Failure and Ethics in Engineering: The 2004 Charles de Gaulle Airport Collapse

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In a perfect world, bridges do not collapse, planes do not crash, and buildings do not fall. Our inventions hold as planned and perform as expected, as we achieve success without the bitter taste of failure. And we are fast approaching this sort of perfection – with modern computer-aided technology and other high-level simulation software, today's engineers can more and more readily predict and prevent fatal flaws in design. Therefore, when things do fail in this modern era, we inevitably ask, *why*? Henry Petroski (2003) suggests that "the design of any device, machine, or system is fraught with failure. Indeed, the way engineers achieve success in their designs is by imagining how they might fail" (p. 1). However, it is naïve to neglect the ethical concerns and breaches of protocol that often accompany these failures. Engineers must analyze both these structural and ethical failures in order to learn from them; progress can only be made by learning from these often devastating situations. One such situation arose from the collapse of Terminal 2E in the Charles de Gaulle Airport in France. The roof of this futuristic and sleek terminal collapsed barely a year after its completion due to glaring mistakes and fatal assumptions. The Charles de Gaulle Airport Collapse exemplifies the fact that engineers must prioritize ethics and careful practice above all else, for the consequences of static failures are devastating.

On the morning of Sunday, May 23rd, 2004, a cleaning crew in the Charles de Gaulle Airport noticed that the concrete shell of Terminal 2E was beginning to tear away from its metal supports, scattering concrete dust. Less than two hours later, six of these concrete arcs fully tore away from the lateral walls, collapsing onto the terminal below. An investigation into this accident, fatal to four individuals, revealed that "there was no single fault, but rather a number of causes for the collapse, in a design that had little margins of safety" (Ishak, Chohan, & Ramly, 2007, p. 122). Surprisingly, May 23rd was not the first instance when signs of failure were observed. "Between the beginning of the construction phase and the date of the collapse, many incidents took place" (Kamari, Raphael, & Chateauneuf, 2015, p. 89). After the construction team installed the first rings of the structure, cracks appeared in the columns. Other deformations, creeping, and shrinking of the concrete caused it to weaken and crack. However, these signs were dismissed as not "showing any undue concern" regarding the overall structural integrity (Kamari, et al., 2015, p. 89). The events of the following months proved otherwise.

In order to fully understand how and why the Charles de Gaulle Airport terminal collapsed, we must first understand the design that ultimately led to its failure. From a side view, the terminal itself looks like a "deformed tube which rests on parallel longitudinal beams" (Kamari, et al., 2015, p. 89). This "tube" is composed of a 30 cm-thick concrete shell, which is what initially showed signs of failure in the months leading up to the collapse. The entire structure is surrounded by a translucent, glass-like roof. The space in between the concrete shell and glass roof, which can be seen in the zoomed-in circle of the Figure 1, is composed of an external steel tension truss. A truss is defined as "a framework composed of members joined at their ends to form a rigid structure." (Meriam, 2014, p.171). In the case of the Charles de Gaulle Airport, these "members" are steel supports or beams that are connected, likely by welding, end-to-end to form the circular shape shown in the figure below.

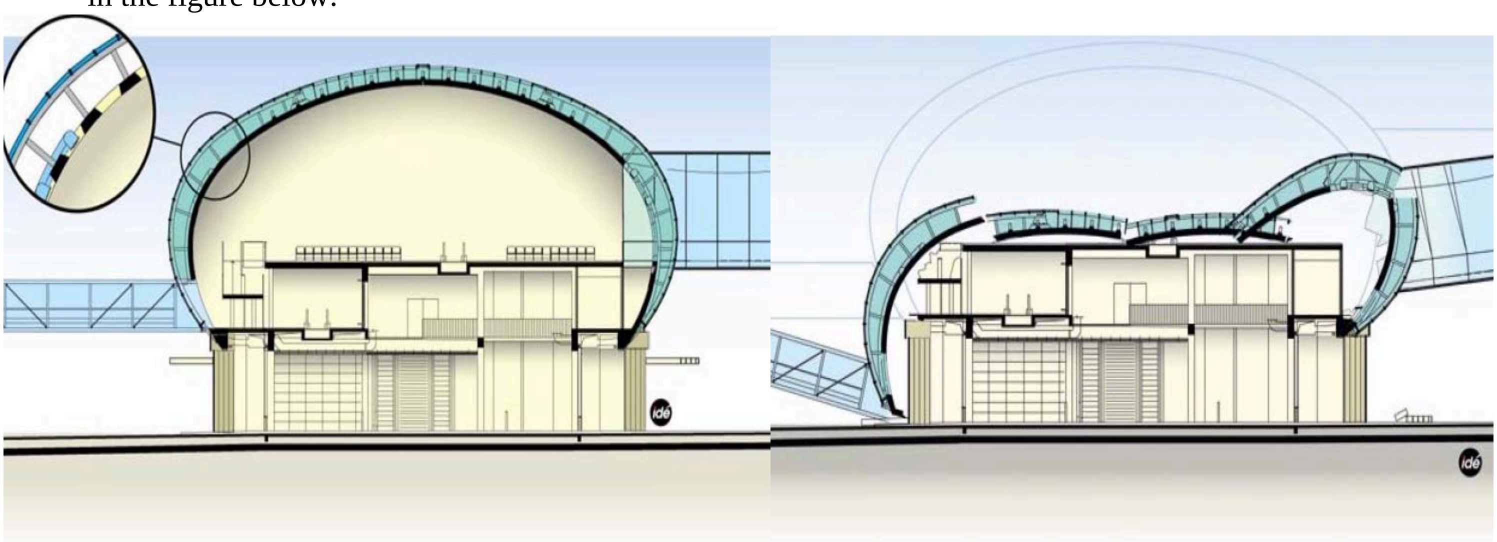

Figure 1. Terminal 2E of the Charles de Gaulle Airport, side view pre- and post- collapse; concrete shell shown as the thick black and yellow band in the zoomed in portion of the figure (Torres 2004).

