Human Factors in Structural Failures

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While relatively uncommon, structural failures continue to occur, sometimes with catastrophic consequences. Investigations of such failures have typically focused on the physical factors involved, which is understandable given the technical orientation and background of engineers. However, the design, construction, and management of structures always involve physical and human factors, and this broader dynamic *system* is responsible for both the safety and failure of structures. Moreover, because structural behavior is deterministically governed by mechanistic physical laws, with no possibility of physical "mistakes," we can assert that failure of structures – in the sense of not fulfilling human design intentions – is fundamentally due to human factors; i.e., humans falling short in various ways.

The propensity toward failure is determined by the balance of factors that contribute to failure versus safety. The human factors contributing to failure include three categories of primary drivers:

- Pressure from *non-safety goals*, such as achieving functional design, reducing cost, increasing profit, meeting schedules, engaging in competition, building and maintaining relationships, pursuing political objectives, and following personal agendas.
- *Human fallibility and limitations* due to misperception, faulty memory, incompleteness of information, lack of knowledge, unreliability of intuition, inaccuracy of models, cognitive biases operating at a subconscious level, use of heuristic shortcuts, adverse effects of emotions, and fatigue.
- *Complexity*, resulting from multiple interactions of multiple components, which exacerbates the other drivers and can result in nonlinearly large effects from small causes, as well as difficulties in modeling, predicting, and controlling structural behavior.

These primary drivers of failure lead to various types of *human errors* – e.g., slips, lapses, and mistakes – as well as *compromised risk management* due to ignorance, complacency, and overconfidence.

A fundamental human factor that helps prevent failures is *safety culture*, which entails individuals at all levels in organizations placing value on safety, having a humble and vigilant attitude, and conscientiously implementing *best practices*. With respect to general design features, these best practices include conservative safety margins; structural redundancy, robustness, and resilience; and controllable failure modes. Organizational and professional best practices include:

- Sufficient staffing and reasonable schedules.
- Peer review and cross-checking.
- Thorough documentation and effective information-sharing, including allowing dissent, in order to 'connect the dots' on project issues.
- Creating teams who bring in diverse perspectives, while also having effective and continuous leadership.
- Recognizing knowledge limitations, deferring to expertise, and engaging in training.
- Using checklists.
- Careful structural modeling and use of software.
- Meeting professional, ethical, and legal/regulatory standards.
- Learning from failures.
- Promptly and effectively detecting, investigating, and responding to warning signs, including after extreme events and during "quiet periods."

To apply this framework briefly to a case study, consider the failure of the Quebec Bridge in 1907, which collapsed during construction and resulted in 75 fatalities. Drivers of failure for this steel cantilever truss bridge included:

- Excessive cost cutting.
- Schedule pressure due to a substantial financial penalty for delayed completion of construction.
- Cozy and deferential relationships towards an eminent Chief Engineer, Theodore Cooper, who was undercompensated for his services, in poor health, wanted control of the project but never visited the site during construction, displayed considerable hubris, and likely wanted this project to be the crowning achievement of his career.
- Lack of other sufficiently experienced engineers on the project team.
- Inaccurate models for the capacity of built-up compression members.
- Complexities associated with designing and building what was then the longest cantilever bridge in the world, located in a harsh and icy river environment.

Some additional enablers of failure, in terms of not following best practices, included:

- Unconservative safety margins due to excessively high allowable stresses, and not updating an initial dead load assumption that was about 18% too low.
- Lack of meaningful peer review of the design.
- Misinterpreting and denying numerous warning signs during construction, which began more than two months before the failure, such as readily visible and growing bridge member deflections.
- Poor communications among the project team, such as ignoring concerns expressed by laborers.

These factors collectively resulted in poor risk management due to ignorance, complacency, and overconfidence, to the extent of producing a technical and human tragedy.

In summary, structural failures can usually be fundamentally attributed to human factors at both individual and group levels. Understanding these factors requires going beyond identifying "human errors" and assigning blame, in order to also carefully consider the systemic pressures, tradeoffs, complexities, and uncertainties which powerfully influence human decisions and drive a "drift into failure." To deal with these challenges, successful engineers and teams have a shared family of traits, the most central of which is safety culture, which results in a humble and vigilant preoccupation with avoiding failure, as well as implementation of best practices. By doing our part in exhibiting these traits, all of us involved in structural safety can contribute to reducing the occurrence of failures.▪

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