Water Collection and Management with Earthen Dams

Maji Marwa

CIVILEN AU2022 4011 & SP2023 4012

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Acknowledgements

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Executive Summary

The Village of Marwa in Tanzania faces two water-related challenges. The first is that during the dry season there is a lack of readily available water for domestic and agricultural uses. The second is that during the rainy season there are heavy rain events that lead to flooding that have induced safety risks and have caused property damage. The team's goal is to find a way to mitigate flooding and collect the rainfall runoff during the rainy season and to utilize this excess water in providing a more centralized water supply for the community and their schools.

The team focused on determining the feasibility of creating an earthen dam to fight against these challenges the village faces. We determined that an earthen dam was the best design to focus on for several reasons. The first was the existence of a similar earthen dam being used in the region that was effective. Another reason is that an earthen dam utilizes local materials and is simple to construct as it will not require excessive construction machinery. Finally, the design would be adaptable for other villages to use.

The team utilized rainfall information from previous projects to determine accessible locations in erosion channels that would be the most effective in mitigating flooding and providing localized water access to the community. Key elements and other considerations for the dam design were determined using literature research, informal field testing, and work from previous projects. The final deliverable for the team is a completed earthen dam construction drawing set. This includes a site plan, general notes, plan view, cross sections, and details. Proposed future work would include professional field testing and the actual construction of the earthen dam.

Project Background

The Marwa village is a rural village located in the Ruvu Ward of the Same District in the Kilimanjaro Region of Tanzania. The village is located several kilometers away from its main source of water, the Pangani River. A breakdown of the four sub-villages in relation to the Pangani River and the country of Tanzania is shown in Figures 1 and 2 below. Traditionally, the inhabitants of Marwa led a nomadic lifestyle. They would travel to various regions in different countries during the wet and dry seasons to access water for their animals and domestic use. However, due to pressures from national governments, the community members of Marwa village have established a permanent settlement. During the dry season, the villagers continue to travel great distances outside of the community to access water for their livestock. This results in the children of the village missing school to help their fathers retrieve water during long trips with the cattle, and the women of the village spending much of their day retrieving water for domestic use (Sours, 2019). The Marwa village also experiences localized flooding during the wet season. The floods pose a significant risk to the Marwa school. When the school experiences flooding, it negatively impacts the children's attendance and their learning.

Figure 1: Location of Marwa, Tanzania (123F, 2020)

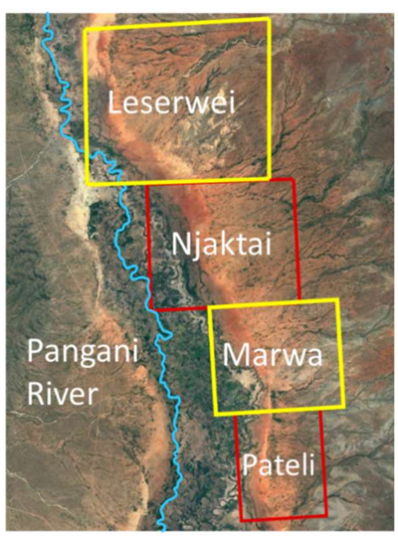

Figure 2: Marwa Sub-Villages (Sours, 2019)

The Marwa schools need a more local source of water for the children and a mechanism to divert flooding away from the buildings. Systems addressing rainwater collection and rainfall runoff have previously been conducted. Rainwater harvesting systems have been implemented throughout Marwa to collect water for the dry season (Sours, 2019). Topographic analysis, rainfall data, and fundamental hydrology have been previously conducted to identify rainfall runoff paths and flood zones. A graph of the average rainfall amount and the timing in the year is in Figure 3 below. The high data points represent the wet season whereas the lower data points represent the dry season.

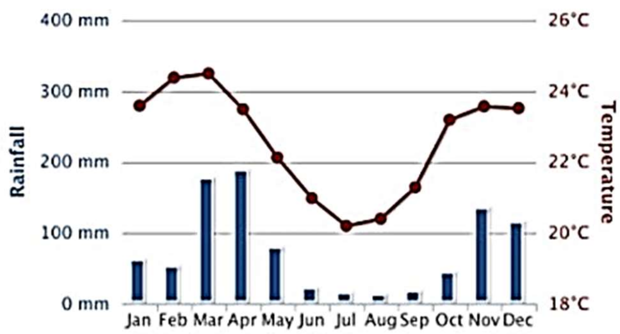

Figure 3: Average Rainfall Data (Sours, 2019)

This project is a continuation of the ongoing Maji Marwa initiative that focuses on addressing the water collection and management systems of the Marwa village. A map of the stakeholders involved, and their corresponding value matrix can be found in Appendices A and B. This map and table identify the differing relationships to the project and the positive and negative impacts an earthen dam can have on the economic, social, environmental, political, and technological aspects of all parties involved. Previous Maji Marwa projects focused primarily on rainfall collection. A hydrology and topographic analysis identifying rainfall runoff paths and flood zones were conducted, but flood mitigation techniques were not addressed. Utilizing the previous rainfall data, the team designed an engineering solution for flood mitigation and water retention systems for the Marwa school and surrounding Marwa community. An earthen dam was determined to be the best engineering design for flood prevention.

The design process for the team started with researching various earthen dam types and combing through previous rainfall runoff data to determine accessible locations for implementation. Discussions with Dr. Pradel and Randall helped the team decipher the best earthen dam types and utilize applicable hydrology calculations and previous analysis. In December 2022, Dr. Hagenburger went to Marwa and collected necessary data for an earthen dam design. Based on Dr. Hagenburger's field information, Dr. Pradel's geotechnical and dam design expertise, and Randall's hydrology knowledge, the team moved forward with creating a full earthen dam design ~~from scratch~~. The design process and consideration for key elements are described in the sections below. The final deliverable for the team was a completed earthen dam construction drawing set.

