ISP Proposal : Tacoma Narrows Bridge

David Tsenter, Sabrina Nguyen, Diana Kowal

SPH4U3

Mr. Gruszecki

April 9, 2015

Background Information

The original Tacoma Narrows Bridge was designed by Leon Moisseiff and spanned Puget Sound in Washington State. Its design was similar to the Bronx-Whitestone Bridge. The construction of the bridge began in October 1938 and was completed in July 1940 (Kawada, 2010).

The bridges span was 853 m. The bridge had two lanes and its width was 11.9 m (Kawada, 2010). The truss (girder) depth-to-span ratio was 1:350 and the width-to-span ratio was 1:72 (Kawada, 2010). The narrowness contributed to the bridges oscillation. When it was completed, the bridge was nicknamed Galloping Gertie due to its wild oscillations during mild to moderate crosswinds (Denny, 2010, p.180).

The Tacoma Narrows Bridge collapsed on November 7, 1940, four months after opening (Kawada, 2010). On the day of the collapse , the deck of the Tacoma Narrows Bridge can be seen to wobble from side to side (not along its length) with increasing amplitude (Denny, 2010, p.181). As reported by the Engineering News-Record, 42 mph winds caused a vertical wave motion...giving the deck a cumulative rocking or side-to-side rolling motion...Failure appeared to begin at mid-span...Suspenders snapped...sections of the floor system...fell out (Kawada, 2010, p.133).

The only fatality of the Tacoma Narrows Bridge collapse was Tubby, a three-legged cocker spaniel who resisted efforts to rescue him from an abandoned car (Denny, 2010, p.181).

Moisseiff was not completely blamed for the collapse, as it was due to actions and forces previously ignored or known to be unimportant (Kawada, 2010, p.142). A new, reconstructed, redesigned Tacoma Narrows Bridge was completed in 1950.

Cause of Collapse

A suspension bridge has cables that rest atop two towers on opposite sides of the bridge, suspend the roadway, and extend from one end of the bridge to the other. The weight from the roadway is evenly distributed throughout the cables and is transferred to the concrete-embedded anchorages (Figure 1). The cables transfer the force of compression from the deck to the towers, where it is finally dissipated down to the earth. Most suspension bridges have a truss system beneath the deck which helps to reinforce the deck and reduce roadway swaying motions. (Figure 1).

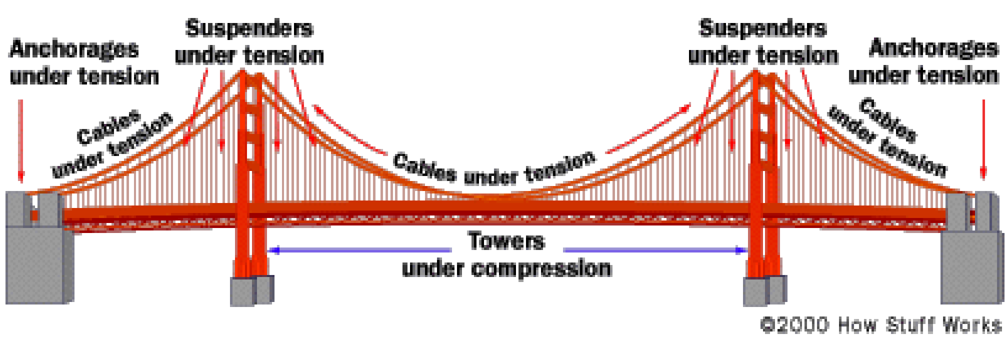

Figure 1: A force distribution of of tensile and compressive forces

In addition to tension and compression, an important force to consider in suspension bridges is torsion. In fact, the lack of calculations accounting for torsion may have been the main downfall of the Tacoma Narrows Bridge. The original bridges unique supports were fashioned out of plate girders of carbon steel embedded in large chunks of concrete. In earlier bridge designs, wind would pass through the truss. The bridges new design diverted the wind above and below the structure. This did not actually work and bridge buckled under severe weather conditions in a transverse-wave pattern. At the time, the bridges mass was considered to be sufficient to keep it structurally sound, especially with the introduction of the new girders.

