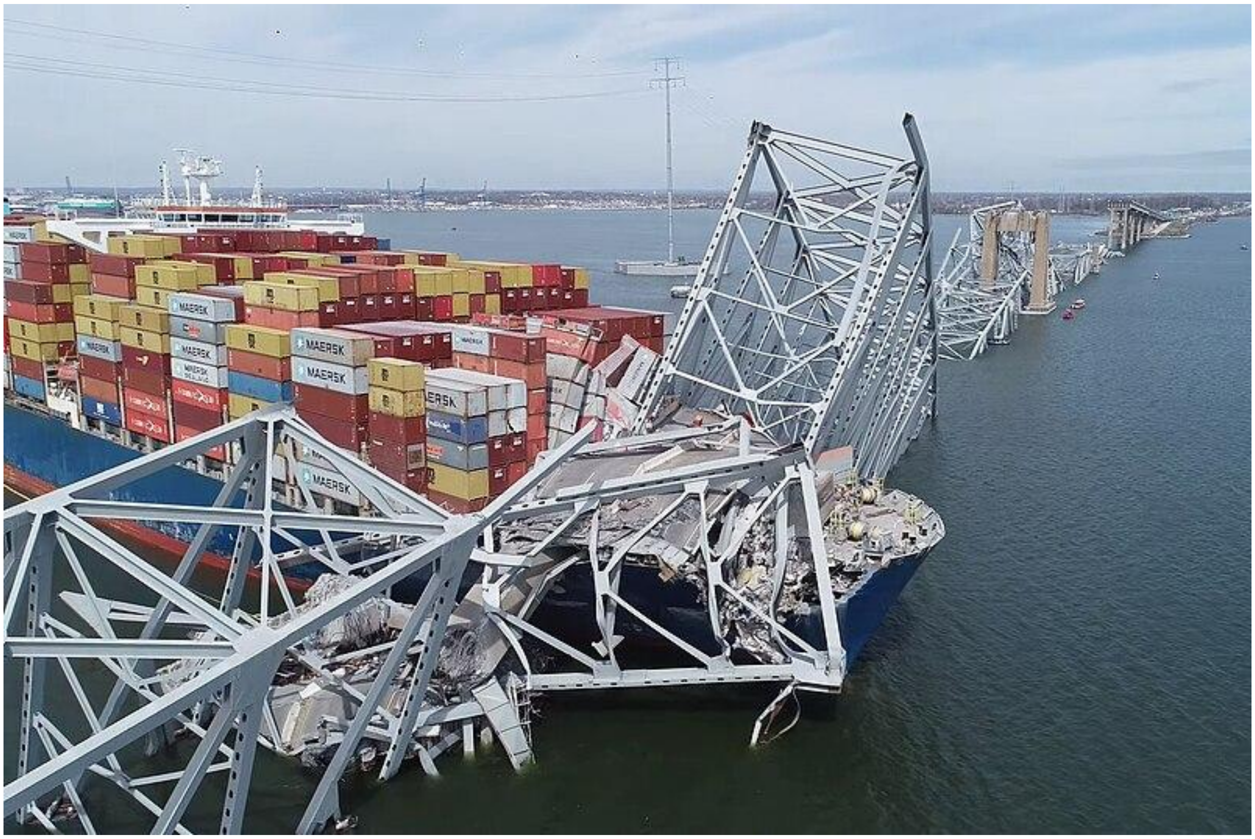


Figure 1: Drone view of the Francis Scott Key Bridge and
cargo ship Dali taken later on the same day of the collision.
Source: commons.wikimedia.org/wiki/File:Francis_Scott_Key_Bridge_and_Cargo_Ship_Dali_NTSB_view_(cropped).jpg

A tripped electrical breaker caused a loss of power on the ship and the main propulsion engine shut down. The Dali drifted with the outgoing tide toward a bridge pier. The crew was able to restore that power, however, a second blackout occurred before the ship struck the bridge.