Proposed future work for this project would be the actual construction of the earthen dam. Professional hydrology and geotechnical testing would need to be completed to determine the area's rainfall data and soil properties. The earthen dam design would need to be updated accordingly as it is based off assumptions from literature and informal field testing. The final design would need to be submitted for professional review and approval before construction can begin.

Design Process

There are multiple constraints and assumptions that have affected the design process of the earthen dam. A significant constraint placed on the team is a lack of visual awareness of the Marwa area. None of the four team members have traveled to Tanzania or the Marwa region at the time of this final report. Thus, the team is limited to photos and videos from course instructors, as well as Google Earth satellite imagery. One impact of this constraint is the struggle of visualizing the placement of our dam. Another constraint in the design process is the labor ability of the Marwa community. The village is limited to physical labor, making the collection and placement of soil more difficult. Other constraints are the experience and skillset of the team. Each team member needed to learn about earthen dams from a position of having no knowledge, and the team had to relearn technical skills such as AutoCAD. The overall design process consisted of literature research and meetings with experts to learn about earthen dams, a hydrology analysis to identify suitable rainfall runoff locations and the amount of water retention for the dam, and the designing of the earthen dam that included schematic drawings and its supporting calculations. Key elements of the dam and other design considerations are outlined in the sections below.

Key Elements

Several key elements have been identified as being essential to the foundation and stability of the design of the earthen dam. Those are the geometries of the dam, slope protection, drainage filters, trench cutoff, and spillway. Decisions made regarding these elements significantly impact the overall success of the dam design. A drawing of a basic dam design introducing the key elements is shown in Figure 4 below.

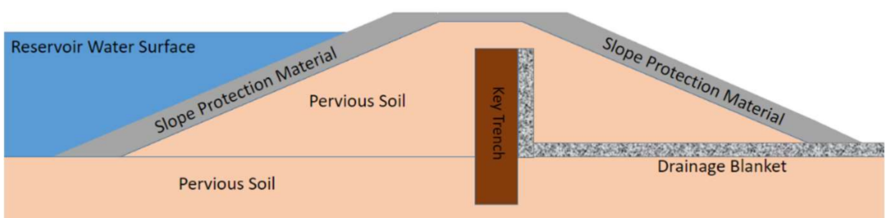

Figure 4: Zoned Earthen Dam Key Elements

The following dimensions of the earthen dam are recommendations based on the standards outlined in *Design of Small Dams.* The earth dam's overall dimensions include the overall dam height and length, which depend on the height and width of the channel where it will be located. Dam height equals the depth of the channel minus the crest drop. The dam's width is equal to the channel's width at any given elevation. The crest's dimensions depend on the height of the dam. The width of the crest is equal to the dam height divided by 5 and multiplied by 10. The dam's upstream and downstream slopes should be 2:1. The freeboard, shown in Figure 5 below is the vertical distance between the crest of the embankment and the reservoir water surface. The dam will include a protective layer of rip rap. Riprap is a mixture of rocky material placed along steep slopes, and other structures to protect from erosion. For the design of small dams with rip-rapped slopes, the freeboard should be sufficient to prevent overtopping of the dam from wave runup equal to 1.5 times the wave's height (Design of Small Dams, 1987). The wave's height depends on the water's velocity and the upstream slope of the dam. Upstream and downstream slope protection are essential to maintaining the stability of the earth dam. The upstream slope of an earth dam must be protected from internal wave action caused by the water collected in the reservoir. Though rarely influenced by seepage forced within the embankment, the downstream slope must be protected from erosion caused by rain and wind. Damage to the upstream or downstream slope may result in premature failure of the dam.

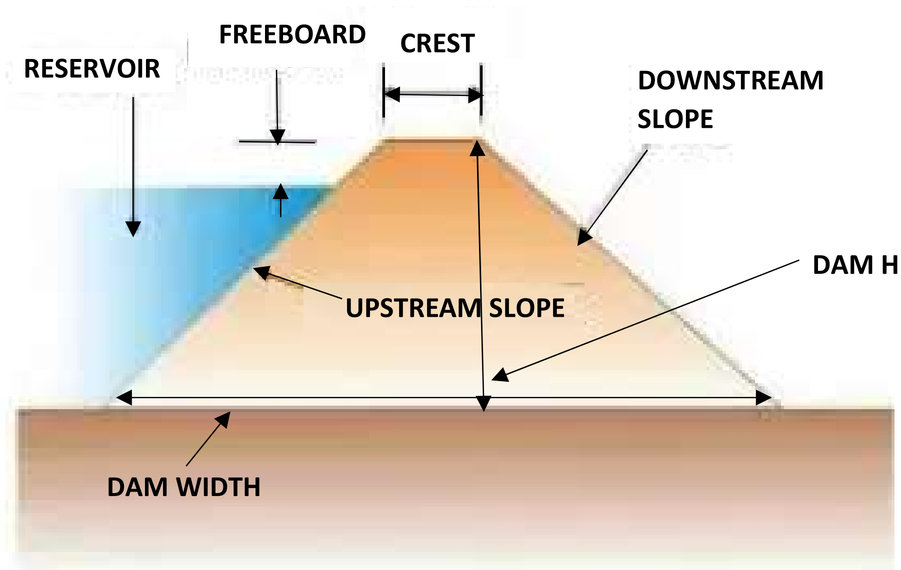

Figure 5: Freeboard Dimensions (Canal Corporation, 2019)

- Slope Protection

Slope protection for earthen dams is essential to combat erosion caused by the wave action of the water. It also provides stability for the soil particles which can be disturbed by flowing water, heavy rain, wind, vegetation growth, and animals or people walking on the surface. Slope protection will be applied to the upstream and downstream surface and the dam's crest or top. The slope ratio is determined by design parameters. The materials considered for slope protection are rocks, clay brick, and concrete. The slope protection of rocks would consist of large boulders, riprap, gravel, and other course-grained material. The clay bricks used for slope protection would be made from the natural clay collected by community members under low heat conditions. Concrete would consist of concrete bricks, excavated concrete materials, poured concrete slabs, or soil cement.

