Vanities of the BONFIRE

By HENRY PETROSKI

History has been punctuated regularly by colossal structural failures. The final configuration of the bent pyramid, completed almost four millennia ago in Dahshur, is believed to have resulted from its initially being built at the overly ambitious angle of 54 degrees. After a landslide of stone during construction, the builders apparently lowered their sights and changed the top section to a 43-degree incline. The 13th-century collapse of the cathedral at Beauvais marked the end of an era in Gothic building during which taller and lighter were the watchwords.

In more modern times, the tendency to build ever longer and more slender bridges led to such catastrophic failures as the collapse of the Quebec cantilever bridge during construction in 1907 and of the infamous Tacoma Narrows suspension bridge in 1940, just three months after it was completed. Such tragedies are rooted in two human characteristics: the cultural drive to build ever-bolder structures and the hubris of master builders and engineers in their attempts to do so.

A recent example of the tragic failure of a construction project fully embodied these all-too-human characteristics. Nearly two years ago, on Nov. 18, 1999, the massive pile of logs known as Bonfire collapsed spontaneously at Texas A&M University, taking 12 lives and injuring dozens of other students. In the wake of the tragedy, the university president appointed a special commission to investigate the causes of the accident. That report was issued within six months and provides an insightful look into not only the mechanical causes of such an accident but also the behavioral causes stemming from the interaction—or rather the lack thereof—between the student designers and builders of the structure and the university administration.

TRADITION UNEXAMINED

Rivalries are intense and tradition-laden in Texas, and the one between Texas A&M University and the University of Texas is perhaps the most intense, complex and tradition-laden of all. The annual football game between the Aggies and the Longhorns has traditionally taken place on or around Thanksgiving, the venue naturally alternating between the two campuses. And since 1909 the football game has been preceded in College Station by a bonfire.

The first bonfire consisted of a pile of trash set ablaze and was most likely an *ad hoc* affair. In 1912, lumber intended for the construction of some dormitories was surreptitiously diverted to the bonfire. After 1935, when a farmer's log barn was "acquired" and burned, the bonfire tradition was regulated by the college. The first all-log bonfire was constructed in 1943. At 25-ft. tall, it was a modest structure by later standards. By midcentury, a spliced centerpole was being used to erect stacks of logs over 50 ft. tall. The height of the bonfire continued to grow, reaching almost 110 ft. in 1969. It was at this point that the university (for the college had grown in stature along with its bonfire) restricted the size of the structure to 55 ft. tall and 45 ft. in diameter. At some point, the tradition, the process and the stack of logs itself came to be referred to, without an article, but capitalized, simply as Bonfire.

The manpower (until 1979 women were not involved in Bonfire) needed to bring the cut logs from a site in want of clearing to a towering stack ignited on the eve of the big game has been estimated at 125,000 manhours distributed among about 5,000 workers. In recent years, it has also been estimated that as many as 8,000 logs have been brought to the bonfire site to be wired together into a multi-tiered wedding-cake-like structure built around the center pole.

The entire process usually begins in early October, with the stacking of the logs alone taking as many as three weeks. The structure is topped by an outhouse, referred to as the t.u. (as the Aggies refer to the University of Texas, known to Longhorns as U.T.), tea room or frat house. When the outhouse-topped log stack is complete and ready to be set afire, it is doused with about 700 gallons of diesel fuel. This icing on the cake, as it were, has traditionally been applied by the Texas Engineering Extension Service Fire Training School.

Bonfire has over the years generally proceeded on schedule and according to plan. There have been attempts by rival fans to ignite Bonfire early, including the dropping of fire bombs from an airplane and the planting of explosives, but none was successful. All but two Bonfires were lit by the Aggies as scheduled. In 1963, Bonfire was not ignited at all because of the assassination of President Kennedy. In 1999, of course, Bonfire was not ignited because the structure collapsed while still under construction, on the Thursday before Thanksgiving. By that Sunday, Texas A&M President Ray M. Bowen had announced the establishment of a commission "charged to initiate a review of all aspects of the 1999 Aggie bonfire and to examine evidence developed by other investigations" of the tragedy. The special commission was chaired by Leo Linbeck Jr., a Houston construction executive.