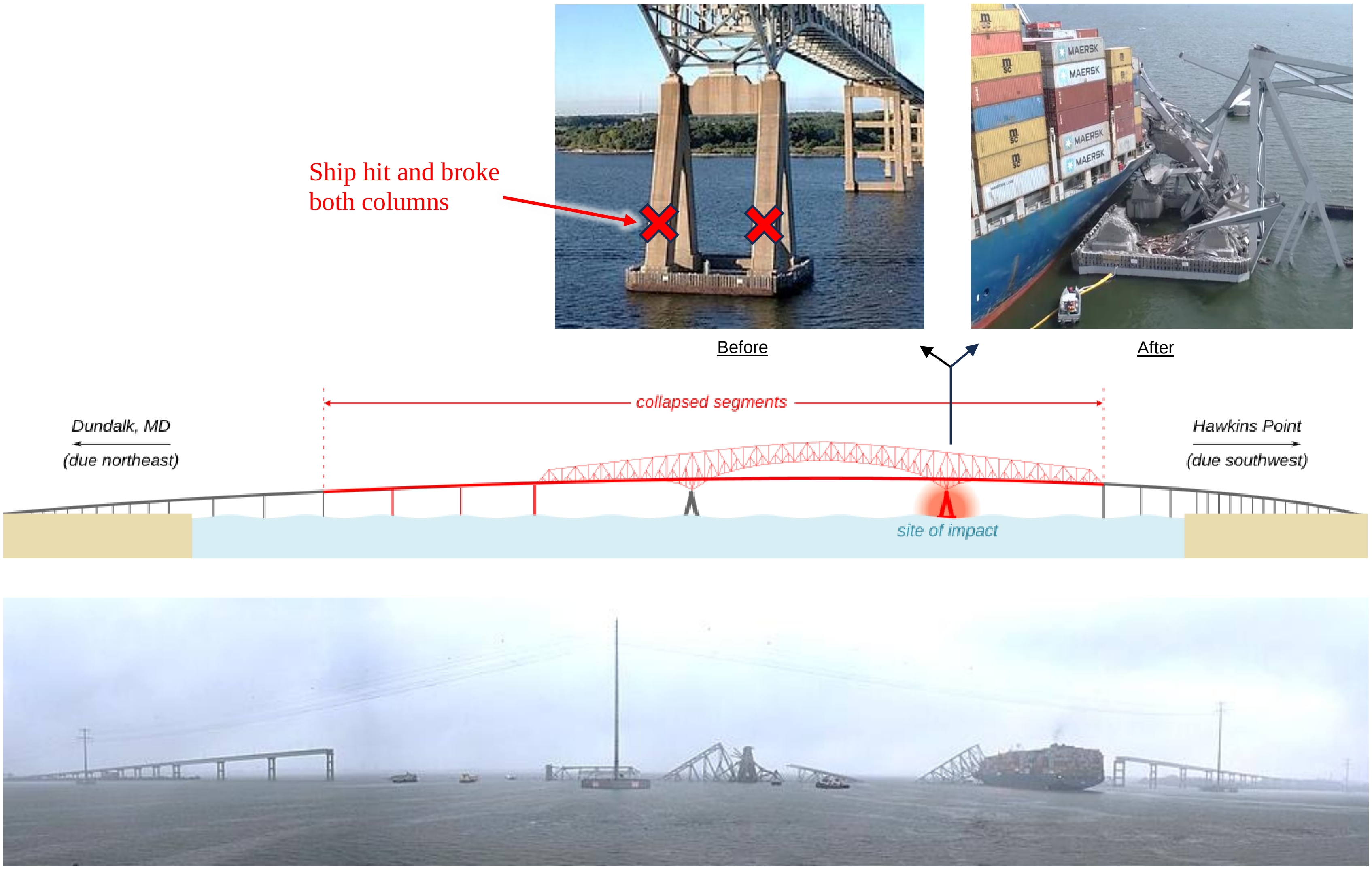


Figure 2: Views looking southeast with collapsed portion of the bridge in red.

Source: commons.wikimedia.org/wiki/File:2024_Francis_Scott_Key_Bridge_collapse_(outbound_view).svg, Fvasconcellos, CC-BY-SA-3.0

The piers are critical support elements. If one pier collapses, the whole truss structure will fall. Each of the two main piers is comprised of two V-shaped concrete columns. The ship hit near the center of each of the two concrete columns, as shown in Figure 2. Columns are vulnerable to mid-point horizontal live loads.

Six (6) members of a road construction crew working on the bridge were killed, while two more were rescued from the river. The construction crew were supposed to have a rescue boat on standby, per federal regulations, but imagery indicates there was no rescue boat, nor anyone watching the water to give a warning to the workers.

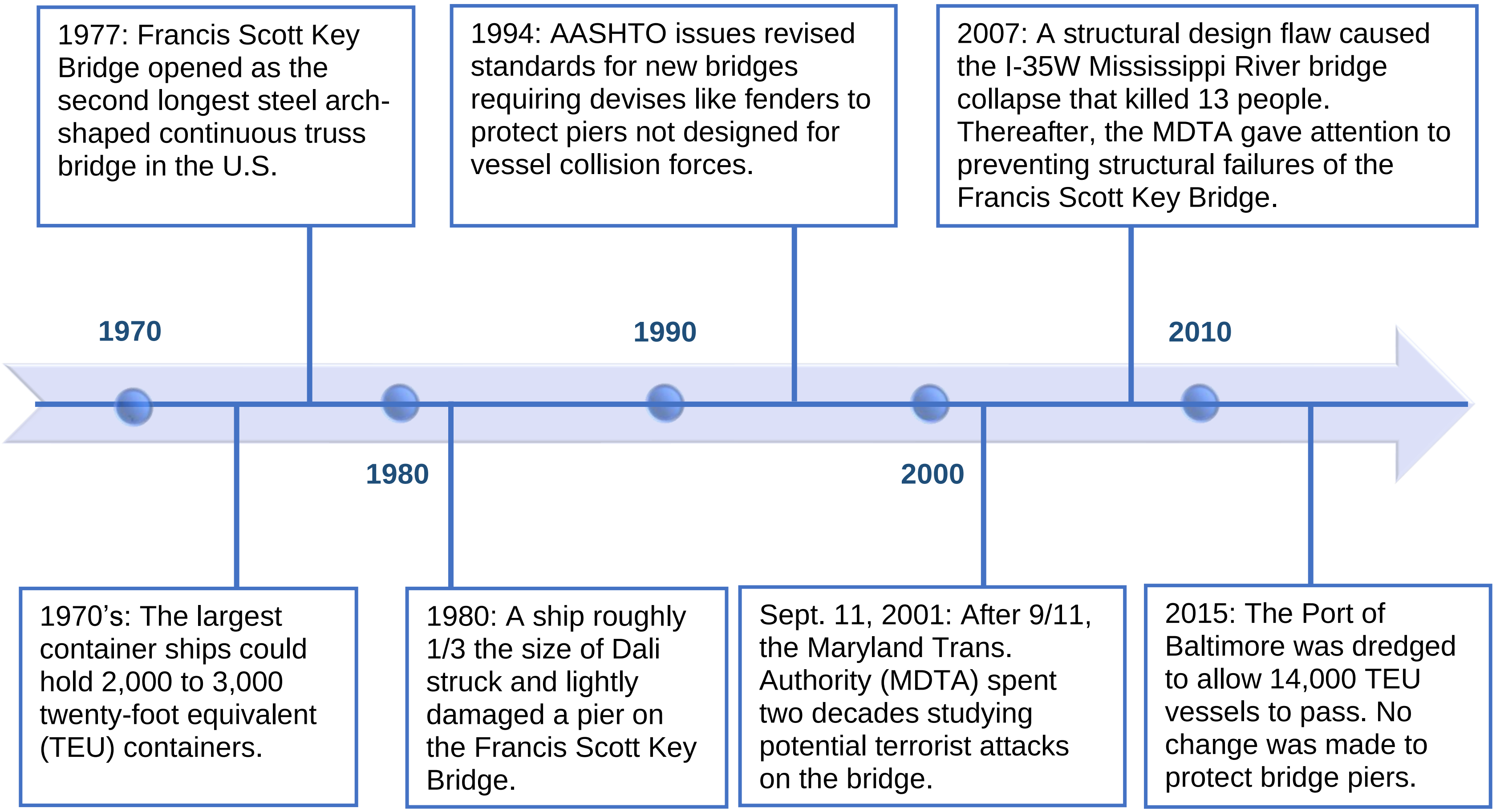
The collapse blocked most shipping to and from the Port of Baltimore for 11 weeks. The Governor called the event a "global crisis" that affected more than 8,000 jobs (the port employs 15,000 people) due to the sudden stoppage of all incoming and outgoing container ships. The economic impact was estimated at $15 million per day, which totals over $1 billion. Plus, the cost to replace the bridge is estimated at $1.7 billion to $1.9 billion, with the earliest completion projected at fall 2028.