- Drainage Components

Drainage filters are essential to controlling seepage in earth dams. Earth dam drainage filters direct water above the saturation zone downstream to drain through the base of the dam to prevent water seeping through its body. This is achieved using filter material such as small gravel at the downstream end of the embankment. The filter drains the excess water inside the confining structure to in turn reduce internal erosion.

Seepage through the foundation of an earth dam results in erosion and damage to the overall structure. To control seepage, a trench cutoff may be included in the design of the dam. The trench cutoff prevents seepage through the walls of the dam and may also prevent subsurface erosion caused by internal erosion known as piping. The cut-off trench is an excavation below the dam's base filled with impervious materials for seepage to drain through. The cut off trench requires pre-excavation of the soil, ideally down to solid rock to prevent all seepage. Figure 6 below shows an approximate location for a trench cutoff in an earth dam.

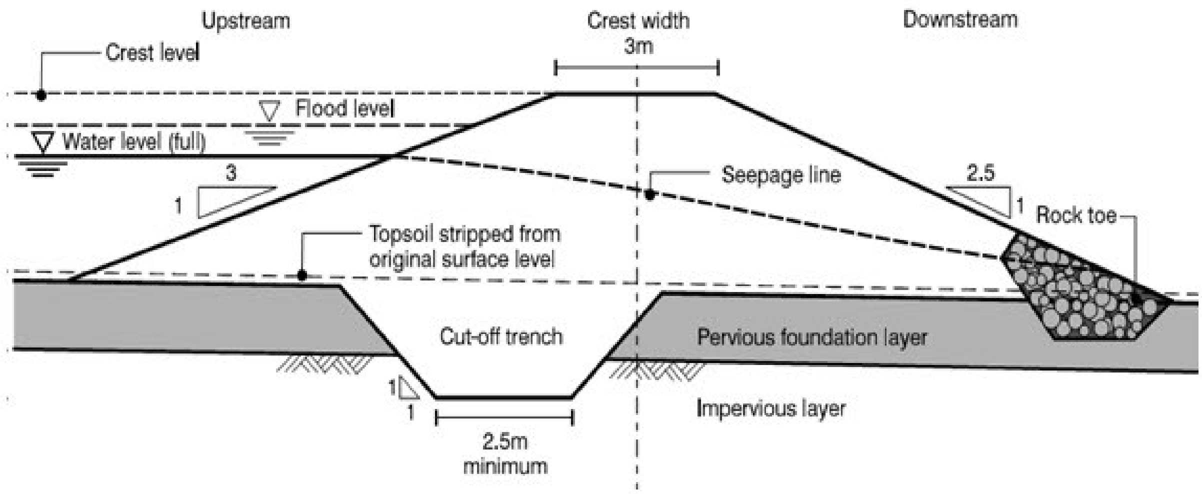

Figure 6: Cutoff Trench (R&FPD: Lesson 7 Components of Embankment)

- Spillway

Spillways allow earth dams to release surplus water or floodwater that cannot be contained in the allotted storage space. The excess water is typically drawn from the top of the reservoir and conveyed through a constructed waterway back to the river or to some natural drainage channel. Many failures of dams have been caused by improperly designed spillways or by spillways of insufficient capacity. In addition to providing sufficient capacity for overflow, the spillway must be hydraulically and structurally adequate and must be located so that spillway discharges do not erode or undermine the downstream toe of the dam.

Design Considerations

Out of the key elements described above, an alternative analysis will be conducted for drainage filters, slope protection, check dams, and spillways. These features have been deemed critical in the dam design analysis. Consistent failure of these elements can result in total dam failure which can have negative financial, structural, and public safety consequences. Dimensions of the dam are key elements in dam design but are not considered in the alternative analysis. This is due to its reliance on existing conditions and variability from rainfall erosion patterns. A dam can be designed using slopes and equations once the width and height dimensions are determined. Constraints for the elements considered in the alternative analysis are discussed in the Alternative Analysis Evaluation Methodology.

- Zoned Embankment vs Homogenous Earthen Dam

At the end of the AU22 semester, the team had chosen to move forward with a homogeneous earthen dam. The main factor in this decision was soil type and simplicity. At this time, it was believed that the soil type in the dam site area was silty clay. Course instructor Dr. Hagenberger was in the Marwa region in December of 2022, and performed some soil inspections near the estimated dam site. Upon further analysis, Dr. Hagenberger found that the clay was less of a silty clay and more of a sandy clay.

This discovery was presented to Dr. Pradel at the beginning of the SP23 semester. Dr. Pradel concluded that the soil was indeed sandier than previously discussed. Dr. Pradel suggested to the team to move forward with a zoned embankment dam which was more appropriate for the newly found soil type. A zoned embankment dam is different from a homogeneous earthen dam in that it features an impervious core in the middle of the dam to help control excess water seepage from the surrounding pervious soil.

- Soil Excavations

From the project's start, it was understood that the construction of an earthen dam would require a significant amount of soil. This has been confirmed using a 3D model of the dam as seen in Figure D8 in Appendix D. Thus, it was decided to include soil excavation cuts in the design deliverables. These excavations are placed at the front toe and back toe of the dam. The geometry of the excavations was determined with the consideration of the required volume of soil, estimated depth of clay, and safety factors in mind. The exact geometry of the excavations can be found in Figure D7 in Appendix D. An additional benefit to having these soil excavations is that they also act as a form of check dam, providing incoming flowing water with a location to fill into and slow down.