The final report of the special commission was issued on May 2, 2000, and revealed design factors and patterns of behavior on the part of those participating in Bonfire that contributed to the accident. The report shows the structural collapse to be a classic case of design evolution and engineering hubris contributing to what in retrospect appears to have been the all-but-inevitable accident waiting to happen. Bonfire tradition was to build on the successes of past years, but modifications made from year to year negated what could be learned from the experience. The builders took the energy stored in a two-million-pound stack of logs a little too lightly, and they approached the construction problem as if it were actually a piece of cake.

Even before the commission had begun its methodical study of the catastrophic failure, there were theories about the collapse, as there are with any structural accident with so many fatalities and such visibility. Among the prime early suspects was the tall center pole, which was made by splicing two standard utility poles together along an elaborately fashioned lap joint. Bonfire proper may be said to start with the raising of the center pole, which is buried as much as 15 feet in the ground and steadied by guy wires anchored to other, outwardly inclined poles spaced around the perimeter of the construction site.

Bonfire is a 90-year-old tradition at Texas A&M University. The collapse in 1999 killed 12 students and injured many others.

PHOTO COURTESY OF THE BONFIRE SPECIAL COMMISSION.

The use of a center pole was introduced in the mid-1940s, when the configuration of the bonfire stack was conical, like a teepee, a shape achieved simply by leaning logs against the center pole. The height of such an arrangement was limited by the size of the logs used, but in the late 1950s a teepee bonfire could reach a height of 70 ft. Such a height required finding logs as long as 75 ft. to lean against the pile, and it was their scarcity that led in the 1960s to the development of the wedding-cake style of log stack.

The center pole serves not only as a symbolic axis for Bonfire, but also enables the use of block and tackle to assist in raising logs and workers as the stack rises. The 1999 Bonfire stack reached about 45 ft. up the center pole when the accident occurred. Students who witnessed the collapse reported that they noticed the stack begin to shift, then heard a loud crack, followed by the collapse of the incomplete structure.

Some observers interpreted this sequence of events as pointing to the fracture of the center pole as the initiator of the fatal event. However, after a structural analysis, the commission found that "given the enormous weight of the stack, even a perfect center pole could not have played a significant role in providing structural strength." In other words, for all its symbolic function, the center pole did not and could not support the stacks of logs piled around it, and so another cause had to be found.

The soil on which Bonfire was built had also been an early suspect in the collapse. This seemed to provide a credible explanation, given the fact that in 1994, soil softened by rain was identified as the reason that the pile of logs fell over just two weeks before the big football game. However, the fall of 1999 was not as wet as that of 1994 and, as reported by the special commission, "analysis showed the soil to be sufficiently compact and stable and that it could easily support a structure at least twice as heavy."

The guy ropes steadying the center pole were also looked to as possible causes of the collapse, but "all ropes tested were of good quality." Furthermore, "although one of the guy ropes did fail during the collapse, it was not a contributing factor because it broke after the collapse sequence had started."

An incident that occurred a few days before the collapse also came under suspicion. Witnesses reported that one of the cranes used to lift logs into place had hit one of the cross ties fastened to the center pole, breaking off a piece of the tie. However, the commission found that the force which would have accompanied such an impact "could not have materially affected the center pole or contributed to the collapse."

Even a strong wind, an earthquake, ground movement associated with trains passing nearby and sabotage were looked to as possible initiators of the accident, but the commission's analysis could give no credence to such causes. Furthermore, no defects were found in any of the perimeter poles used to anchor the guy wires or in any structural member or piece of equipment used in the construction. In other words, the causes of the collapse were in fact subtle and, according to the commission:

> The engineering analysis of the Bonfire collapse turned out to be much more challenging than originally anticipated. The physical factors ultimately determined to be drivers of the collapse were not obvious to the engineering teams at

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the outset. In fact, it took a number of weeks and considerable effort before the collapse mechanism and sequence were determined.