Engineers were caught off guard when a never-before-seen twisting mode occurred from winds at a mild 40 miles per hour. This was called torsional vibration mode. When the left side of the roadway went down, the right side would rise, and vice versa, with the center line of the road remaining still. Forgetting to account for torsion destined the bridge for failure. Although tension and compression are accounted for, the bridge was not able to handle forces acting on the z-plane (into the bridge). The Tacoma Narrows Bridge experienced the second torsional mode (Figure 2), in which the midpoint of the bridge remained motionless while the two halves of the bridge twisted in opposite directions. This vibration is said to have been caused by aeroelastic fluttering (Figure 3, Figure 4).

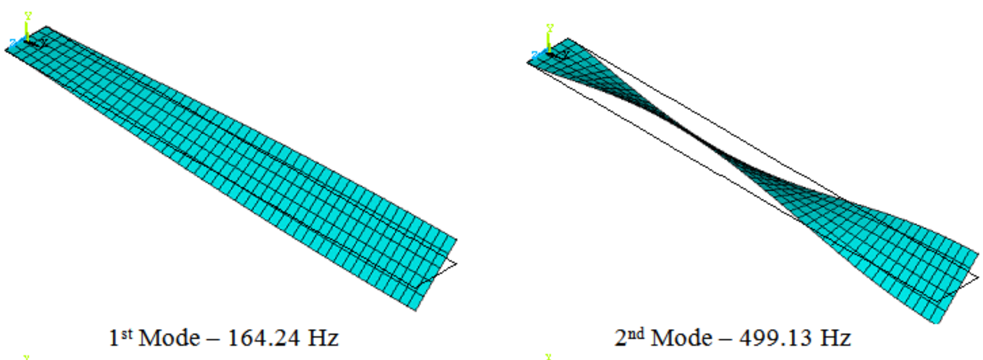

Figure 2: A visualization of the first and second torsional-vibration mode

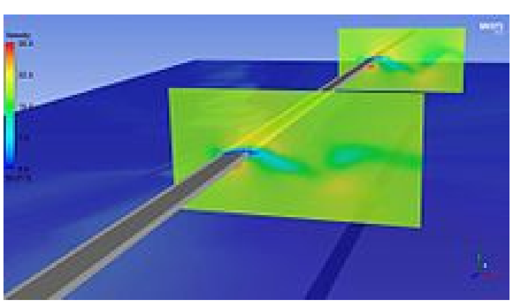

Figure 3: Computer-generated animation of the aeroelastic fluttering. The concentration of blue tint in the wave indicates the strength of the force

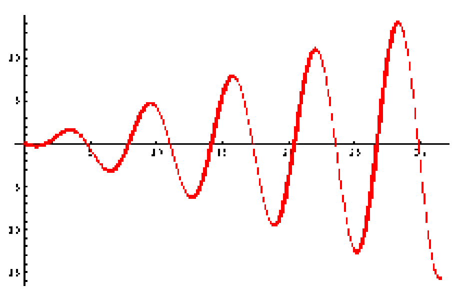

Figure 4: A standard torsional-vibration wave. Note the exponential growth of each oscillation (created by Wind)

The term fluttering is often used when discussing resonance. Resonance is a phenomenon where a system (bridge) acted on by external forces (wind) oscillates with greater amplitude with every cycle. In the Tacoma Narrows Bridge, the wind pumped in more energy than the flexing of the structure could dissipate, leading to exponentially growing twisting motions. The continuous increase of deflection and stress finally drove the bridge toward failure. The wind speed that causes the beginning of the fluttering is known as the flutter velocity. Fluttering occurs even in low-velocity winds with steady flow (Figure 5).

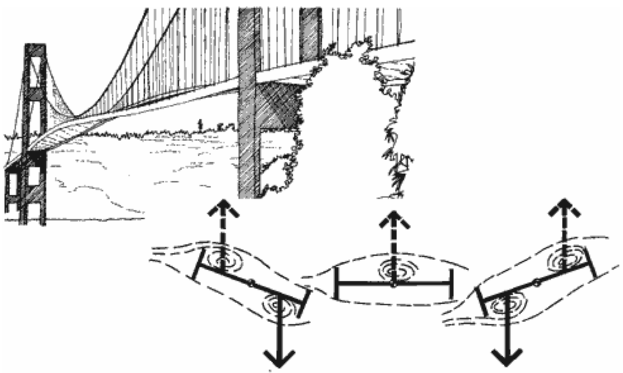

Figure 5: The 3 types of fluttering that occurred during various weather conditions. Note: Arrows indicate torsional forces (not net force)

Figure 6: The collapsed bridge

In the case of the Tacoma Narrows Bridge, the amplitude of the motion produced by the fluttering increased beyond the strength of the suspender cables. Once several cables failed, the weight of the deck transferred to the adjacent cables. These cables broke in turn until almost all of the central deck fell into the water (Figure 6).