- Drainage Filters

Drainage filters are essential to protect the structural integrity of the dam. They control water seepage, piping, and the prevention of the movement of soil particles. Drainage Filters provide critical control measures for water movement and erosion which are vital to the dam's success. Drainage filters the team considered for the Maji Marwa earthen dam were a horizontal blanket, rockfill toe, and a combination of the two. These alternatives can lower the phreatic line, the top flow line of where seepage will take place, therefore decreasing the upper limit of seepage, pore water pressure, seepage gradient and velocity, and stabilizing the dam (Design of Small Dams, 1987). Originally, the team decided on a horizontal blanket. Horizontal blankets consist of two sand layers, a course-grained sand layer on the top and a fine-grained sand layer on the bottom. After discussing with Dr. Pradel, it was recommended that a combination be used instead. A combination of drainage filters will use the horizontal blanket along the backside of the dam and along the backside of an impervious clay core as the filter and the rockfill toe drain as a toe drain.

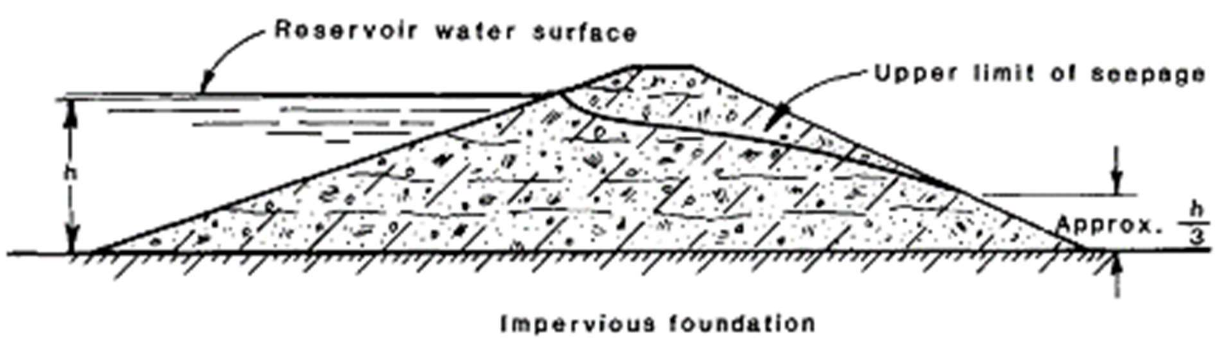

Figure 7: No Drainage Filter (Design of Small Dams, 1987)

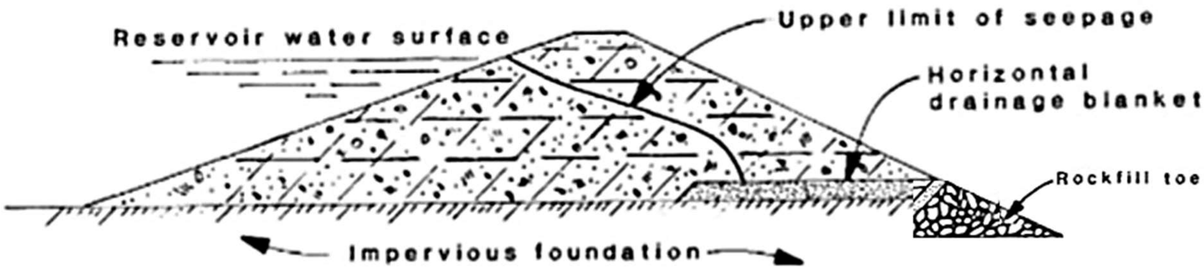

Figure 8: Combined Horizontal Blanket & Rockfill Toe (Design of Small Dam, 1987)

- ## Check Dams

Check dams are used to slow the upstream velocity of water before it reaches the dam. Slowing the velocity of water before impact can prevent damage and erosion to the dam structure. The size and slope of the check dams will be small and flat enough to only slow the flow of water rather than fully stop it. Keeping the check dam small also leads to easier constructability and less strain on materials. The factor to be determined through alternative analysis is whether check dams should be used. Factors to consider include availability of materials and constructability. Based on current knowledge of soil availability in the area, the check dams would be constructed out of clay or small rocks. An example of check dams constructed out of small rocks is shown in Figure 9 below. After an alternative analysis, check dams were not used moving forward. The excavation cuts for the dam will act as a pseudo check dam.

Figure 9: Check Dam Constructed Out of Small Rocks (The Constructor, 2018)

- Spillway

The spillway can exist in many forms. The team considered a chute spillway and internal piping. The chute spillway is a chute excavated from the dam reservoir. When the water in the reservoir fills beyond the chute crest, it flows through the chute and is redirected, either back to its original source or to a nearby channel. The piping spillway that the team considered consisted of pipes going through the dam. When the water in the reservoir exceeded the height of the pipes, the water would flow through the pipes and be ejected on the other side of the dam. The primary complication occurring with the internal piping is the difficulty that would come with construction. Not only would it come with a more complex design, but it would also require a significant amount of planning prior to laying the pipes. This all ultimately leads to a higher cost for the overall dam. For this reason, the team decided to design the spillway as a chute. Unlike many spillways, the chute goes from the reservoir, through the center of the dam, and then is ejected on the other side of the dam. Choosing to have the chute go through the center of the dam rather than the side of it or around it was primarily to maintain the simplicity of the dam overall. The chute itself could easily be integrated into the dam design and reduces the amount of soil excavation and materials required overall. This is because a chunk of the dam is being cut out to act as a spillway. The chute is designed to have a base of four feet, then will slope outwards with a one-to-one slope. The chute will be lined with a layer of concrete followed by a layer of clay brick for protective lining. Because the chute goes through the center of the dam, erosion protection is especially important. With the addition of the protective lining, the dam's freeboard was raised as well.

Through basic hydrology analysis the dam is estimated to hold about 10,000-11,000 cubic feet of water before the emergency spillway would be used. This accounts for ~ 5,000 cubic feet of water in the front excavation and slightly more than ~5,000 cubic feet of water held in the channel above the excavation and below the height of the freeboard. The geometry of the spillway is designed to withstand the flow of at least a 25-year storm.

