Maji for Masaera

REHABILITATION OF A MAN-MADE IRRIGATION CANAL

Abstract

For the past four years, about 40 students from our Engineers Without Borders (EWB) chapter have worked with the village of Masaera-Kilema in northern Tanzania to both repair a deteriorating canal and to educate the villagers about the importance of water sanitation and canal maintenance. Last year, five civil engineering, two mechanical engineering, and two students from other fields designed, with the assistance of our civil engineering faculty (all licensed P.E.s), a faculty member from our college of business, and a practicing P.E. from the regional EWB chapter, a drop box mechanism to absorb energy from water flow. They then travelled to Tanzania and performed assessments of canal bank health, installed the drop box, trained local workers in concrete mixing and repair methods, and brokered a memorandum of understanding (MOU) with the village's water council to ensure future canal maintenance. Their activities not only contributed to eliminating water losses from erosion and infiltration and securing clean and reliable water supply for 2,437 villagers, but also contributed to the villagers' understanding of, and ability to apply, standardized quality construction methods.

1. Background

Four years ago, our student chapter of Engineers Without Borders (EWB) was approached by the water council chairman for the village of Masaera-Kilema in Northern Tanzania for assistance in repairing a dangerously compromised irrigation canal. Its 2,437 inhabitants—mostly farmers—currently have rights to 200 liters of water per second from the Wona River, which flows perennially from the slopes of Mount Kilimanjaro. Approximately 70 years ago, a canal was built by local workers to redirect water to the village for irrigation and domestic consumption. Since then, many leaks and breaches have formed in the canal walls, allowing water to escape back to the river or to illegal farm plots between the canal and the river. During the dry season, this is devastating to crops in Masaera and has begun causing conflict in the lower village. During the rainy season, uncontrollable flows are undercutting the banks and scouring the canal surfaces. The Masaera village council recognized the importance of repair and maintenance and, in conjunction with MAVCODEG, a local community organization, implemented a water council to reach out to EWB.

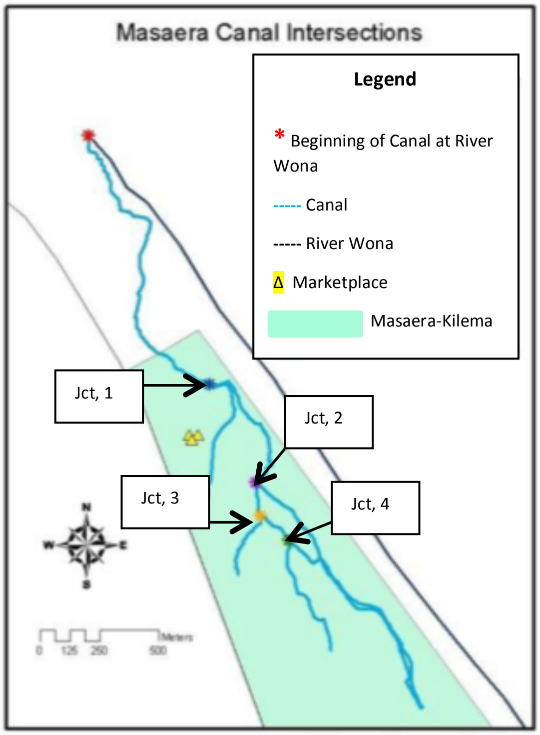

Figure 1: A canal map generated from GIS data. The source at the River Wona is at the top with Junctions numbered 1 through 4 as they occur downstream.

Building on their extensive assessments, analyses (including water velocity measurements, a soil survey, stream modeling using the River Analysis System developed by the Hydrologic Engineering Center in Davis, California [HEC-RAS], and more), and emergency repair work from previous trips, this past May, the student team concentrated on repairing Junction 1 (see Figure 1). Figure 2 shows how a significant change in elevation results in a waterfall of approximately seven feet down the left branch of the junction. This drastic elevation change increases water velocity, promoting quickly expanding erosion, which had already resulted in a large basin on the downhill side of the canal and increased the breach risk. A mechanism to reduce the water flow rate was severely needed (Fig. 2).

