History Repeats Itself

Building the City Destroyer

By Jennifer Prichard, E.I.

What lies beneath the glass and brick architectural façade of a building is seldom seen. The steel and concrete structural skeletons often go unnoticed, as do the structural engineers that design them. As structural engineers, we generally carry out our responsibilities behind the scenes, and out of the spotlight and the public eye. It is usually the architects that bask in the limelight and are interviewed for their contributions to the overall aesthetic appeal of their designs. In addition, how often are engineers thought of as people drive on our country's never-ending network of roads and bridges? Unfortunately, our profession is all too often unnoticed by a surprising number of people, regardless of age group. While some engineers might not think much about it, I personally enjoy participating in any event which could help spread the word about our fine profession.

In local communities, there are events such as Engineer-for-a-Day, volunteering with Mathcounts, or with Odyssey of the Mind. These engineering events are prime examples of ways that structural engineers can interact and, in turn, help better inform people of what we do. While some involvement efforts are local, others include experiences that take this to the extreme. I was fortunate to be able to participate in just such an experience.

In April 2004, I had the chance to take part in a truly unique project, *Superweapons of the Ancient World*, a documentary reality series filmed in Essouira, Morocco, on the northwest coast of Africa (*Figure 1*). It has aired on both the Discovery Channel and the Science Channel in the last year. As I found out, we as engineers can be just as uninformed when we look at where our profession came from. How did engineering come about and who performed the analysis on structures 2000 years ago?

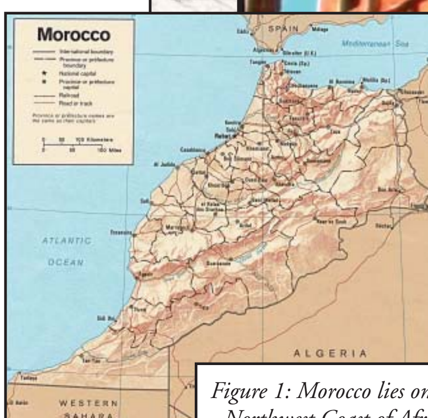

Figure 1: Morocco lies on the Northwest Coast of Africa

Background

In late 2003, Darlow Smithson Productions went on a worldwide search for teams of welders, blacksmiths, timber framers, riggers, and - last but not least - engineers. After a lengthy interview process, I was one of the lucky applicants selected for the show. There would be three one-hour episodes to air. Each episode would challenge a team to rebuild an ancient superweapon that set the standard in warfare 2000 years ago. One weapon would be a Battering Ram (*Figure 2*), one an Archimedes's Claw, and one a Siege Tower. I was selected to be on the Siege Tower team, or the *City Destroyer* team as it was called on the show. As a structural engineer, my role in the project focused on Timber/Structural Design, Drafting, and Project Management.

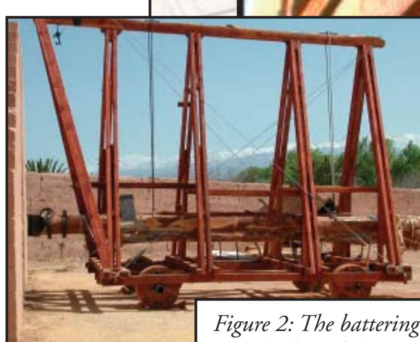

Figure 2: The battering ram was the first of three projects to be filmed for the series

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Materials		
Type	**Eucaluptus**	**Pine**
Density	60 pcf	25 pcf
Bending Strength	Fb = 9900 psi	Fb = 800 psi
Compressive Strength	Fc = 5200 psi	Fc = 350 psi
Properties	Heavy, strong	Light, weak

Figure 3: These properties from '97 NDS and "Some Investigation on the Mechanical Properties of Eucalyptus Camaldulensis Dehn Wood" were used in the design

The use of a siege tower was first recorded in the Battle of Motya in 394 B.C. Dionysius I led his Greek army, consisting of tens of thousands of men, from Syracuse on the east coast of the island of Sicily. Motya, an island off of the west coast of Sicily, was once the homeland of Dionysius I. However, Motya was taken over by Carthaginians and Dionysius I was determined to get it back. Dionysius I gathered all of his leading mathematicians, scientists, and inventors to create the most powerful weapons of the day. While we may take brainstorming for granted, it was Dionysius I who strategically used it to his advantage. This brainstorming session not only brought about the creation of the first high-powered catapult and belly bow, but also the first siege tower.

Figure 4: The carriage portion was the lowest 12 feet of the tower and was constructed with classical joinery

In general, the siege tower was created to attack a walled city, such as Motya. Cities with a surrounding wall would usually have the height advantage when under attack, and the wall served as the main defense. The siege tower took away the height advantage by having an attack floor above the wall height. This attack floor would provide a place from which the attackers could fire to clear enemies off the city wall below. The siege tower also had a floor at the height of the wall that was equipped with a draw bridge. Once the wall was clear, the attackers could lower the drawbridge, storm the wall, and overtake the city. With animal hides covering its exterior, the tower also provided protection to most of the army until they crossed the drawbridge. On the attack floor, the attackers could also mount weapons. As an armored mobile vehicle, the siege tower effectively became the first tank.