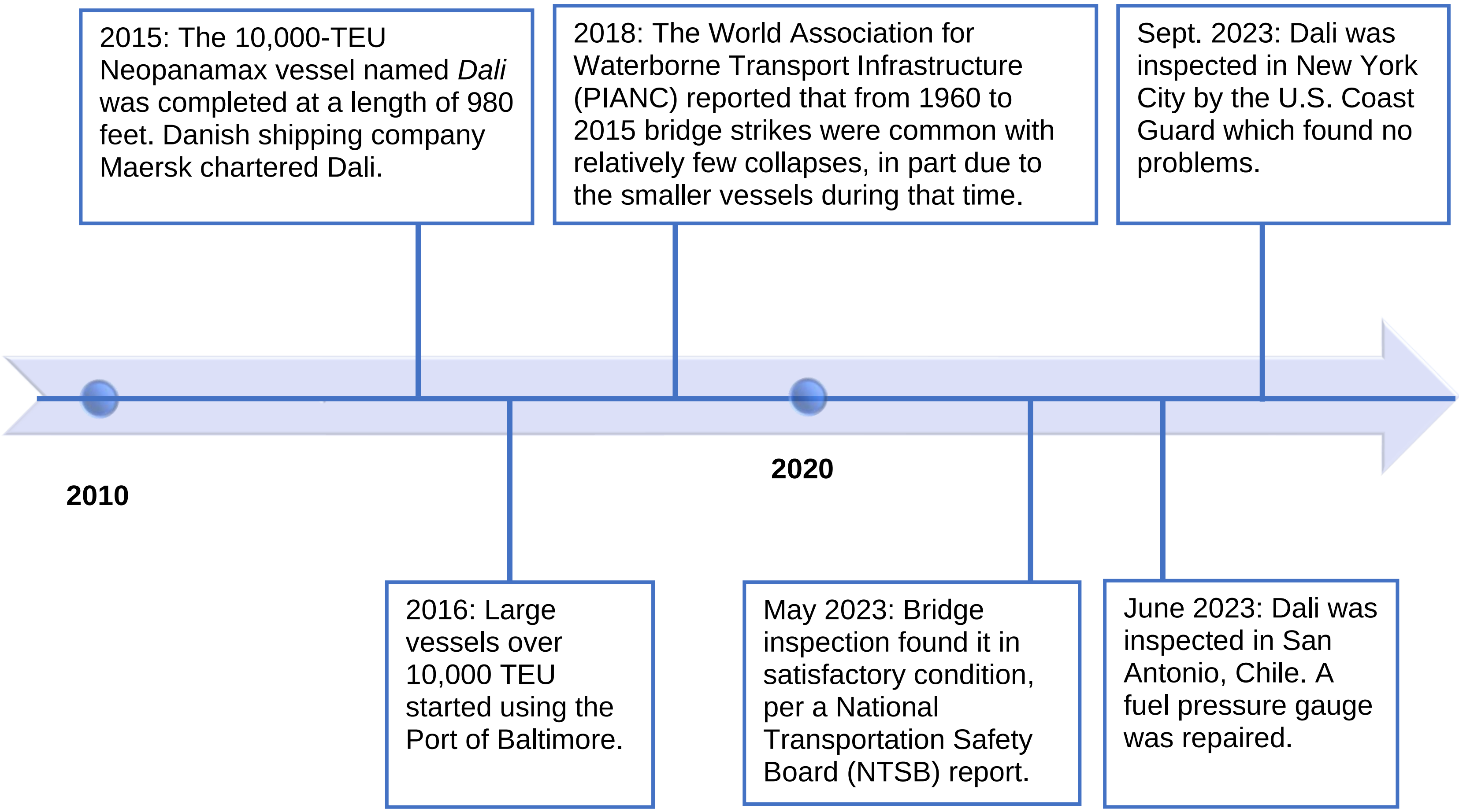
Although it is unusual for a bridge to totally collapse, it is surprisingly common for vessels to hit bridge piers. As container ships get larger and more powerful, the risks grow for a repeat of this disaster. Engineers play an important role in preventing such repeats.