The outer truss is connected to the concrete shell via struts, or vertical connecting supports that resist compression. Compression occurs when forces push into the strut from either end; in the case of the airport terminal, these forces were the weights of the glass roof and the terminal itself. By design, these struts provided the connectivity that allowed the external truss and the concrete to both support the weight of the terminal. However, it is believed that these struts punctured the concrete, weakening its connection to the struts and external truss, which likely contributed to the collapse of the terminal as shown in the right image of Figure 1.

Initial analyses revealed that although the collapse was a combination of many factors, there were a few key weaknesses that likely initiated the terminal's collapse. First of all, the concrete shell was not strong enough, causing it to be significantly weakened under load-bearing conditions. As mentioned before, the metal struts connecting the concrete to the external metal truss pierced through the concrete, causing cracks and openings that led to its eventual failure. It was also discovered that the construction company "had worked as close to the limits as possible, so as to reduce costs" (Kamari, et al., 2015, p. 90). Although this certainly raises ethical concerns, it also raises the concerns of inadequate supports.

All the buildings standing today are in static equilibrium – the forces acting on the structure, such as gravity, are entirely balanced so the structure stays in place. To achieve this balance, supports must be added to compensate for other forces; these are called statically determinate structures, where only the amount of supports necessary to achieve equilibrium are added. However, statically determinate structures are a major risk because if one support fails, the whole structure could fail. Therefore, most structures are built to be statically indeterminate, where there are more supports than needed for equilibrium in order to prevent collapse in case a singular component fails. By working "as close to the limits as possible," the engineers building Terminal 2E may have created a nearly statically determinate structure (Kamari, et al., 2015, p. 90). When small, singular supports failed, the loads from the dead weight of the concrete and the metal frame, along with the weight of the glass roof, could no longer be supported by the structure. As the roof began to collapse and other supports continued to fail, more pressure was put on other supports such as the connecting footbridges, shown in Figure 1. With progressive failure, the loads shifted so much that the induced moment about these footbridges "exceed[ed] by far the shell's resistance" (Kamari, et al., 2015, p. 93). In essence, the weights and forces that were originally balanced moved entirely out of place when other supports began to fail. When these forces moved, the structure became unbalanced, causing it to want to rotate. This tendency to rotate is moment, and the shifting of forces caused it to be induced, or applied, at footbridges that normally did not have a moment. Consequently, the footbridges could not sustain this rotational pull, and they broke free, bringing the roof down with it.

At first glance, the collapse of the Charles de Gaulle Airport terminal seems to be entirely an issue of statics principles. Yet the root of these problems actually resides in an issue of ethics. The architectural firm that built this terminal, Aéroports de Paris (ADP), "is a public establishment in charge of the planning, design and operation of the Paris region airports" (Torres, 2004, p. 2). As the only firm involved in the entire design and construction process, "ADP has always been both judge and jury", with no other organizations available to check their decisions or planning (Torres, 2004, p. 13). Therefore, it is no surprise that ethics were often overlooked in favor of a more prestigious or more cost-efficient design. ADP oversaw everything regarding Terminal 2E, from the planning to the finances to the construction. They had no checks on their power, for no other companies were involved who could step in when corners were being cut. Likely trying to minimize their budget, ADP circumvented important protocols to save money, and no one was the wiser until the day of the collapse. In addition, the leading architect, Paul Andreu, was notorious for wanting to "impose his particular design shapes regardless of costs, risks and efficiency" (Torres, 2004, p. 13). This increased pressure from architects and managers limited the engineers and contractors from being entirely careful and methodical. To meet deadlines, the ethical basis integral to this and any structural project was ignored. In this case, that arrogance and oversight proved to be fatal.

This incident proves, like so many others, that Henry Petroski has a point – engineers have a greater role to play in the process of innovation and failure. Engineers cannot be simple cogs in the machine of invention and design. They must have not only an active role in the creation of a product, but also a presence throughout its implementation as well. The design engineers are the ones who will "know best how it can fail", not the architects, not the managers, not the stakeholders (Petroski, 2003, p. 2). Multiple engineers may have noticed the failures in the construction of the Charles de Gaulle Terminal 2E, yet they failed to voice their concerns and the result was devastating. Current engineers can learn from their downfall, moving forward with the knowledge that engineers have a responsibility to act on their intellect, be a voice for their creations, and step up when ethics are being tossed aside. The National Society of Professional Engineers states in first fundamental canon of the Engineering Code of Ethics: "Hold paramount the safety, health, and welfare of the public" (2007). There is no clause that excuses engineers under pressure, time limitations, or financial constraints. No matter the situation, ethics, especially regarding public safety and well-being, must *always* prevail. Although engineers also have a duty to act as faithful agents or trustees to their employers, engineers cannot remain complicit in a breach of ethics.

Yet despite our best efforts, even if all ethical standards have been upheld, some engineering failures are inevitable. In those situations, it is the job of the engineers, the problem solvers, to accept their failures, return to the design and figure out what went wrong. Future mistakes can be prevented with detailed knowledge about the nature of past failures. As Petroski (2003) succinctly stated: "without that knowledge, another fatal accident is inevitable", and failure will not only be an option, it will be the *only* option.

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