Mentored by three civil engineering faculty members, one of whom travelled with the team, one water resources/ hydrology expert from the regional professional chapter of EWB-USA (all licensed P.E.s), and by a faculty adviser from our college of business, this year's student team designed and implemented a "drop box" structure to absorb the energy from the waterfall and nearly eliminate the erosion in the canal at this location, and brokered a long-term post-implementation maintenance agreement with the local water council.

Figure 2: Junction 1 dry showing canal bed erosion (left), then with water flow showing runoff to the right (middle), and with emergency fix (rocks) implemented in 2010 (right).

2. Project Description

Beginning in March 2010, the nine students on the 2011 EWB Team planned and executed a 10-day implementation trip, from its fundraising phase to its final evaluation and reporting.

2.1 Fundraising Phase

During the fundraising phase, they reached out to, and beyond, the campus community through successful grant writing, running a silent auction of donated merchandise at a university basketball game, recruiting matching funds from a major donor, organizing a local "'stache off" event (in which participants raised money to have their mustaches shaved), soliciting individual contributions, and conducting a letter-writing campaign. Exclusive of their own contributions, they raised $34,200 to cover anticipated expenses, from travel to materials and equipment.

2.2 Technical Planning Phase

During this preparation phase, the students diligently reviewed data and reports from three previous assessment trips and regularly communicated with the project stakeholders: their village liaison in Tanzania, four licensed P.E.s (including one professional mentor from the nearest EWB chapter and the local faculty member specializing in reinforced and prestressed concrete structures who would accompany the trip), and especially the student team who had undertaken an assessment trip in the previous year. Having thus obtained a 360-degree view of the problem, they developed four design alternatives:

1. Sloped Channel with Mortared Rocks
2. Perforated Water Drum
3. Drop-off with Rock System
4. Drop Box

In the evaluation of alternatives, they created a continuous feedback loop with all stakeholders to ensure that the chosen design and the resulting work plan would correctly identify the construction requirements, delineate a feasible project scope, offer a financially and qualitatively appropriate engineering solution, ensure materials could be easily procured, and establish an interculturally viable mindset of project collaboration. Based on these criteria, Alternative 4, installing a concrete drop box to reduce the water flow rate, emerged as the preferred solution and informed the main trip objectives:

- Construct a drop-box structure at Junction 1 with an adjustable steel gate
- Assess work performed in the previous year at two other junctions, breached areas, and the source
- Teach the community how to build mortar walls to prevent infiltration and erosion
- Meet with the Masaera Village Water Council to sign a memorandum of understanding (MOU) and encourage maintenance and repair of the canal

Rather than executing the entire construction plan themselves, the students decided to take a demonstrate-and-supervise approach, not only because it offers a training opportunity for local workers, but also because including the villagers in the effort promotes a sense of local ownership—both of which are instrumental for the capability and willingness of the locals to continue erosion abatement by themselves once the EWB team left. To implement a locally administered accountability structure and impress the importance of ongoing canal maintenance, the students also decided to meet with the local water council, to jointly develop a canal operation and maintenance plan, and to tie this plan to a mutually signed MOU.

2.3 Detail Design Phase

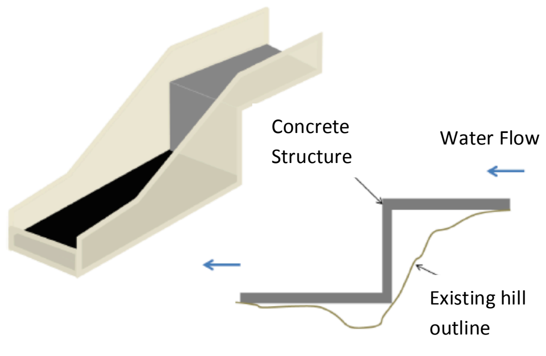

Figure 3: A concept sketch for the concrete drop box to be implemented at Junction 1.

The students designed the structure such that the water approaches the drop box in a 14 ft concrete channel approach. At the end, there is a 3 ft drop onto a 12 ft long concrete slab, such that, once the water falls 7 ft into the concrete box, it is contained by the wing walls to prevent continued erosion of the banks. The box floor extends far enough downstream that, combined with the drop onto concrete, water velocity is sufficiently reduced and the energy contained to prevent further erosion damage. Thus, the channel and the slab walls contain all the water, and a sluice gate installed at the head of the left branch will help control the flow of water in the two branches of the canal.