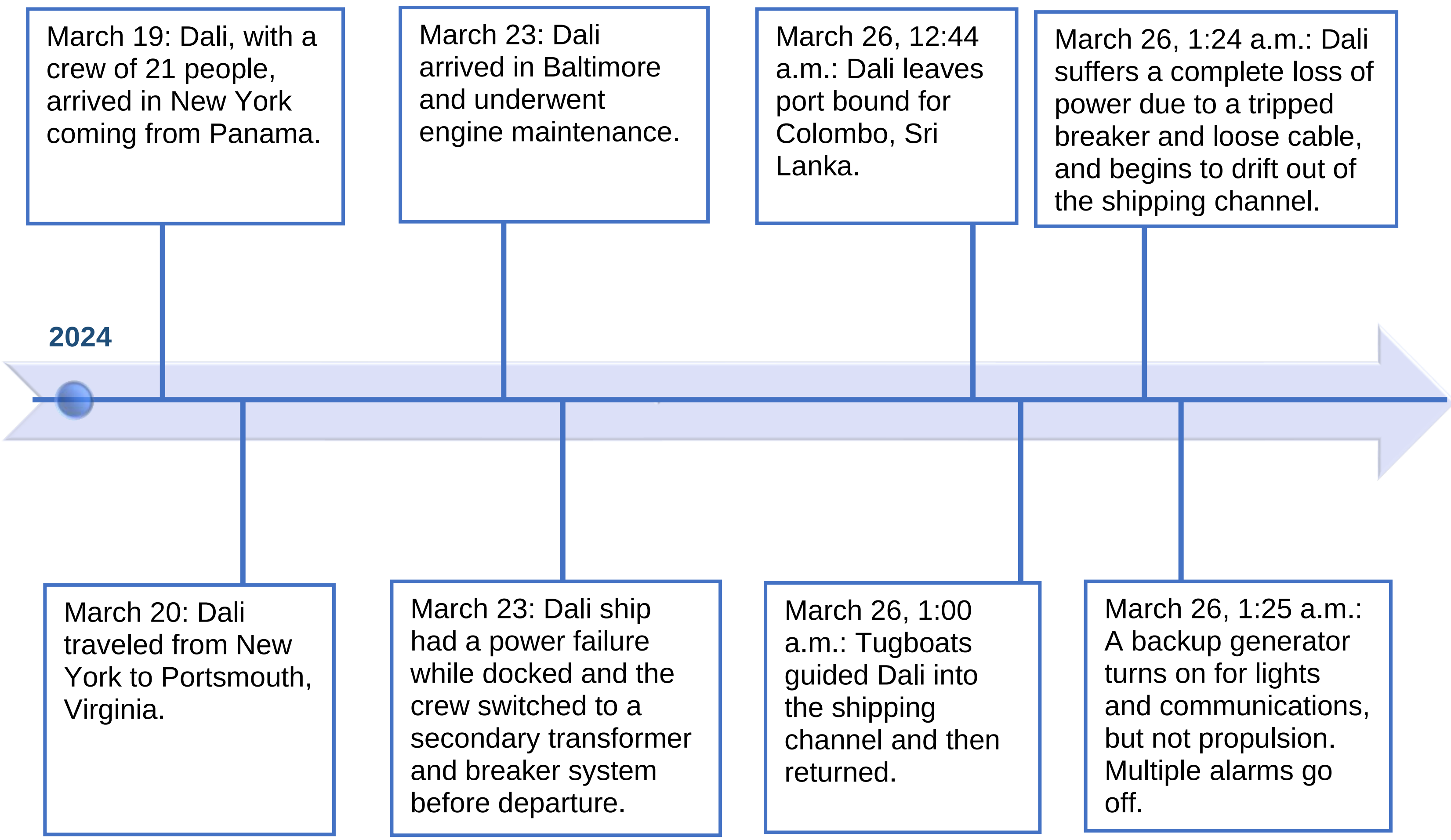
The incident is a stark reminder of the vulnerability of existing bridges to allision (collision) from modern vessels, the need to assess and upgrade critical structures, the need for greater reliability in container ships, and the potential consequences of an inadequate risk assessment.

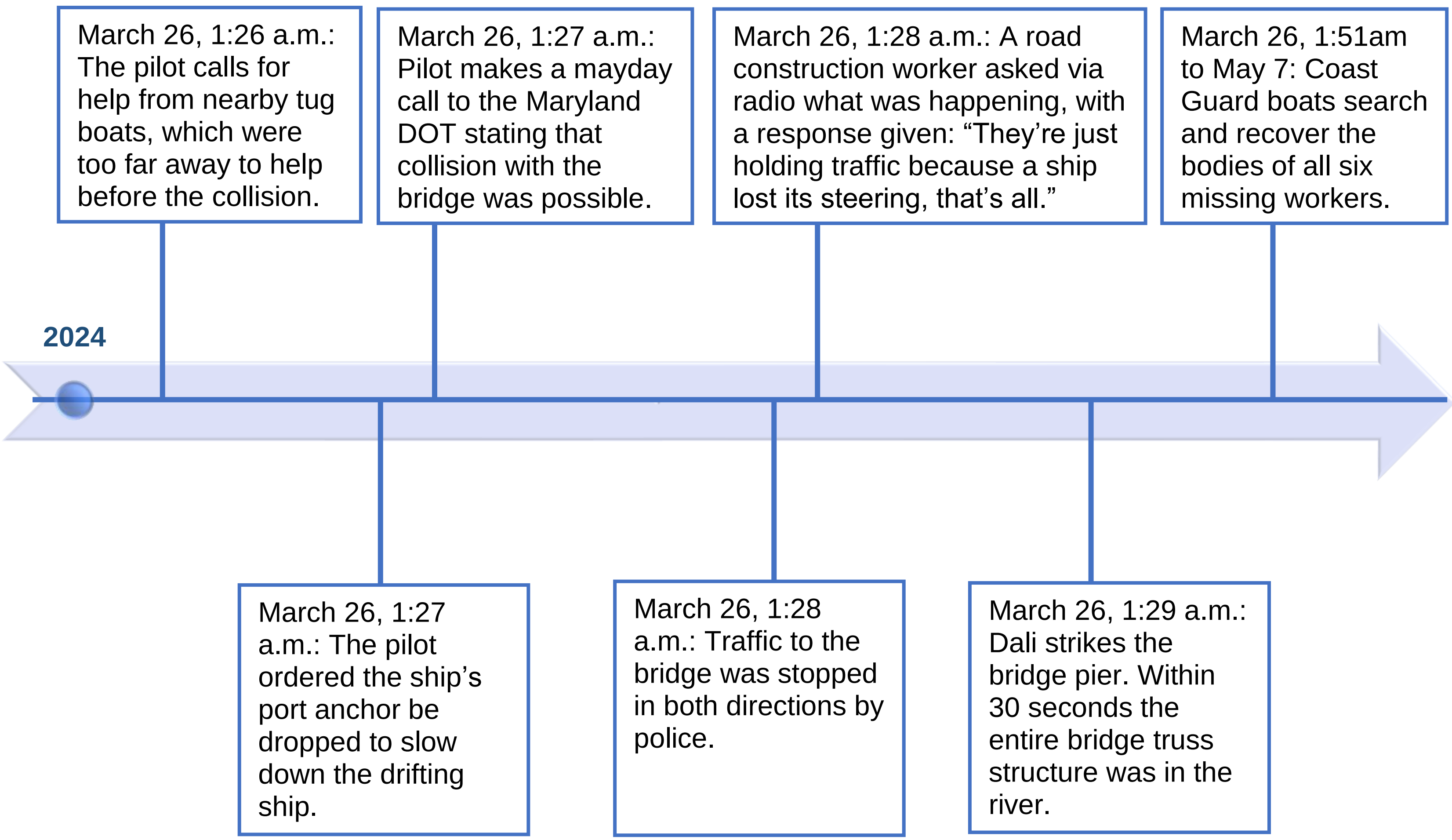
Ethical concerns raised from this disaster apply to many engineering applications.