PHYSICAL FACTORS

Those efforts included the development of a composite design of "the historical Bonfire" and its examination by means of the general-purpose finite element analysis computer program ABAQUS. The computer-based model enabled an engineering team to simulate hypothesized conditions in the ill-fated log stack and to confirm its posited behavior. In the final analysis, the commission found the collapse to be driven by a combination of factors, rather than any single factor, and each of those factors points to a mindset among the university's students and administration characterized by complacency, hubris and a disrespect for the forces of nature.

1) *The bonfire was built on slightly sloping ground.* Although the ground was solid, it was not level, dropping about one ft. from the northwest to the southeast side of the structure, which was on the order of 50 ft. across. This meant that the first tier of logs leaned to the southeast. The upper tiers of logs and the tall center pole they were built around were aligned with the true vertical, however, creating a bent structure not unlike the Tower of Pisa. For a two-million pound tower of logs to be built in this manner is to invite instability, and the structure did in fact collapse downhill to the southeast.

2) *The logs used were more crooked than usual.* In past bonfires, the logs used were very straight and so fit closely together, like uncooked spaghetti held tightly in the fist. The logs used in the fatal Bonfire stack, by being more crooked than usual, allowed numerous gaps to exist among the logs in the lower tiers. This feature might actually have been seen as a plus by the bonfire erectors, since upper tier logs could be inserted into the gaps, thus providing an interconnection between bonfire tiers. In fact, rather than providing a beneficial interconnection, the logs so used proved to be a major contributor to the collapse.

3) *Upper tier logs were wedged between lower tier logs.* The advantage of interconnection became a disadvantage when the second-tier logs were wedged so tightly and so deeply into the tier below that additional outward pressure was created in the foundation stack. Because wedging was used more aggressively in 1999 than in previous bonfires, the lower stack was like an already full pencil holder being stuffed with more and more pencils. In effect, the Bonfire stack was filled to bursting.

4) *The upper tiers of logs were built out farther than in past years.* After Bonfire reached 109 ft. high in 1969, restrictions were imposed on the height and width of the stack of logs. However, the width restriction of 45 ft. was interpreted to apply only to the base of the stack and to place no restrictions on higher levels. In order that Bonfire contain as many logs as possible, the 1999 structure was being constructed with wider upper stacks. Like a skyscraper built without regard for setback restrictions, the bonfire had a larger than anticipated volume and therefore bore down with a greater weight on its lower levels. This additional weight caused the wedged logs to be driven even deeper into the tiers below and created still further outward pressure on the ground-level logs in the bonfire.

5) *Steel cables were not wrapped around the lowest logs.* In past bonfires, the lowest tier of logs was held together by steel cables wrapped around the outside of the entire bundle. However, there had been some disappointment in recent years that bonfires were burning too quickly, and this was attributed by some students to the use of the cables. For this and other reasons, steel cables were not used in the fatal Bonfire stack, perhaps in part because it was thought, incorrectly, that the effects of some of the other modifications, like wedging, were mitigating. In effect, the ground-level stack of logs was constructed like a barrel without barrel hoops, leaving the staves free to expand under the pressure of the barrel's contents. The collapse does indeed appear to have been triggered by this bursting of the bottom tier, with the falling stack bringing the center pole and the unfortunate students down with it.

BEHAVIORAL FACTORS

As important as it is to understand the role that physical factors play in the collapse of a structure of the magnitude of Bonfire, human factors must also be understood to grasp fully why decisions that in retrospect so adversely affected safety were made in the first place. The special commission called these behavioral factors and considered them in detail, using a "behavioral cause analysis" that relied heavily on the idea of identifying what are metaphorically described as "holes in barriers." According to the team responsible for the behavioral analysis:

> Today, few catastrophic events are caused by simple human error. Modern systems have defense-in-depth in the form of multiple barriers to prevent events. Examples of these barriers include training, procedures, inspections and reviews. So now when a significant event is experienced, there is virtual certainty that several causes acted together to both trigger the event sequence and to fail all of the barriers provided to prevent the event.

