8.4 Infrastructure and Structural Failures

- Infrastructure is the network of structures, utilities, and facilities that supply and support our basic needs for mobility, power, water, sewer, and communications.
- This chapter covers large, complex infrastructure failures that are *not* triggered by some other hazard (e.g., an earthquake). Failures to digital and communications infrastructure is discussed in the cyber-attack and disruption chapter.
- The American Society of Civil Engineers (ASCE) gives the infrastructure of the United States an overall D+ grade and estimates it will cost $2 trillion to fix. The ASCE gives Washington a C grade, with the main concerns being roads and mass transit.
- Infrastructure can be damaged during construction, such as a contractor breaking a water main; or fail after construction due to a design flaw, such as the collapse of the Tacoma Narrows Bridge in 1940.
- Occasionally, our understanding of a threat to infrastructure becomes clear only after we build it. This has occurred with many bridges built in the early 20th century before Seattle was aware of its earthquake risk.

8 4.1 Context

On May 23, 2013, the I-5 Skagit River Bridge collapsed in Mount Vernon, Washington. Fortunately, there were no fatalities, but traffic on the busiest freeway in the state had to be rerouted for weeks.[459] This bridge collapse, along with other recent infrastructure incidents, such as the I-85 bridge collapse in Atlanta in 2017 and the sinking Millennium Tower in San Francisco, highlight aging and vulnerable infrastructure across the United States. This chapter encompasses infrastructure failures that can rise to the level of a disaster: bridge collapse, building collapse, crane collapse, dam failure, main breaks, pipeline failure, steam pipe explosions, industrial system failure, accidents at nuclear plants, and similar events. Because power failures are especially complex, they are covered in the power outage chapter.

Most complex infrastructure is now controlled with computer systems (called supervisory control and data acquisition or SCADA systems). While SCADA system failure is a type of infrastructure failure, it is covered in detail in the cyber-attack and disruption chapter.

Problems of failing infrastructure are typically small scale and cumulative. For example, a vast number of small leaks can cause some municipal water systems to lose up to 20% of their water during transmission. While reducing the effectiveness of a system, small, cumulative failures do not typically rise to the level of a disaster. This chapter concentrates on the upper end of the problem, large scale failures with immediate consequences. Nevertheless, it is important to note that these large-scale failures represent only part of a wider issue, and cumulative failures can have disastrous impacts, as was the case in Flint, Michigan, where lead contamination in the city’s water supply eventually resulted in a public health emergency.

Locally, responsibility for Seattle’s infrastructure rests with a collection of public and private agencies. Details of these systems and agencies are described in the Community Profile.

Many, though not all, of the problems are related to the age of American infrastructure. In many places pipelines, bridges, and other structures are over 100 years old. Some systems in Seattle are approaching or are past this age. The Fremont and Ballard bridges, as well as the Hiram M. Chittenden Locks, were all 100 years-old as of 2017. The shear amount of investment it would take to upgrade all of America’s aging infrastructure would be $2 trillion according to the American Society of Civil Engineers (ASCE), which also assigned an overall D+ grade to the nation’s infrastructure.[460] Washington’s infrastructure received a C grade from ASCE, with roads and mass transit systems rating lowest and dams rating highest.[461]

Other causes of infrastructure failures can be structural fatigue, such as increased carrying loads on bridges, corrosion of materials due to environmental exposure, erosion, and stress beyond what the system was designed to do.[462] Infrastructure failures can also be a result of human error or accidents that occur during a construction phase. Workers can accidentally damage utility mains, errors can be made in the building’s construction that cause failures later on, and construction equipment, such as cranes or scaffolding, can fail and collapse. Additionally, infrastructure failure is often felt as a secondary hazard to another incident such as an earthquake. While many of these primary hazards would damage even healthy infrastructure, the problem is compounded by weakened infrastructure.

Replacing aging and inadequate infrastructure is costly and politically difficult. Without a clear crisis, it is a challenge to convince taxpayers to replace expensive structures. Nonetheless, some programs have been implemented and are addressing infrastructure improvement needs, such as the $365 million “Bridging the Gap” levy, which addresses paving, bridge repairs, seismic upgrades, and transit enhancement.[463]

8 4.2 *History*

The Seattle region has experienced some large failures, but none included major loss of life. This is a list of the major infrastructure failures in Seattle.

November 7, 1940. Tacoma Narrows Bridge Collapse. One of the most famous infrastructure failures in the world occurred when a 42-mph wind caused the bridge to twist until its cables snapped. There were no casualties.

November 11, 1957. Sinkhole. A sewer line tunnel built in 1909-10 collapsed, causing a massive sinkhole under Ravenna Boulevard. Ten families had to be evacuated. The system took two years to repair and cost $16 million (in 2013 dollars).