Timeline of Events




2015: The 10,000-TEU Neopanamax vessel named *Dali* was completed at a length of 980 feet. Danish shipping company Maersk chartered Dali.
2018: The World Association for Waterborne Transport Infrastructure (PIANC) reported that from 1960 to 2015 bridge strikes were common with relatively few collapses, in part due to the smaller vessels during that time.
Sept. 2023: Dali was inspected in New York City by the U.S. Coast Guard which found no problems.
2010
2020
2016: Large vessels over 10,000 TEU started using the Port of Baltimore.
May 2023: Bridge inspection found it in satisfactory condition, per a National Transportation Safety Board (NTSB) report.
June 2023: Dali was inspected in San Antonio, Chile. A fuel pressure gauge was repaired.


2024
March 19: Dali, with a crew of 21 people, arrived in New York coming from Panama.
March 20: Dali traveled from New York to Portsmouth, Virginia.
March 23: Dali arrived in Baltimore and underwent engine maintenance.
March 23: Dali ship had a power failure while docked and the crew switched to a secondary transformer and breaker system before departure.
March 26, 12:44 a.m.: Dali leaves port bound for Colombo, Sri Lanka.
March 26, 1:00 a.m.: Tugboats guided Dali into the shipping channel and then returned.
March 26, 1:24 a.m.: Dali suffers a complete loss of power due to a tripped breaker and loose cable, and begins to drift out of the shipping channel.
March 26, 1:25 a.m.: A backup generator turns on for lights and communications, but not propulsion. Multiple alarms go off.


2024
March 26, 1:26 a.m.: The pilot calls for help from nearby tug boats, which were too far away to help before the collision.
March 26, 1:27 a.m.: The pilot ordered the ship's port anchor be dropped to slow down the drifting ship.
March 26, 1:27 a.m.: Pilot makes a mayday call to the Maryland DOT stating that collision with the bridge was possible.
March 26, 1:28 a.m.: Traffic to the bridge was stopped in both directions by police.
March 26, 1:28 a.m.: A road construction worker asked via radio what was happening, with a response given: "They're just holding traffic because a ship lost its steering, that's all."
March 26, 1:29 a.m.: Dali strikes the bridge pier. Within 30 seconds the entire bridge truss structure was in the river.
March 26, 1:51am to May 7: Coast Guard boats search and recover the bodies of all six missing workers.

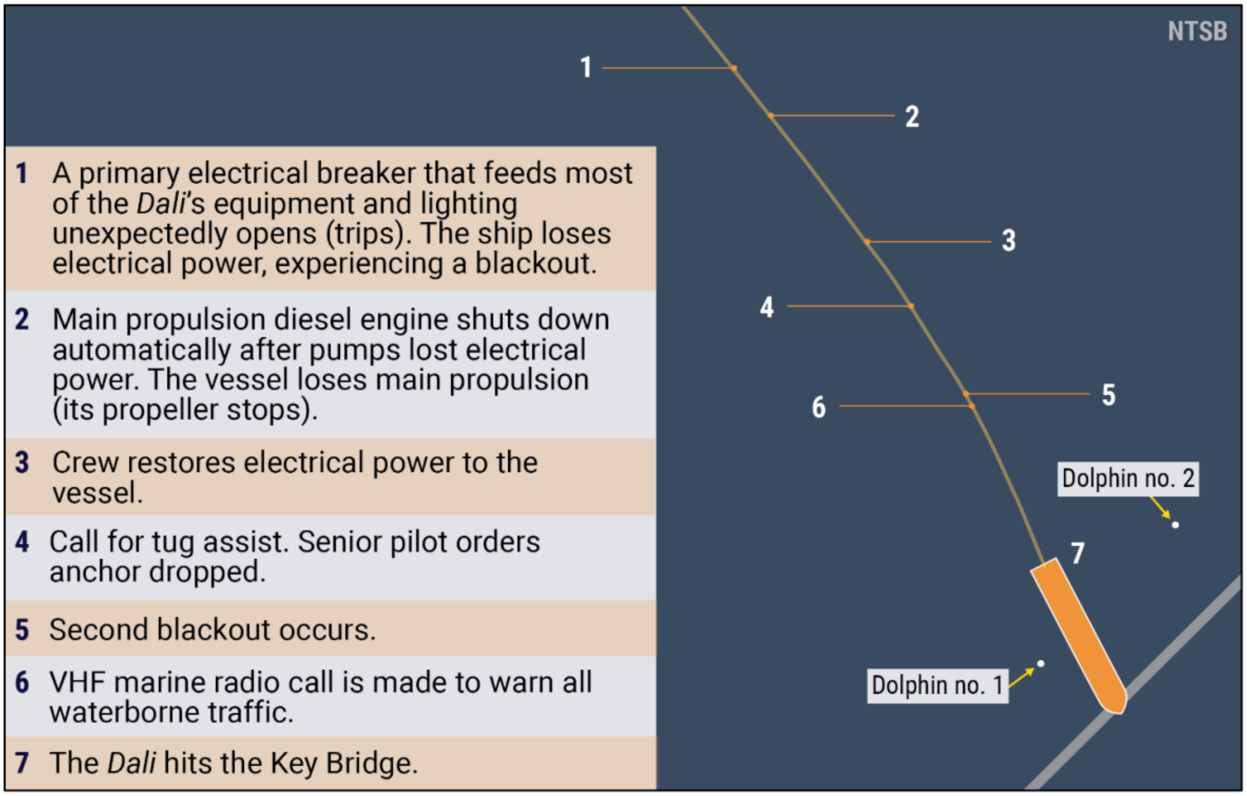


Figure 3: The Dali's route on March 26 with key events from the timeline. The two "dolphins" are sheet pile and concrete structures that align with the critical bridge piers.
Source: www.ntsb.gov/investigations/Documents/DCA24MM031_PreliminaryReport%203.pdf

Engineering Failures Related to the Bridge

The Francis Scott Key Bridge Collapse involved an engineered bridge and an engineered vessel. Although it was an accident with no single individual to blame, the magnitude of the disaster makes it worth considering how it could have been prevented and thus how similar incidents may be prevented in the future.