As a result of their use of "barrier analysis as a method of cause analysis," the behavioral-science team identified four "root causes" of the bonfire collapse:

1) *Bonfire was designed without adequate engineering analysis.* Decisions regarding the design of Bonfire were made by the Red Pots, a group of nine juniors and nine seniors so named because of the color of the helmets they wear. The Red Pots, although not experienced structural engineers, were allowed to make crucial decisions regarding size, wedging practices, steel cable use and the like for a structure of major proportions. As long as Bonfire took the form of a relatively simple and stable teepee design, the decisions of the Red Pots were not so crucial. However, with the introduction of the wedding-cake configuration, the structural behavior of Bonfire became more complex and nonintuitive. The conventional wisdom among Bonfire enthusiasts was that the structure was safe because it had worked successfully for many years, even though it was being modified from year to year.

2) *Crucial details of Bonfire design were not documented.* The accident investigators could find no evidence that "critical design attributes" which ensured adequate safety margins were documented in drawings, specifications or procedures. Although the Red Pots appeared to have allowed only what were considered small and insignificant changes from a "historically proven design," in fact the cumulative effect of these changes led to a design that was not historically proven.

3) *The university did not acknowledge the magnitude of the danger.* The behavioral scientists call the "organizational equivalent of tunnel vision" cultural bias, and the bias of the Texas A&M culture was to not recognize that "the Bonfire structure had grown too large to be constructed using past practices." Even though Texas A&M is an institution known for its technical prowess, engineering and construction-sciences faculty members were not especially involved with Bonfire. Those few specialist faculty members who were involved "focused on improving the structure to extend the time the fire burned before collapse of the structure. They did not interpret the performance problems as symptoms of structural instability."

As further evidence of the institution's hands-off approach to Bonfire, the structure's height routinely exceeded the administration's 55-ft. height limit, which was imposed to lower the risk of the fire spreading to nearby buildings. When concerns continued to arise about this danger, rather than enforcing strict size limitations on Bonfire, it was moved to the Polo Field, the site of the fatal accident.

Though various concerns over Bonfire arose over the years, the question of structural design or stability never appears to have been studied by the administration or anyone else. According to the special commission, "No credible person ever suggested to TAMU administration that the Bonfire structure was unsafe. However, evidence suggests that TAMU administration and staff should have recognized several precursor events as indications that the structure had small safety margins."

Among these events were the structural collapses in 1957 and 1994 and the "steady decrease in time of burn before collapse to an approximate mean of 30 minutes for years 1995-1998." In response to the last indication, structural changes were made to increase burn time, apparently without regard to "structural integrity during construction." Through a naive logic incomprehensible to a structural engineer, it was to increase burn time that the steel cables were left off the lower stacks of the 1999 Bonfire. According to one student speaking of Bonfire, "From the outside you can't understand it, and from the inside you can't explain it."

4) *Student organizations did not heed warnings that Bonfire was unsafe.* There was clear evidence that Bonfire was not supervised by the students themselves as well as should have been expected. Among the evidence were the facts that injury rates were several times what they are in the construction and forestry industries; that injury rates demonstrated a steadily increasing trend; that fatalities had occurred; that falls from the bonfire stack occurred repeatedly; that hazing and harassment happened, even though forbidden; and that there were alcohol-related incidents that compromised safety.

In the end, the behavioral failure analysis found no specific individuals to blame for the fatal accident. According to the report:

> The 1999 Bonfire Structure Collapse is neither a 1999 problem nor a 1999 Red Pot problem. The 1999 Bonfire Structure Collapse is a classic example of an organizational accident with failure causes that existed for many years before the event. No one person in Bonfire performed at such a substandard level as to directly cause the collapse. . . .
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> For modern era TAMU administrations, Bonfire was and is an institution. Leaders generally do not change institutions unless there is a perceived need for change, and in this case no one noticed the mounting risk.
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> Bonfire grew. Bonfire grew in size (from a trash fire to a structure), grew in complexity (from a single-tiered cone to a multi-tiered wedding cake), grew in the number of people . . . and grew in the number of problems. Most relevant to the 1999 collapse, the structure grew from a simple one that could be "designed" and constructed by students to a complex and risk-significant one that could not. Red Pots continued to maintain the design of a complex structure

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through an oral tradition. As a result, Bonfire was never built the same way twice even though the accepted basis for safe design was 'we have always done it this way and it always worked.'