Logistics

While Dionysius I had an army and a lengthy amount of time, our team had four members and seven build days. Besides myself, the other team members were Larry Shanes, a mechanical engineering senior at University of North Carolina in Charlotte; Al Cobb, an insulated panel company owner and timber framer; and Jordan Finch, a furniture builder and timber framer as well.

For the construction of our siege tower, we were allowed to use some modern tools. We constructed the tower using ancient joinery methods on some portions but, due to time constraints, we were allowed to use more modern methods and materials such as welding, threaded rod and angle iron. The materials we would use were local to the region and might have been similar to the materials used by the ancient Greeks. We had eucalyptus and pine available at our site. Although we submitted a preliminary bill of materials before we arrived onsite, the list would have to be finalized before any construction could begin.

Before the team met, we corresponded through email and selected a preliminary design to use until we arrived onsite. Using this estimate, a basic StaadPro model gave me generalized forces throughout the tower. I also used estimated material strengths (*Figure 3*) in Enercalc to check some member sizes, but had to perform old-fashioned hand calculations during the build in Morocco. During construction, I checked members as changes occurred and performed a wind analysis to assure the other team members that the tower would not blow over.

Wheels and Carriage

Construction started with the wheels. Being the last team in the series had its advantages. We used Dionysius' brainstorming strategy and consulted with the battering ram team. Although their ram weighed between five and six tons and their wheels were only 20-inches in diameter and eight inches thick, we learned that they had bearing problems with their wheel design. Larry and Al developed an original design to eliminate any bearing problems, as our weapon was two times heavier than the ram and our wheels would be twice as large. We constructed them by stacking five layers of four-inch-thick planks of both eucalyptus and pine. We rotated each layer 45 degrees to change the direction of the grain to eliminate any bearing problems. By using through bolts and steel plates across the face of the wheel, and steel rings around the circumference, our wheel design held the weight of our tower without so much as a creak. The final specifications on our wheels were 48 inches in diameter, 20 inches thick, and approximately 1000 lbs each.

Figure 5: Both the wheel and the mortice and tenon joints used techniques that are rare today

Once the wheels were complete, the team moved on to the carriage portion of the tower, which comprised the lowest 12 feet of the structure (*Figure 4*). Because eucalyptus is stronger and more dense than pine, we constructed the entire carriage using this material. The higher strength was important because the loads from the upper floors would be carried down to these members. The density of eucalyptus also gave us an advantage by shifting the center of gravity lower. We used mortise and tenon joints on portions of the carriage, and tied the joints together by driving hot stakes through them. *Figure 5* shows both the details of a completed wheel, as well as a classical mortise and tenon joint.

Upper Floors

The second and third floors began with a tilt-up wall for each side. We lifted these into place (*Figure 6*), and connected them with temporary members. Once we had raised both walls, we could frame them together. Comparing the ancient joinery methods used for constructing the carriage with the more modern tilt-up technique for the upper floors, the faster way was obvious. It took five of the seven build days to complete the wheels and the carriage. We constructed and assembled the upper floor walls in less than one day. The third floor would serve as our drawbridge floor. After temporary flooring was in place, we stick-framed the fourth and uppermost floor together. This attack floor was 36 feet off the ground. This gave our team the desired height advantage over the "enemy" on the 28-feet-tall wall that we were planning to attack.

The final step for completing the tower was adding ramps between floors. We first thought that ladders would be the easiest way to reach the drawbridge and attack floors of the tower. However, when thinking of troops carrying armor and trying to move quickly through the tower, a ladder did not seem very logical. Our second thought was to use stairs, but they would be very steep due to our predetermined tower dimensions. We eventually decided to use ramps. They were easy to use, fast to construct, and accessible to more troops, plus we could frame them with stringers for added support.

Figure 6: Modern construction techniques were used to build tilt-up walls for the second and third floors, and to raise them into position

Figure 7: The drawbridge rests on the wall after a successful attack

Conclusion

On our last build day, we climbed to the top of our tower. Camels acted as an engine as our siege tower rolled towards the wall. Water balloons rained down on the wall as hired locals retaliated by throwing tomatoes and avocados at us. Under the protection of the tower, we had no fear and easily made our way across the drawbridge to overtake the wall. *Figure 7* shows the tower at the wall after our attack.

By experiencing what engineering might have been like 2000 years ago, I learned that we should feel privileged to have the technology that we do. Today we can take advantage of a college education, computer modeling software, and textbooks. It has taken centuries to define structural engineering as a profession, and to develop the tools and equipment we depend on today. Although some may take for granted what we now have, I know that I, as a structural engineer, have found a whole new appreciation of its origin. I am proud to be an engineer and will continue to share my knowledge with anyone who stands to benefit from it — even if it takes me back 2000 years.▪

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