The original structural design of the bridge was done in the mid-1970's and considered the force of impact from the container ships used in the Port of Baltimore at that time, which was around 2,500 TEU. Since that time vessels have increased greatly, as shown in Figure 4. In 2015, the Port of Baltimore was dredged to allow 14,000 TEU vessels to pass, which put the bridge at risk.

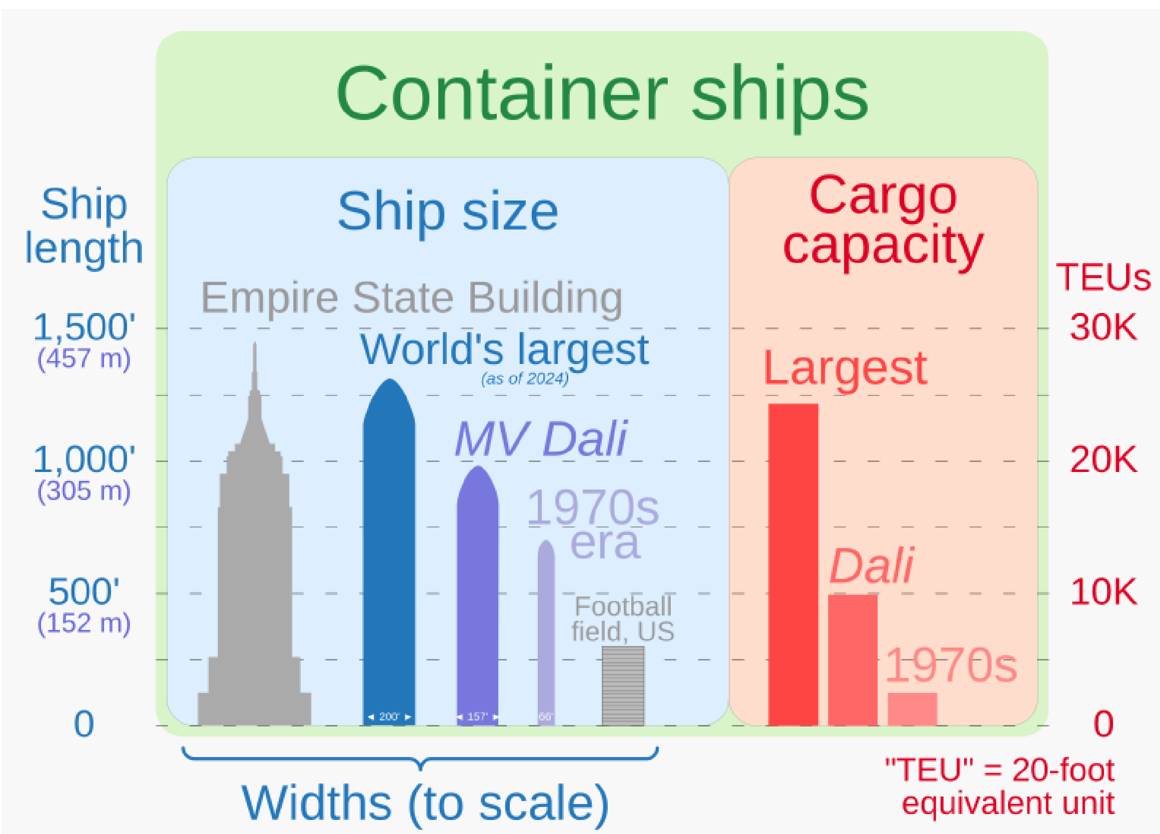


Figure 4: Chart showing how container ships have grown since the design of the Francis Scott Key Bridge in the 1970's.
Source: commons.wikimedia.org/wiki/File:Francis_Scott_Key_Bridge_and_Cargo_Ship_Dali_NTSB_view_(cropped).jpg

The Dali has a capacity around 4 times larger than ships for which the bridge was designed. On the day of the incident, the Dali was loaded close to 10,000 TEU with 4,700 forty-foot containers. The total mass of the Dali was several times larger than the bridge was designed to handle.

Since 1994, AASHTO bridge design standards have required pier protection from vessel collisions, typically through a rock wall, island barrier or fenders (see Figure 5). However, existing bridges are not required to comply with all the latest bridge standards and each state has different regulations for bridge upgrades. Federal and state funding also impacts which bridges and how many are selected for upgrades.

Figure 5: Fiberglass fenders to protect a bridge pier along a boating channel.
Source: www.creativecompositesgroup.com/blog/prioritizing-bridge-protection

The Maryland Department of Transportation (MDOT) and Maryland Port Administration (MPA) did not respond to journalist questions on whether the bridge was ever considered for fender retrofits. It seems logical that pier protection would be added, or at least seriously considered, when the channel was dredged for larger vessels. Known reports from that time focus on risks from terrorism or structural failures such as from corrosion.

Perhaps engineers did not perform risk assessments with a proper risk ranking based on a combination of likelihood of failure and consequences of failure. Or perhaps engineers were influenced by leadership to give recommendations that avoid the cost of fender retrofits on the piers and thereby save money.

Here are some ways that engineers influence which bridges receive upgrades:

- Consultants perform risk assessments of bridges and provide recommendations.
- Structural engineers perform inspections and condition assessments of bridges and give recommendations.
- DOT engineers summarize bridge information and provide recommendations
- DOT engineers and engineering societies influence politicians on bridge repair policies.
- Engineering societies influence politicians on bridge repair policies and funding levels.
- Engineers author articles on bridge vulnerabilities and influence public policy.