TRADITION TO A FAULT

Ironically, the strong tradition of Bonfire at Texas A&M, which could have been the source of a long institutional memory about the dangers and pitfalls associated with such a major structural undertaking, was in fact an impediment to safe practice. Rather than encouraging the sharing of an institutional memory that might have prevented the fatal accident, the tradition had developed into a separation of the mind from the body. What had evolved into such a strong tradition on the surface had, in fact, devolved into an almost traditionless and *ad hoc* practice when it came to the crucial structural details of Bonfire. It was as if an engineering office had maintained the appearance of order by presenting its plans in carefully color-coordinated reports with eye-catching logos but had given its engineering interns free rein to devise their own plans and carry out their own calculations, all of which were accepted without being challenged or inspected.

In reading the report of the special commission, the divide between the students and the administration—between what should have been the junior and senior partners in the undertaking—is striking. Apparently the long-standing overall success of Bonfire, in which the overwhelming majority of the extended Texas A&M community took great pride, had made all the participants overconfident and suppressed the legitimate concerns of the few naysayers.

Seven months after the accident and six weeks after the release of the investigative report, university president Bowen announced that Bonfire would be suspended for at least two years. This hiatus would allow planning to proceed for a scaled-down and tightly supervised event, which could resume as early as the fall of 2002. In the meantime, a new university committee will work on reorganizing Bonfire.

Among the changes that have already been decided on by the Texas A&M administration is the length of the activity in the future. Students will no longer cut down the trees used, which had taken as long as three months, thus reducing the time they spend on Bonfire to about two weeks. The design of the tower will revert to the teepee shape, and its size will be reduced and enforced, thus also addressing the concerns that had been growing in recent years over the environmental waste represented in burning so many trees.

Finally, professional engineers will work on the structural design of the log structure and will prescribe its construction sequence. This anticipates any rulings of the Texas Board of Professional Engineers, which is continuing to investigate the implications of the 1999 failure. (The Texas Engineering Practice Act requires that professional engineers be involved in the design of and supervise the construction of major structures involving public health, welfare or safety. The Board of Professional Engineers continues to look into the implications of the act for Bonfire. The interpretation of the governing law appears to revolve around the question of whether Bonfire is a "public work.")

If the Texas A&M Bonfire had not collapsed last year and had been allowed to continue in the *laissez-faire* manner of the 1990s, some future Bonfire likely would have led to a tragedy that demanded a reassessment of the practice. The virtually unregulated evolution of the design of such a massive structure was a prescription for disaster. It is human nature, of which students especially have a great deal, to build on past successes with a bravado that so often can only be checked by tragedy. Had anyone pointed out before the fact the dangers of the individual acts of abandon identified after the fact, they would have no doubt been scoffed at, for Bonfire had been such a successful tradition. Unfortunately, it was a tradition carried forward without conservatism. In that regard, the 1999 Bonfire collapse repeats the pattern of a great number of other colossal failures that have plagued amateur and professional builders alike throughout history. ■

In response to the commission's findings, Texas A&M formed a steering committee to coordinate the university's effort to develop and plan Bonfire 2002 consistent with the Bonfire Commission Report and President Bowen's directives. That committee is made up of several task forces, including one for safety, one for risk management, and one for design and construction. Following are some of these groups' key responsibilities.

Safety Task Force

- **Develop a safety plan to address design, training and construction issues consistent with the commission report and President Bowen's directives.**
- **Develop a plan for independent expert review to determine viability of the safety plan.**
- **Develop an evaluation and certification process for each succeeding Bonfire.**

Risk Management Task Force

- **Develop a risk management plan to address Bonfire risk issues.**
- **Develop a plan for independent review to determine the viability of the plan.**
- **Develop recommendations for the improvement of risk management of other student organization activities.**

Design & Construction Task Force

- **Identify all design and construction issues that must be addressed in the design, training for and construction of Bonfire 2002.**
- **Solicit expert bids for the professional design and construction oversight of Bonfire 2002.**

REFERENCES

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