Alternative Analysis

To begin the evaluation process, the team identified every key element necessary for the design of the dam, as laid out in the previous parts of this report. With each of these important key elements identified, the team used decision matrices to objectively determine the optimal dam design. Elements such as the dam dimensions, dam type, and trench cutoff were determined through expert judgement or constraints listed in the Design of Small Dams.

- Evaluation Methodology

The team initially weighed each of the four criteria by 25%. However, the team adjusted the criteria based on importance in increments of 2.5% to weigh important criteria. The most important criteria for this design and most designs are the cost. Since this project is taking place in a developing community, initial investment capital is a major hurdle. With this context in mind, cost would be the key factor in the decision process justifying its 30% weight. The second most important criterion determined was the difficulty of constructing the dam. If the dam is too complicated to be constructed by the people in the village, it would prohibit it from being built or replicated by other villages. With how important this criterion is, it warranted being weighed 27.5%. The third most important criterion for the design was the availability of the materials. The team determined that the availability of the materials needed was the third most important criterion. However, the reason this is slightly less important than the other two considerations is that there is the possibility of getting necessary materials from outside the community brought into the construction site. Due to these factors, it was determined a weight of 22.5% for this criterion was sufficient. The least important criteria in the decision matrices were the dam's long-term durability. This was the least important criterion because the dam would be constructed in a rapidly developing community. Hence, the dam will serve as a more temporary solution that will eventually be replaced. It was determined to only give durability a 20% weight. Tables 1 and 2 below show the definitions of each criterion and their corresponding rating scale system. Utilizing these tables, an alternative analysis was completed for the four design elements of drainage filters, slope protection, check dam, and spillways and are displayed in Tables 3-6 below.

Table 1: Criteria Definitions

	Definitions					
Criteria	**Weight**	**1 - Poor**	**2 - Fair**	**3 - Adequate**	**4 - Good**	**5 - Excellent**
Cost Efficiency	0.3	10,000$	In between 1 and 3	1,000$	In between 3 and 5	Less than 100$
Installation / Construction	0.275	Multiple Heavy Machines	In between 1 and 3	One Heavy Machine	In between 3 and 5	Only Hand Tools
Risk / Durability	0.225	No Failure during 20-year flood	In between 1 and 3	25% Chance of Failure During 20 Year Flood	In between 3 and 5	50% Chance of Failure During 20 Year Flood
Availability of Materials Needed	0.2	Would need to be shipped 1000 miles away	In between 1 and 3	Are Available Withing the Region	In between 3 and 5	Available Within the Village

Table 2: Rating Scale System

Criteria	Weight	Definition
Cost Efficiency	30%	What are the building and maintenance costs?
Installation / Construction	27.5%	What are difficult measures, machinery, and time involved?
Availability of Materials Needed	22.5%	Are materials easily available in the community?
Risk	20%	What are the chances of failure of the key element?

Table 3: Drainage Filter Analysis

Drainage Filter Alternatives Analysis							
Criteria	Weight	Horizontal Blanket		Rockfill Toe		Combined Filter	
Cost Efficiency	**0.3**	Moderately expensive, will need some additional material.	3	Moderately expensive, will need some additional material.	3	Moderately expensive, will need some additional material.	3
Installation / Construction	**0.275**	The difficulty of construction increases compared to having no filter.	3	The difficulty of construction increases compared to having no filter.	3	To combine both a toe filter and a horizontal blanket the construction necessary is not much more complex	3
Risk / Durability	**0.225**	This alleviates some chance of failure.	1	This eliminates potential erosion of toe providing alleviating most chance of failure	1	This design completely alleviates the risk of failure	5
Availability of Materials Needed	**0.2**	Materials are made available with a little effort	4	Materials are made available with a little effort	4	Materials are made available with a little effort	4
Totals	**1**		2.7		2.7		3.65

Table 4: Slope Protection Analysis

Slope Protection Alternatives Analysis									
Criteria	Weight	Clay Bricks		Concrete		Rip Rap		None	
Cost Efficiency	**0.3**	Made inexpensively in village	5	Is an expensive material for this project	1	Is a material that is free in the village	5	No material is needed	5
Installation / Construction	**0.275**	Is easy to lay a layer of bricks on top of the dam	4	Takes formwork, would need pump truck, finishing and hydration of concrete	1	Difficulty in ensuring rip rap is properly graded and placed.	3	No additional construction is needed at all	5
Risk / Durability	**0.225**	Protects the slope from most failure	4	Does a poor job of protecting dam slopes	2	Protects dam in all circumstances	5	Provides no protection	1
Availability of Materials Needed	**0.2**	Village makes clay bricks	5	Would have to put in significant effort to get concrete to use.	2	Is available in the village will just need collected	4	No material is needed	5
Totals	**1**		4.5		1.43		4.		4

Table 5: Check Dam Analysis

Check Dam Alternatives Analysis					
Criteria	Weight	Check Dam		No Check Dam	
Cost Efficiency	**0.3**	Materials are free but labor is needed.	4	No materials needed	5
Installation / Construction	**0.275**	Light labor and simple construction required	4	No installation needed	5
Risk / Durability	**0.225**	Dam is less susceptible to erosion and failure	5	Dam is more susceptible to erosion	4
Availability of Materials Needed	**0.2**	Available nearby	5	No materials needed	5
Totals	**1**		4.425		4.775

Table 6: Spillway Analysis

Spillway Alternatives Analysis					
Criteria	Weight	Concrete Spillway		PVC Piping Spillway	
Cost Efficiency	**0.3**	Small amount of concrete inexpensive	4	PVC is fairly inexpensive	3
Installation / Construction	**0.275**	Pouring a thin layer of concrete should be simple	4	Piping through existing soil or foundation may be difficult	2
Risk / Durability	**0.225**	Dam unlikely to fail with properly operating canal	4	Dam unlikely to fail without properly operating pipe	4
Availability of Materials Needed	**0.2**	Concrete available in region	3	PVC available in region	3
Totals	**1**		3.75		3.0

- Results

The alternative analysis yielded particularly important design results. It yielded design choices such as using a combined filter and using clay bricks as the primary slope protection material. It was also determined that we will use a spillway channel through the dam. Check dams will not be necessary for our design. These results changed from our original alternative analysis in Appendix D due to different soil type assumption and a completed hydrology analysis.