Engineering Failures Related to the Ship

The ship Dali was only 9 years old when the power systems failed leading to the collision with the Francis Scott Key Bridge. The average age for a container ship is 14 years old. Ships over 15 years old tend to have increased mechanical and electrical failures from aged equipment. It is unusual for a 9 year old ship to have failures to both the primary and secondary electrical power systems, raising concerns for the design, maintenance, and operations of the Dali electrical system.

The National Transportation Safety Board (NTSB) investigation points to a number of electrical failures as the cause of the ship drifting and hitting the pier. The failures started when the ship was still in port. The ship was allowed to depart with transformer 2 (TR2) turned off due to failures (on the left in Figure 7) with the hope that the single remaining transformer (TR1) would suffice. The TR1 breakers (LR1 and HR1) then failed when the ship was headed toward the bridge, leaving the crew to troubleshooting the issues with both TR1 and TR2 systems and ultimately did not have enough time. It was later found that a loose wire (unconnected) caused one of the breakers to trip.

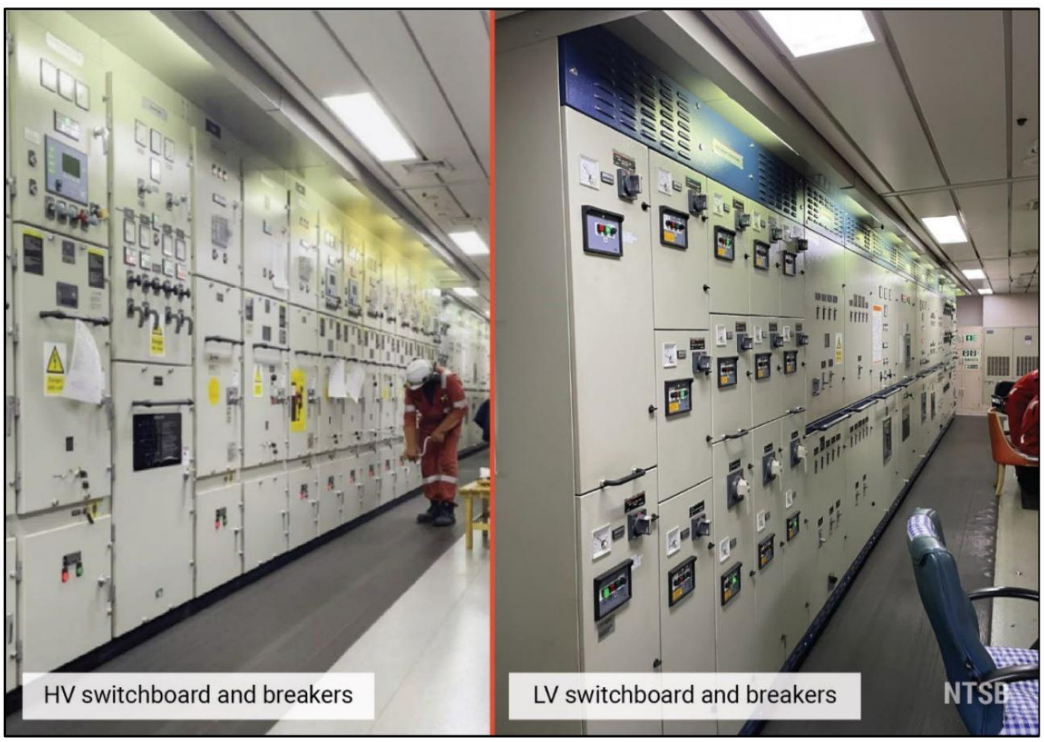


Figure 6: Dali's HV and LV power management system in the engine control room.
Source: www.ntsb.gov/investigations/Documents/DCA24MM031_PreliminaryReport%203.pdf