The only maintenance required in this design, should a failure occur, is to patch the concrete, and, if needed, to pour one or more wear layers at the bottom (shown in black in Fig. 3). The limited-maintenance design also easily ties in with other erosion abatement measures such as undercut backfills with rocks and soil, infiltration sealing, and bank stabilization through mortared walls.

Students performed all project calculations and estimations in collaboration with their faculty and professional P.E. mentors. Stress calculations showed that this design can withstand up to 4,000 kips and handle a water velocity up to 10 ft/s, both of which comfortably exceed the capability needed based on on-location measurement (e.g. float rod trials, etc.) and can withstand significant flood scenarios. Material calculations for the concrete structure were performed using the MicroStation® software, which provides the surface area of the concrete structures when viewed from a plan view. To plan mobilization logistics, the students used delivery vehicle information to calculate the needed crushed-stone backfill and coarse aggregate down to the required number of truckloads, making sure to include a sufficient overestimate to address any unknown erosion issues. All this information, including detailed cost estimates and a work schedule, was included in a professional project plan.

2.4 Implementation Phase

Once on the ground, all needed supplies, tools, and materials were purchased locally and an initial survey of Junction 1 was conducted. The students then split into two teams: an implementation ("Junction 1") team consisting of five students plus mentor was put in charge of building the drop box; an assessment team consisting of four students and a hydrology expert focused on identifying, during a canal walkdown, sites needing immediate erosion mitigation and on engaging the community in dialogue about erosion repair methods and ongoing maintenance requirements. Each morning, both teams met with the villagers to assign to each team local translators, guides, and assistants/trainees for the day. Each evening, both teams met with their mentors to review and evaluate daily progress. Whenever a concrete placement was underway, the assessment team assisted with construction activities.

Junction 1 Team

Figure 4: Villagers and EWB students tie the rebar for the drop box.

The Junction 1 team and their local collaborators spent the first workday excavating soil and stone, grading and backfilling the drop-box floor, and forming the drop-box slab. They also cut and assembled reinforcing steel structures for the drop box. On the second workday, they finished the rebar for the wall and slab tie-ins, dug toe walls, and installed the rebar properly. In addition, they completed the formwork for the drop box, placed the concrete, and finished the slab. The following day, the team worked on the rebar cage for the drop box and the channel, constructed the exterior base formwork, and also backfilled the channel with aggregate. On their fourth workday, they finished the rebar cage for the channel slab and the formwork for the drop-box back wall. They also placed concrete for the back wall and in the floor of the channel, so that all walls of the drop box were finished the following day, which included finishing the formwork and placing the concrete. The next day, the formwork for the channel walls at the beginning of Junction 1 was assembled, the concrete placed, and the previously painted steel gate installed between the walls to complete the work at this site.