Schematic Design

Through the combination of the design process, design considerations, and the evaluation methodology, a schematic drawing for a zoned earthen dam was designed. All drawings and supporting materials are found in the appendices. The References section contains a list of all research sources used throughout the project. Appendix A contains a stakeholder value matrix. This table lists all stakeholders in the Maji Marwa project and the impact they bring to the various aspects of the project. Appendix A also contains a data template used by Dr. Hagenberger during his December 2022 trip to Marwa. This data helped confirm assumptions made about the area. Appendix B contains a stakeholder map and their relations to each other. Appendix C contains all tables used in the previous alternative analysis for each key element from the autumn 2022 global capstone semester. Appendix D contains schematic drawings of the project. Finally, Appendix E contains calculations used within the project.

Appendix – alternative analysis, design, calculations, referencces

Design with Communities Considerations

The Maji Marwa initiative was created in 2013 in coordination with the Marwa Village Chairman and the Kilimanjaro Hope Organization, a local Tanzania NGO, to support the provision of clean and safe water to the Marwa village. Since its formation, many water development projects have been conducted using participatory community consultations to address the water needs of the area (Sours, 2019). Maji Marwa water development projects are vastly different from traditional engineering projects. Traditional engineering projects provide the best and most efficient engineering solution within given technical parameters. Even though Maji Marwa projects provide quality engineering solutions within given technical parameters, they must also consider unique constraints, contexts, and values imposed by the community and accompanying stakeholders. Maji Marwa projects utilize values-based, participatory development, and community consultation processes to provide the best engineering solutions to the community of Marwa. These projects use human-centered design concepts as engagement with the community is conducted throughout the project's inspiration, ideation, and implementation phases. Training is also performed during the implementation process to empower the community to continue these projects without the Maji Marwa team being there. This long-term capacity building along with designing technical solutions with community considerations makes Maji Marwa projects unique and sustainable in comparison to traditional engineering projects.

The Maji Marwa project of a design for a zoned earthen dam addressed water retention and flood mitigation problems for the Marwa primary school. This project used human-centered design concepts and engineering for global development techniques as the community and surrounding environment was considered throughout the project’s plan, learn, design, realize, and sustain processes. Previous relationship building from instructors and research of the cultural context of the community using the Hofstede Cultural Dimensions and PESTEL Analysis tools were used to gain a better understanding of the Marwa community. Notable takeaways from these tools were relations power distance and ideas of individualism. The people of Tanzania respect hierarchy and have clear leaders within the community. Proper communication, respect, acceptance, and permission from the elders and leaders of the Marwa village, Ruvu Ward, and Same District is essential to ensure the success of the dam. Tanzania is considered a collectivist and feminine society. This means they value working together to achieve an excellent quality of life for everyone in their community (Hofstede Insights, 2017). This cultural dimension was considered in the location of the dam to ensure everyone has equal access to it. Figure 10 below shows the Hofstede Cultural Dimensions of Tanzania and the United States to demonstrate the differences in value and perspective.

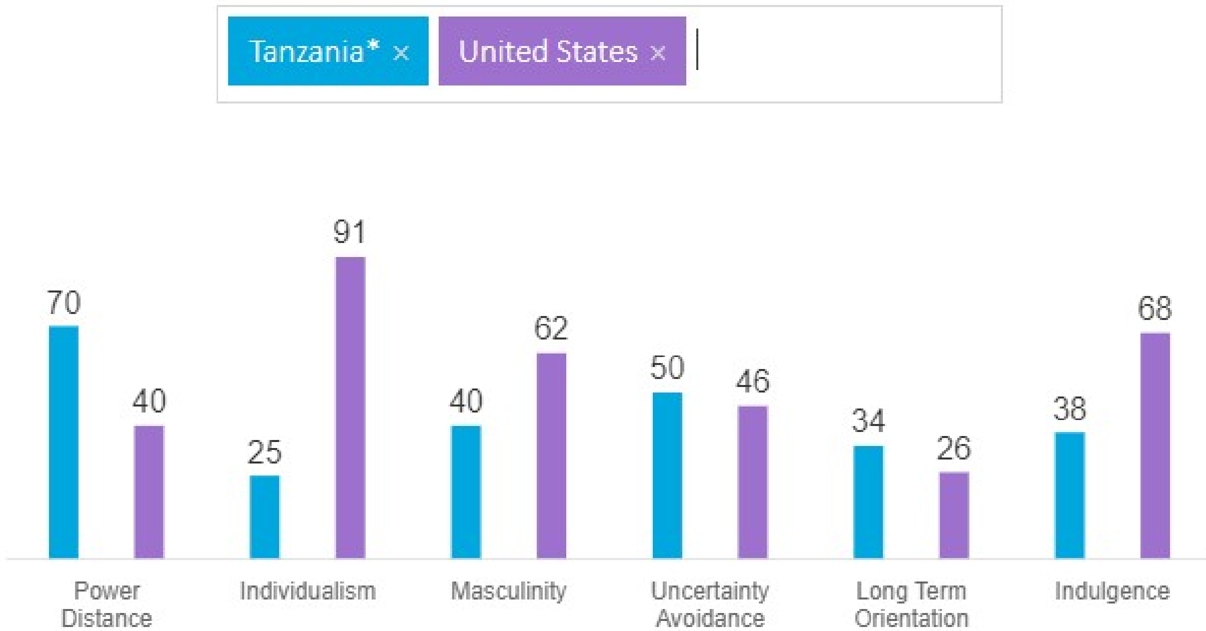

Figure 10: Hofstede Cultural Dimensions Tool Analysis (Hofstede Insights, 2017)

Designing a zoned earthen dam as an appropriate technology for the developing community of Marwa considered the technical capability, values, perspectives, and types of communication for the various stakeholders. The values from engineering for social responsibility and global competence, along with consideration for language, financial, environmental, and technical ability barriers were woven into the sustainability of the dam design. Proper communication methods, simplification of dam design drawings, and respect towards the culture, traditions, landscape, and sensitivity to substantial change were conducted to keep economic costs low, positive social impacts high, and to effectively manipulate the environment to work in the best interest of the whole community. Overall, designing with community considerations helps make the Maji Marwa initiative and the zoned earthen dam project the most sustainable, appropriate, and human-centered it can be.