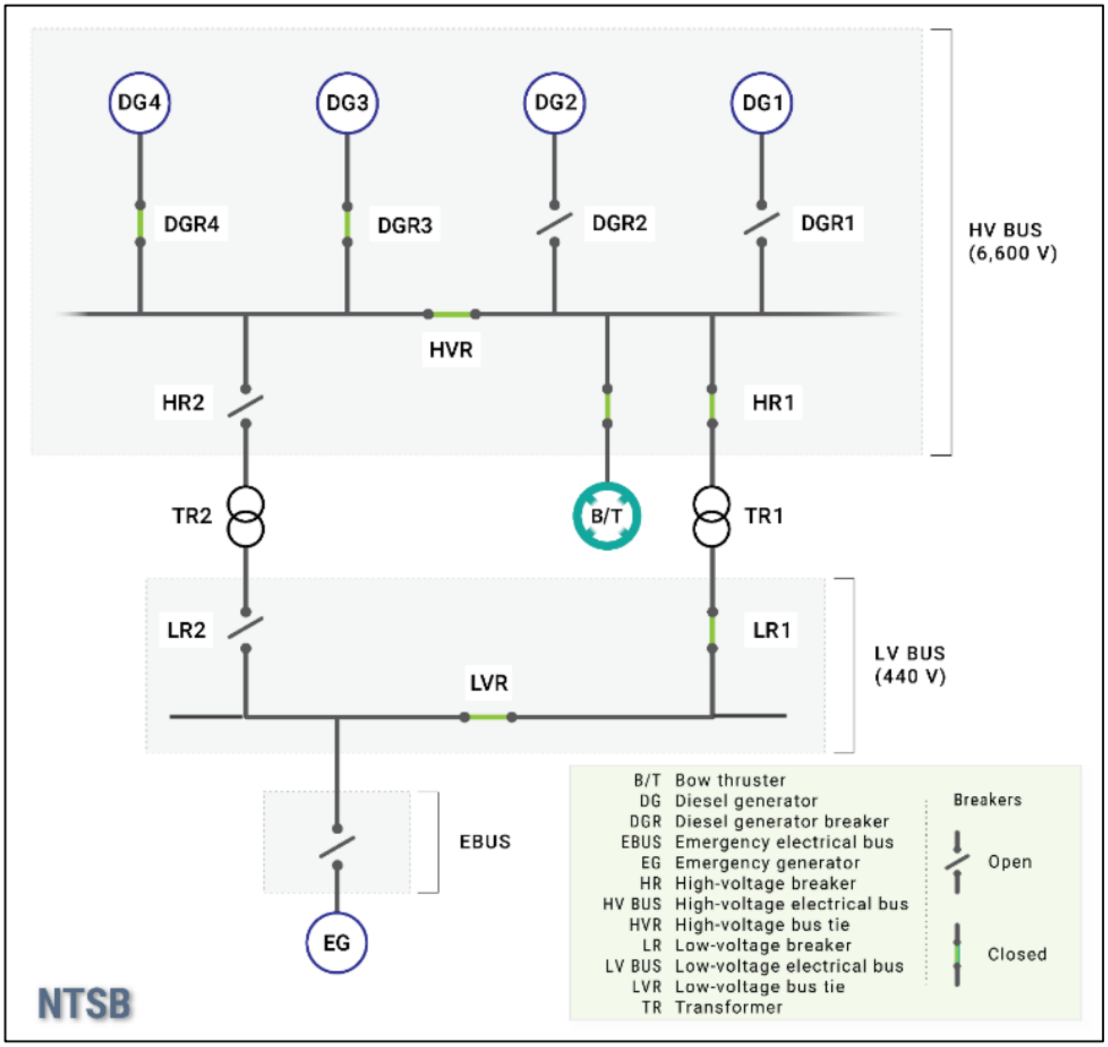


Figure 7: One-line electrical diagram of the Dali electrical power distribution system, with breaker positions during departure on March 26 (prior to power failure).
Source: www.ntsb.gov/investigations/Documents/DCA24MM031_PreliminaryReport%203.pdf

The main engines require both high voltage (propulsion/propellers, bow thruster) and low voltage (lubrication pumps, cooling pumps, steering gear pumps). The design of the electrical system included redundant transformers between high and low voltages, but the critical nature of these transformers seems not to have been realized. Also, the emergency generator for low voltage did not automatically start.

Although much of the blame is pointed at the operations staff, the following are potential engineering solutions that could have helped prevent the disaster include:

- A third installed transformer and associated breakers
- Automatic transfer switch (ATS) and advanced controls for the emergency generator
- Redundant emergency generator
- An artificial intelligence (AI) predictive maintenance for the transformers, generators, and other equipment
- Automated power supply controls and real-time troubleshooting assistance
- Automated emergency alerts to authorities
- Requiring an electrical engineer's approval prior to departing with known electrical problems
- More robust anchor system to slow down the ship

Lessons Learned

The following are lessons learned from the Francis Scott Key Bridge Collapse as applied to each of the fundamental cannons.

Canon 1: Hold paramount the safety, health, and welfare of the public.

A comprehensive risk assessment can identify potential failures that could jeopardize the safety of workers and the general public. The risk assessment should include all possible known causes (aged infrastructure, terrorism, accidents, power failures, etc.). Solutions should be identified to protect the welfare of the public.

Engineers designing the dredging of the port and channel likely realized much larger ships would pass under the bridge and potentially strike a pier. When public safety is involved, engineers should make known the potential consequences and recommend engineered solutions, such as pier protection improvements (fender retrofits).

Canon 2: Perform services only in areas of their competence.

It seems that electrical engineering decisions were made by unqualified ship staff prior to the Dali departing.

Canon 3: Issue public statements only in an objective and truthful manner.

It appears the MDOT and MPA have not made it publicly known if the bridge was ever considered for fender retrofits. It would be helpful to understand the logic behind the decision and if engineers were involved, as a lesson learned if nothing else.

Canon 4: Act for each employer or client as faithful agents or trustees.

Engineers designing the dredging of the channel and performing bridge risk assessments should have pointed out the bridge would collapse if a container ship struck a pier. Although it would have added capital cost, it could have prevented billions in losses from the disaster.

Engineers involved in the ship's design and upgrades could have made improvements such as additional power redundancy, AI preventative maintenance, automation, and additional anchorage. These would have helped the client in the long run.

Canon 5: Avoid deceptive acts.

There were no known deceptive acts by engineers.

Canon 6: Conduct themselves honorably, responsibly, ethically, and lawfully so as to enhance the honor, reputation, and usefulness of the profession.

See notes above under Canon 4.

In general, there was a general lack of engineering involvement with both the bridge and the Dali since their original commissioning. Engineers should be making themselves useful for assessments and upgrade designs to help prevent such disasters.

Helpful References

Caprani, Colin (2024) “Baltimore bridge collapse: a bridge engineer explains what happened, and what needs to change”. https://theconversation.com/baltimore-bridge-collapse-a-bridge-engineer-explains-what-happened-and-what-needs-to-change-226716

MI News Network (2024) “Loose Electrical Cable On MV Dali Ship Led To The Collapse Of Baltimore Bridge”. https://www.marineinsight.com/shipping-news/loose-electrical-cable-on-mv-dali-ship-led-to-the-collapse-of-baltimore-bridge

National Transportation Safety Board (NTSB) (2024) “Contact of Containership Dali with the Francis Scott Key Bridge and Subsequent Bridge Collapse”. https://www.ntsb.gov/investigations/Documents/DCA24MM031_PreliminaryReport%203.pdf
https://www.ntsb.gov/investigations/Pages/DCA24MM031.aspx

National Council of Examiners for Engineering and Surveying (NCEES) (2021) “Model Law”. https://ncees.org/wp-content/uploads/Model_Law_2021_web-2.pdf

National Council of Examiners for Engineering and Surveying (NCEES) (2024) “Model Rules”. https://ncees.org/wp-content/uploads/2024/01/Model_Rules_January-2024_web.pdf

National Society of Professional Engineers (NSPE) (2019) “NSPE Code of Ethics for Engineers“. https://www.nspe.org/resources/ethics/code-ethics

StreamTime Live (March 26, 2024). "Official Footage of the Francis Scott Key Bridge Collapse". https://www.youtube.com/watch?v=mULzspJZuf8