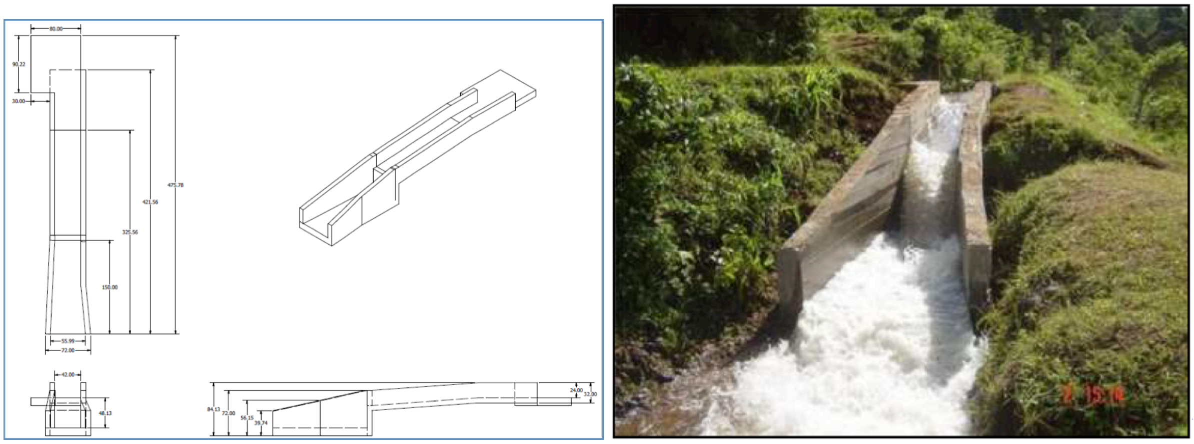

Figure 5: Drawing of the final implementation at Junction 1 (left). Water flows through the new drop box (right).

The drop-box construction came in one day under schedule although the students had to navigate logistical complexities: The concrete had to be transported via a bucket line, and all ingredients hand-carried to the work site. This required extensive coordination of concrete batching and mixing in order to prevent cold joints in the structure and close monitoring of supplies, so that lack of material would not interrupt a placement. Each night, unused supplies had to be secured to prevent theft, so that stockpiling material on-site was not possible.

In addition, the students discovered that the local workers' batching method for mixing concrete produces qualitatively inconsistent outcomes. In response, they showed the villagers how to improve quality and consistency by mixing the material dry, then adding the correct amount of water and mixing the entire batch before placing any concrete. The end result was consistent, good-quality concrete and a set of trained local workers who will implement this change in local construction methods.

Erosion Assessment Team

The assessment team, together with its professional mentor and representatives from the water council, began its work by inspecting the canal structures and documenting the worst erosion sites. They discovered an area of about 60 feet at the beginning of the canal where the escaping water had already undercut the canal by as much as one foot below the canal bed, increasing the risk of structural failure—a costly issue that could have been prevented with proper maintenance (Fig. 6). The same problem was discovered at other sites, as well, increasing the risk of total canal breach and resulting irrigation system shutdown. Since the urgently needed repairs were outside the scope of this trip, but well within the villagers' expertise, the students prepared step-by-step instructions with drawings illustrating how to execute the process and left these with the water council. These instructions became the basis for the village's Canal Operation, Maintenance, and Repair Manual.