Renovations, Current Bridge, and Improvements

The second and third Tacoma Narrows Bridges were completed in 1950 and 2007 respectively. This twin suspension bridge was built to accommodate increasing traffic across the Tacoma Narrows.

Following the collapse of the original bridge, Charles E. Andrew was appointed as principal engineer and chairman for the construction of the second bridge by the Washington Toll Bridge Authority. Alongside him was chief design engineer, Dexter R. Smith, and principal tester, F.B. Farquharson.

Farquharson built scaled-down test models to put his designs to the test. He also employed wind tunnels, a new technology that allowed him to study the effects of wind vortices on suspension bridges. He knew his final design was successful when it hardly torqued or fluttered from the winds. The entire research and testing process lasted three-and-a-half years.

Smith and Farquharson made several key changes to the bridge design: 33-foot deep steel Warren stiffening trusses with shallow truss members, top and bottom lateral truss bracing, wind grates, hydraulic shock absorbers, less cable sag, and better load distribution.

The deep stiffening trusses and the accompanying bracing provides strong resistance to torsional movements. In the old bridge, the entire truss structure was shallow and there were no additional supports, allowing it to twist easily. The new bridge is able to stay relatively immobile, even during strong winds. The new bridge has shallower truss members and more wind grates. The increased airflow through the bridge and fewer large, solid surfaces decreases the forces that the wind has on the structure.

Hydraulic jacks were placed on the tower structure and thicker cables were used for the new bridge. This ensured that the structure remained rigid and supportive while being flexible enough to withstand tension and compression forces.

The positioning of the towers and piers were modified. The width of the towers and piers were also increased. These two changes ensure an even distribution of the load. Some towers from the original Tacoma Narrows bridge were reused, but many were rebuilt in order to meet the new design requirements.

Work Equalization and Integration Summary

For the ISP, the group selected the topic Structures that have failed. They could either have researched one failed structure in depth, or researched three failed structures in less depth and draw connections between them. The group swiftly and unanimously decided to research one failed structurethe Tacoma Narrows Bridge. To complete this project effectively, the group decided to have three main areas to research and present. Each person is looking at one of the following areas:

DIANA:

- **Background Information:** Overview of the Tacoma Narrows Bridge and its failure
- Work Equalization and Integration Summary

DAVID:

- **Cause of Collapse:** The physics behind why the Tacoma Narrows Bridge failed
- Formatting

SABRINA:

- **Research, Improvements, and Current Bridge:** Building the new bridge and avoiding previous errors
- Bibliography
- Final Editing

These three main areas cover the topic of Structures that have failed adequately and they flow well from one to the other during both research and presentation. By having three main areas, this ensures that each member of the group is conducting clear, directed research and creating and presenting their own distinct part of the presentation. The group members unify the formatting within both the ISP progress report and the ISP presentation to guarantee professionalism, clarity, and aesthetic.

References

Denny, M. (2010). *Super Structures: The Science of Bridges, Buildings, Dams, and Other Feats of Engineering.* Baltimore: The Johns Hopkins University Press.

Kawada, T. (2010). *History of the Modern Suspension Bridge: Solving the Dilemma between Economy and Stiffness.* R. Scott (Ed.). (H. Ohashi, Trans.). Reston, Virginia: American Society of Civil Engineers. (Original work published 2002).

WSDOT. (2005, January 1). WSDOT - Tacoma Narrows Bridge: Extreme History. Retrieved April 8, 2015 from http://www.wsdot.wa.gov/TNBhistory/.

University of Washington. (2014, January 1). Introduction - Exhibit: History of the Tacoma Narrows Bridge. Retrieved April 4, 2015 from http://www.lib.washington.edu/specialcollections/collections/exhibits/tnb.