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Appendices

A – Tables

Table A1: Stakeholder Value Matrix

Stakeholders	Value Categories				
	Economic	Social	Environmental	Political	Technological
Marwa Village	increase time and productivity, enhances business opportunities (+), costs time and money (-)	more leisure time, increase attendance in school and education rates, structural devlopment will last longer and promote settlement (+), decrease community bonding time, cultural change of lifestyle (-)	Less agricultural erosion, decrease flooding and environmental and development damages (+) Disrupt natural flow and sources for the Pagani River, (-)	promotes settlement (+), infringement on traditional values and lifestyles (-)	Opportunities for advancement in health, technology, and energy (+), Lack of technical maintanence ability (-)
The Ohio State University	Provides more project opportunities (+) Costs time and money - student costs, travel fees, coordination (-)	Cultural engagement, new project exposure, application of design and techincal knowledge (+)	-	promotional for students and grants (+) may be seen as pushing western ideals on different cultures (-)	increase technical design skills (+)
University of Dodoma	Invest in local development (+), travel costs and coordination ability (-)	exposure to rural areas, cultural engagement (+)	-	exposure and involvement to development practices (+)	Exposure to engineering designs and application procedures (+)
Ruvu Ward / Same District	can increase revenue by providing more economic opportunites, decreased cost in property maintenance (+) Maintenance costs (-)	promotes growth in the area (+)	less agricultural erosion (+), disrupts natural flow of water, may effect other water sources (-)	enforce settlement (+-), encourage growth in the communities (+) May affect communities outside of their district (-)	access to dam designs and technical analysis of existing conditions (+) , may become cookie cutter design (-)

Table A2: Site Collection Data Sheet

Potential Leseirwei Dam Location #1 - Coordinates:

Category	Description	Picture	Video	Instructions	Notes/Results
Channel Dimensions	Width (top & bottom)			Refer to sketch	
	Height				
Vegetation	Erosion Pattern				
	Elevation			Measure Height from bottom of channel to vegetation	
	Root Holes			Measure Height from bottom of channel to vegetation	
	Material in Channel			Soil, organic, sand, gravel, etc	
	25ft Perimeter Check			Check for vegetation surrounding the dam	
Soil Test	Clay			Hand- Rolled Test: Pick up a handful of dirt, roll it around in hand, If sticks in hand pores, the soil is fine-grained	
	Silt				
Spillway Location(s)	Existing Channels			note width, height, and distance from dam for spillway	
Slope Armor	Clay Brick Availability			Check: Size Dimensions + General Strength, making/finding capacity	
	Boulder Size/Availability				

B – Figures

Figure B1: Stakeholder Relations Map

C – Preliminary Alternative Analysis

Table C1: Drainage Filter Analysis

Drainage Filter Alternatives Analysis							
Criteria	Weight	Horizontal Blanket		Rockfill Toe		Chimney Filter	
Cost Efficiency	**0.3**	Moderately expensive, will need some additional material.	3	Moderately expensive, will need some additional material.	3	More expensive because more material is needed.	2
Installation / Construction	**0.275**	The difficulty of construction increases compared to having no filter.	4	The difficulty of construction increases compared to having no filter.	3	To combine both a toe filter and a horizontal blanket the construction necessary is more complex but still possible.	2
Risk / Durability	**0.225**	This alleviates some chance of failure.	4	This eliminates potential erosion of toe providing alleviating most chance of failure	4	This design completely alleviates the risk of failure	5
Availability of Materials Needed	**0.2**	Materials are made available with a little effort	4	Materials are made available with a little effort	4	Materials are made available with a little effort	4
Totals	**1**		3.7		3.425		3.08

Table C2: Slope Protection Analysis

Slope Protection Alternatives Analysis										
Criteria	Weight	Clay Bricks		Concrete		Rip Rap		None		
Cost Efficiency	**0.3**	Made inexpensively in village	5	Is an expensive material for this project	1	Is a material that is free in the village	5	No material is needed	5
Installation / Construction	**0.275**	Is easy to lay a layer of bricks on top of the dam	4	Takes formwork, would need pump truck, finishing and hydration of concrete	1	Difficulty in ensuring rip rap is properly graded and placed.	3	No additional construction is needed at all	5
Risk / Durability	**0.225**	Protects the slope from most failure	4	Does a poor job of protecting dam slopes	2	Protects dam in all circumstances	5	Provides no protection	1
Availability of Materials Needed	**0.2**	Village makes clay bricks	5	Would have to put in significant effort to get concrete to use.	2	Is available in the village will just need collected	4	No material is needed	5
Totals	**1**		4.5		1.43		4.3		4

Table C3: Check Dam Analysis

Check Dam Alternatives Analysis					
Criteria	Weight	Check Dam		No Check Dam	
Cost Efficiency	**0.3**	Materials are free and nearby but labor is needed.	4	No materials needed	5
Installation / Construction	**0.275**	Light labor and simple construction required	4	No installation needed	5
Risk / Durability	**0.225**	Dam is less susceptible to erosion and failure	5	Dam is more susceptible to erosion	4
Availability of Materials Needed	**0.2**	Available nearby	5	No materials needed	5
Totals	**1**		4.425		4.775