February 25, 1987. Husky Stadium Collapse. An addition to the northern deck collapsed during construction. The cause was the premature removal of six temporary wire supports that allowed the structure to sway too much. Workers noticed a support buckling and had time to escape, so there were no casualties.

November 25, 1990. I-90 Bridge Sinking. The bridge was under construction and not being used. It sank following a major windstorm. The pontoons that support the bridge had been opened to temporarily store water. The openings allowing additional storm water to enter.

July 19, 1994. Kingdome Ceiling Tiles and Crane Failure. Hours before a baseball game, four large waterlogged tiles peeled from the ceiling and plunged into the seats. Two construction workers died during repairs when the basket on top of a crane broke loose and fell 250 feet. The cause of the ceiling tile failure was a badly leaking roof.

December 14, 2006. Drainage System. (Also in Flooding). Heavy rains overwhelmed the drainage system along Madison Street. Water built up in a valley in the street. It overtopped the curbs and rushed downhill, slamming into a home and killing one person.

May 2, 2007. Water Main Break Under University Bridge. A 24-inch main broke, causing a large sinkhole and worries about the integrity of the bridge abutment. The incident also damaged an 8-inch gas main and a conduit housing Qwest trunk lines. The bridge was not damaged, but water and gas service in the area had to be cut for most of a day.

January 19, 2009. Howard Hanson Dam. Engineers learned that parts of the abutment had a void. To reduce the chance of a catastrophic failure, dam operators would not be able to hold as much water in the reservoir, increasing the chance of flooding in the Kent valley. Temporary repairs were completed before a flood.

February 9, 2017. West Point Treatment Plant. Heavy rains and high tides caused flooding at the waste-water treatment plant, which fired an electrical circuit that shut down operating systems.[464] 235 million gallons of untreated waste was dumped into Puget Sound.[465]

8 4.3 Likelihood of Future Occurrences

Infrastructure failures are unavoidable, and often unpredictable. Even if our entire infrastructure system was in top shape, there would still be construction accidents, operations errors, design flaws, and unanticipated environmental issues. These types of failures occur every year but can normally be handled through daily business procedures. The question is how likely are major failures that precipitate large-scale emergencies? Unless a single failure, such as a dam failure or nuclear accident, affects a large area, most infrastructure failures do not scale up to the catastrophic level. There are no dams in the city limits and Seattle is far from the state's only nuclear power plant in Eastern Washington. The likelihood of an infrastructure failure as a secondary hazard seems to be decreasing as we become more aware of the potential effects of hazards, such as earthquakes. Scientific developments have allowed the city to identify its most vulnerable infrastructure and make the necessary upgrades. Developments in building code standards also make newly constructed infrastructure more resilient to hazards.

There is no data source containing all infrastructure failures, making it difficult to examine trends. However, some national trends in infrastructure age and spending point towards an increased likelihood of failures. The 1950s and 60s saw many of the nation's large infrastructure projects, including many of our national interstate highways.[466] Experts believe that many of these systems are now reaching the end of their lifespan and are in need of upgrades.[467] However, funding for these upgrades has slowed since their construction. For example, spending on transportation and water infrastructure at the state and federal levels has flatlined since 2000,[468] despite the average age of government-owned infrastructure systems increasing from 18 years old to 25 years old between 1970 and 2009.[469] This indicates that systems are being replaced at a slower rate than in previous years, and potentially increases the chance of failure due to age.

The effects of climate change could also impact infrastructure. Rising sea levels can extend the reach of coastal flooding and damage facilities located along the water, such as the West Point wastewater treatment facility. King County estimates that 30 major wastewater treatment facilities are at risk of flooding during storms due to sea level rise (assuming a 15-foot rise) by 2100.[470] Additionally, Seattle is projected to experience more extreme high temperatures. Hight heat can cause steel to expand which may impact older structures like drawbridges.

8 4.4 Vulnerability

Seattle represents the greatest concentration of infrastructure in the Pacific Northwest and one of the oldest settlements in Washington State. Seattle has a bigger collection of infrastructure maintenance needs than anywhere else in Washington State, giving it an intrinsic vulnerability to infrastructure failure. The City also owns or relies on infrastructure in more remote parts of the state, including a number of dams that are used for water supply, power generation, and flood control. The most significant vulnerability is failure of the Howard Hanson Dam, which could cause flooding around the Duwamish River.[471] If other dams were to fail it would mostly affect power generation and water supply capabilities.

The vulnerability of individual systems varies greatly according to the condition of the components, system complexity, the ease and speed with which damage propagates through an infrastructure system and the amount of redundancy in the system.