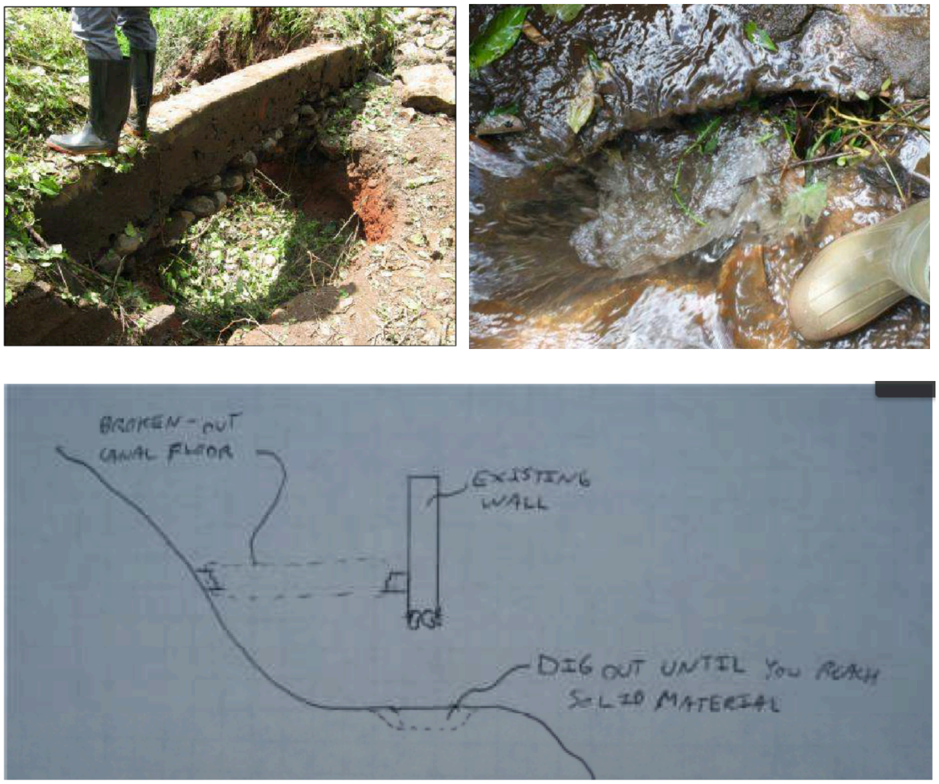

Figure 6: Hole in canal floor and canal wall (top left). Water rushes out through canal floor (top right). Example of drawing left with Water Council (bottom).

As part of their outreach activities, the team surveyed the residents living downstream of the canal about how and when they usually receive their water in order to determine where the water flow stops. They also brokered an MOU with the local water council to ensure that maintenance activities would continue after the team left and visited Mandaka Primary School, where, using nothing but modeling clay and water, they led a fun session for students and teachers on the importance of canals.

3. Collaboration of faculty, students, and licensed professional engineers

On this trip, the EWB student chapter worked with both licensed and non-licensed professional engineers. During the design phase, students worked with three faculty members from our civil engineering department (all licensed P.E.s), who supplied their expertise in various facets of structural, architectural, and concrete-mix design. One of these faculty members travelled with the students for ad hoc on-site support, as did a representative from the regional EWB chapter (another licensed P.E.), who contributed his expertise in hydrology and canal design. All of the team members collaborated successfully with the local, mostly practically schooled, workers and provided training in structural matters and concrete mix design.

4. Benefit to public health, safety, and welfare

The objectives of this project were twofold: On the technical side, students designed and installed a drop-box mechanism to combat the significant erosion at Junction 1 of the canal, thereby reducing an immediate canal breach risk. More than that, though, students also identified sites needing future repair; led village leadership to commit to long-term maintenance; and educated the entire village about the importance, and the process, of maintaining, repairing, and operating the canal effectively and efficiently by demonstrating the most common repairs. In addition, the student team will continue to work with the water council on the completion of a Canal Operation, Maintenance and Repair Manual. Thus, the humanitarian benefit that a more reliable source of water for field irrigation and domestic usage delivers, extends beyond the currently 2,437 villagers to future generations.

5. Multidiscipline and/or allied profession participation

Our EWB chapter is a multidisciplinary organization made up of students from the college of arts and science, college of business, college of engineering, and college of nursing, with supporting faculty from all these disciplines and subdisciplines committed to improving the lives of Masaerans. This allows the students to work with communities on comprehensive projects and produce sustainable solutions—the cornerstone to successful service projects.

6. Knowledge or skills gained

From its inception, the Masaera project has provided at least 40 engineering students with an immediate practical experience in the management and execution of international humanitarian engineering projects—and, through project presentations, engineering design reviews, and other activities, impacted the education of several student cohorts in, and beyond, our college of engineering. Among the most valuable lessons learned during the most recent trip, the students listed the following:

- Sustainable construction methods—Students learned how to use locally available materials and respectfully critique local manufacturing methods in order to improve performance and durability in construction outcomes. For example, the high price of plywood made it necessary to switch to the less expensive lumber for the construction of pouring forms. In addition, students learned how to adjust an industrial concrete mixing process to the complexities of a simple bucket line.
- Logistics planning—Students discovered the need to implement, on future trips, a logistics tracking system in order to ensure that needed tools and materials were available as planned, that any missing supplies can be tracked immediately, and that any needed purchases of consumables can be made in time.
- Concrete estimation—Students realized after a few placements that the actual concrete volume from a batch was lower and produced thicker and higher walls than originally calculated. To combat concrete loss, they redesigned their method of estimating batch yield and achieved greater fidelity, so that in the end, the number of batches required was one fewer than estimated.
- Language barrier—When students noticed that the majority of their translators (i.e. English to Swahili) were unable to convey some of the technical information as accurately as needed, they decided to raise additional funds for their 2012 follow-on trip to hire a professional interpreter.

Along with gaining experience in a real-life setting, the students have learned first-hand how their skills help improve the quality of life and the safety of entire communities.