Lessons from Loma Prieta

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The National Earthquake Information Center estimates approximately thirty-five earthquakes occur around the world every day; of these, two to three moderately large earthquakes occur in California each year (“A whole lotta shakin’ goin’ on”, 2015). With such a history of devastating earthquakes, California engineers must work tirelessly with legislators to develop, approve, and implement new structural design and safety features in an attempt to minimize earthquake damage. However, the time between discovery and implementation of new techniques can be lethal. On October 17th, 1989, the Loma Prieta earthquake proved this when it took the lives of thirty-five people who were driving along the lower deck of the Cypress Street viaduct in Oakland, California. The ensuing analysis of this event proves that even the most meticulous engineers have difficulty prioritizing when faced with the difficulty of planning for the safety of a large city.

Figure 1. Construction of a test section of the Cypress Street Viaduct: the two bridge decks are supported by concrete columns attached to one another at the first deck level (Merport, 2007).

Construction on the Cypress Street viaduct (see Figure 1) was completed in 1957, with engineers meeting the most up-to-date earthquake safety criteria of the time. Unfortunately, earthquake standards changed dramatically after a devastating earthquake in 1971 caused the collapse of five California bridges. Such major damage prompted a re-evaluation of bridge and other column designs, culminating with a three-step reinforcement procedure for all structures built before 1971, including the Cypress Street viaduct. Phase one of reinforcement involved strengthening the connection between all deck sections, and was seen as both the most important and the cheapest phase to implement (United States, 1990). This work was done on the Cypress Street viaduct in 1977, but phases two and three (involving reinforcing concrete columns in single-column structures and multi-column structures, respectively) had not been completed and were in mere planning stages. The engineers responsible for these reinforcement phases reported that, had they completed the third phase, they would have been able to identify the flaws in the structure of the Cypress Street viaduct that ultimately caused its collapse (United States, 1990).

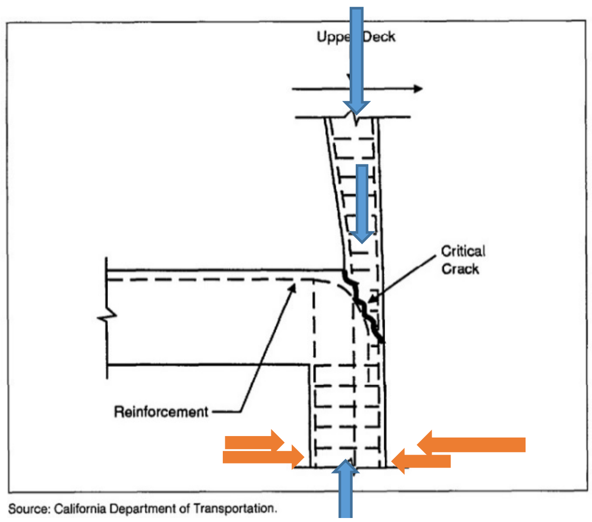

Figure 2. A side view of one column of the viaduct. Forces in blue represent the weight of the deck and the normal force from the ground--these are present in normal conditions. Forces in orange represent abnormal forces that occurred due to the earthquake, which resulted in a shear force along the indicated crack (United States, 1990).

The structure of the Cypress Street viaduct was not particularly elegant—its relatively simple columns and large, five-lane decks were designed for functionality. The upper level was supported by reinforced concrete columns, which were connected to the lower level by four pins. This was more than enough to hold the columns steady under normal conditions. The downward forces, from the weight of the upper deck and the weight of the concrete column itself, are balanced by the upward force of the ground pushing up on the bottom column, or normal force (see Figure 2). The balancing of these forces results in equilibrium, which occurs when the sum of all forces on a body equals zero. Engineers in the California Department of Transportation failed to notice how the structure and connection of these columns resulted in a shear force along the angle in Figure 2. Shear forces, like tension or compression forces, result when two forces oppose each other but do not point directly at one other. If the object in shear can be moved, this results in sliding motion as the forces push past one another. The Cypress street viaduct demonstrated this during the Loma Prieta earthquake as the extreme shaking of the ground put numerous, varying forces all along the base of each column of the viaduct. These forces were amplified by what was known to be very soft ground underneath the structure, worsening the shaking undergone by as much as five times (James, 2006). These forces broke the concrete surrounding the connecting pins between columns, and shook the base column so that it was slightly farther from the upper column. This put the upward and downward forces that had always been present in shear, and they were then strong enough to crack the columns. The columns slid out from under the upper deck, resulting in the collapse of over one mile of the entire viaduct (see Figure 3).

Figure 3. A side view of the collapse viaduct. The cracking from the shear force diagonally between columns can be clearly seen (Wilshire, 1999).

As Henry Petroski stated, “total success can only come if every possible mode of failure is identified and defended against” (Petroski, 1990). In the case of the Cypress Street viaduct, not enough stress was placed on the latter half of this statement. The California Department of Transportation engineers had identified major issues with the structure’s design, but due to time and city budget constraints, very little was done to prevent its failure. The serious ethical questions faced by the engineers and acting officals were most poigniantly made by Robert K. Best, Director of the California Department of Transportation in response to critisicms from the U.S. General Accounting Office (1990):

> In California, the retrofit work to prevent collapse (for user safety) had been completed. The choice facing California, based on what was known prior to the Loma Prieta earthquake, was a choice between investment to provide new services and increased operational safety or investments to protect the services relying on older facilities (p. 28).

While the collapse of the viaduct provides a significant learning opportunity in the field of statics, this quote points out the broader lesson of responsibility both engineers and city officials must retain for past works. The California Department of Transportation made the unethical decision to spend their time and money on other structures, leaving the Cypress Street viaduct (among thousands of other older structures) vulnerable and putting the entire city's population at risk. Their choice to ignore the maintenance of the viaduct does a disservice to the engineers that built it in the first place, because without maintenance, failure of any design is inevitable. An engineer's ethical responsibility for the structures they are a part of does not end once the structure is complete—they are responsible for ensuring its proper maintenance, and for passing this responsibility down to future generations. This is easier said than done, as today's engineers must work through funding issues and input from city leaders when deciding what tasks take priority; however, in the end, it is the duty of every engineer to ensure their concerns are heard by city leaders and given the proper attention they deserve. It is only through better communication with leaders of today and an increased focus on the responsibilities of maintenance that engineers can avoid failures like the Cypress Street viaduct, keeping communities safe while serving them the most effectively.

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