Virtually every part of Seattle is vulnerable to one type of failure or another because of the ubiquity and dependence of every social and economic function on working infrastructure. However, some places are more sensitive than others. These include locations where multiple facilities or pipelines are co-located or where an area can only be serviced by one utility line, facility or transport route.

The most vulnerable periods in the life of a structure are during construction, right after it is built, and as it nears or exceeds it expected operational life. Most of Seattle's larger-scale failures occurred during one of these phases. Many times, visible signs that are present before a failure allow people time to escape. Warning signs are the major reason there were no casualties during the collapse of the Tacoma Narrows Bridge, Husky Stadium, and the I-90 floating bridge.

Seattle's growing population increases its vulnerability to infrastructure failure. Roads and bridges may be degraded faster with the increased volume of traffic. There is also a major construction boom happening across the city, increasing the likelihood of an infrastructure failure occurring during the building phase. In 2018, Seattle had 45 construction cranes, the most of anywhere in the U.S.[472] Seattle has never experienced a disastrous crane collapse, but other urban cities have. In 2006, a 210-foot crane collapsed in the neighboring city of Bellevue, severely damaging an apartment and office building and killing one apartment resident.[473] The collapse caused millions of dollars in building damage, ruptured water and gas mains, and blocked traffic while crews investigated and cleaned up debris. It was agreed that if the crane had collapsed during business hours, many more casualties would have occurred. The cause of failure was associated with a non-standard base construction, leading to more stringent crane-safety laws in the state. Despite new testing and inspection requirements, large cranes that have passed inspections have proceeded to collapse in cities across the U.S. If Seattle's population continues to grow at a similar pace, construction sites and cranes will continue to be erected throughout the city. Downtown is most vulnerable to the potential damages of a crane or building collapse due to its dense network of office, retail, and residential buildings.

8 4.5 Consequences

Infrastructure and structural failures have caused fatalities, injuries, utility outages, and economic losses in Seattle and are expected to do so again.

Many past failures have involved bridges and the water system. Failures are more frequent in systems under construction or in older components. Consequences would be worse if the failure occurs in a heavily used or populated area, and the failed component is co-located with other key infrastructure. Seattle has a lot of infrastructure and will continue to invest in more, creating many potential failure scenarios.

If Seattle were to experience a major structural failure, such as a bridge or crane collapse, or a large sinkhole, there would likely be fatalities and injuries to those in the immediate vicinity. In the past 50 years, the deadliest bridge collapses in the U.S. have caused between 3 and 114 fatalities.[474] If a major road, such as I-5 or SR-99, is damaged or disrupted from the incident, there would be prolonged increases in traffic as vehicles would have to take alternate routes until the road was repaired or cleared. The economic cost of the traffic impacts in the Minneapolis I-35 bridge collapse was an estimated $70 million-dollar reduction in economic output (about 0.01% of the state economic output).[475] Collapsing infrastructure has also disrupted power systems. The Skagit River bridge collapse caused a minor power outage for about 250 customers.[476]

Utility infrastructure failures would likely have fewer casualties, unless it involved a pipeline or steam explosion. Nevertheless, there can be delayed impacts on health from a utility failure. In Flint, Michigan, 12 people died and 90 became ill from legionella bacteria in the municipal water system.[477] Additionally, prolonged power outages have led to deaths from carbon monoxide poisoning. There are also cascading impacts. Water leaks can cause landslides if they are able to saturate slopes, and gas pipe ruptures or failures of waste treatment facilities can lead to hazardous materials incidents.

A break in one of the 42" water mains was chosen as the most likely scenario because Seattle has had large water main breaks in the past, it is critical service and could cause significant 'collateral damage.' A collapse of the I-5 Ship Canal Bridge was chosen as the maximum-credible scenario because it is the most heavily trafficked stretch of road in the city and would have many immediate and prolonged impacts.

8 4.6 Conclusions

Seattle's growing population will put greater demands on infrastructure systems that were built decades ago with lower-capacity designs. Updating or replacing these systems requires huge investments and will happen slowly. In the meantime, old infrastructure has the potential to fail catastrophically. There were over 450 bridge collapses in the U.S. between 1989 and 2000. The average age of these bridges was 53 years.[478] Even if Seattle were able to update all of its infrastructure, the boom in new structures and infrastructure make the city vulnerable to design flaws, construction errors, and accidents.

Single site or structure failures have been shown to cause high numbers of casualties but have a limited geographic scope, such as the collapse of a pedestrian bridge in a Hyatt Regency hotel in Kansas City, Missouri, that killed 114 people.[479] Single failures can usually be contained relatively easily, and recovery tends to be quick and comprehensive, unless the failed infrastructure plays an essential part to the cities functioning, like a major interstate. On the other hand, infrastructure failures can have less severe impacts that are felt on a broader geographic scope. For example, a dam failure could flood communities many miles downstream from the dam.