Table C4: Spillway Analysis

Spillway Alternatives Analysis					
Criteria	Weight	Concrete Canal Spillway		Internal Pipe Spillway	
Cost Efficiency	**0.3**	Large amount of concrete more expensive than single PVC	3	PVC is inexpensive	4
Installation / Construction	**0.275**	Pouring a large amount of concrete may be difficult with given equipment	2	Single pipe should have simple installation	4
Risk / Durability	**0.225**	Dam unlikely to fail with properly operating canal	4	Dam unlikely to fail with properly operating pipe	4
Availability of Materials Needed	**0.2**	Concrete available in region	3	PVC available in region	3
Totals	**1**		2.95		3.8

D - Schematic Drawings

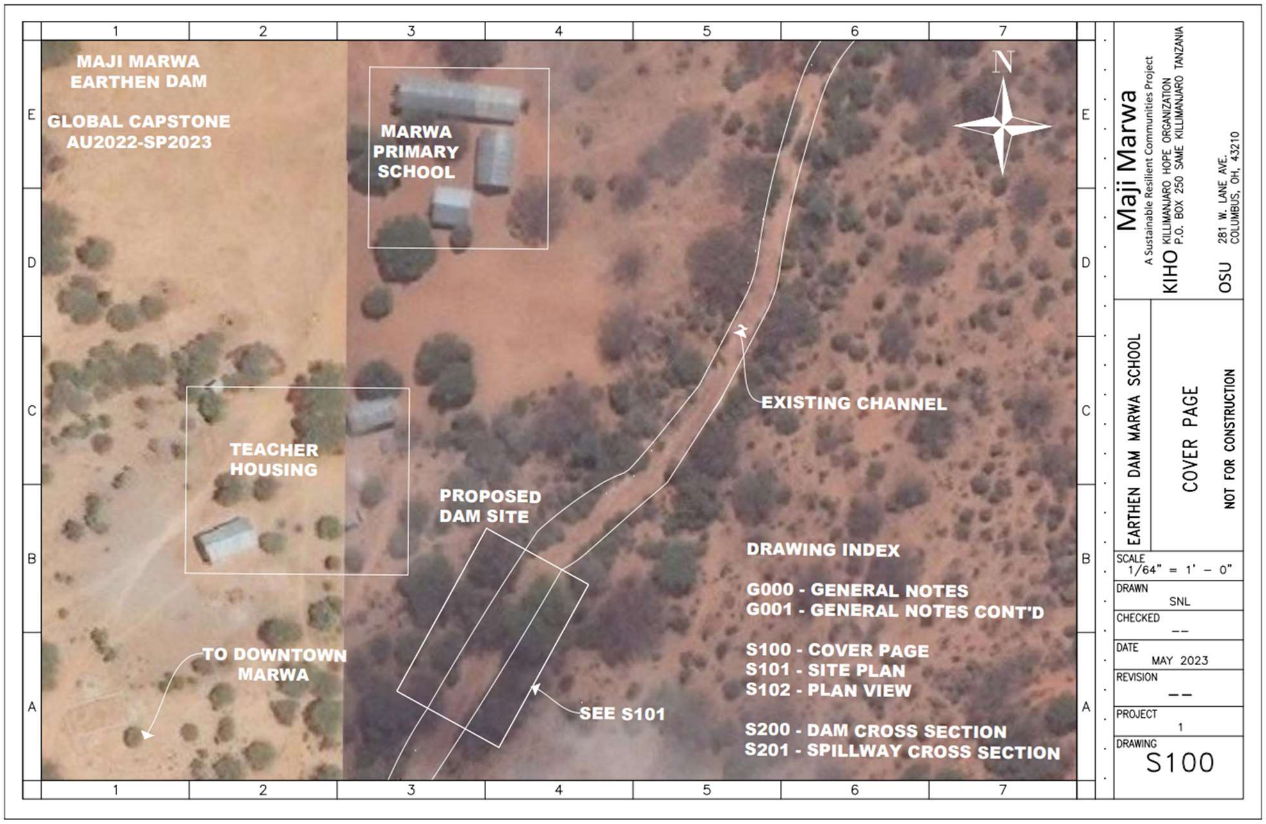

Figure D11: Cover Page

Figure D22: Site Plan

1. SITE PREPARATION

1.1. SITE CLEARING

1.1.1. REMOVE ALL VEGETATION GREATER THAN 5 FEET IN HEIGHT AND/OR 2INCHES IN DIAMETER, INCLUDING THEIR ROOTS, LOCATED WITHIN A HORIZONTAL DISTANCE OF 15 FEET BEYOND THE EMBANKMENT/ABUTMENT CONTACT LINE AND THE UPSTREAM AND DOWNSTREAM EMBANKMENT TOE.

1.1.2. REMOVE VEGETATION AT LEAST 1FT HIGH, A HORIZONTAL DISTANCE OF 5FT FROM THE DAM'S EMBANKMENT.

1.2. FENCING

1.2.1. INSTALL A FENCE TO PREVENT ANIMALS AND HUMANS TRESPASSING ON THE DAM. PLEASE SEE THE DRAWINGS FOR THE FENCING EXTENT.

1.2.2. IT SHALL BE PLACED ON THE SLOPE OF THE BANK. IT SHALL BE 5 FEET UP THE SLOPE.

2. SITE PREPARATION RECOMMENDATIONS

2.1. TRADITIONAL FENCING CAN BE USED TO PROTECT THE DAM PROVIDED THERE IS SUFFICIENT MAINTENANCE TO ENSURE ANIMALS, PEDESTRIANS AND VEHICLES DO NOT CROSS ON TOP OF THE DAM.

3. MATERIALS SPECIFICATIONS

3.1. SLOPE PROTECTION

3.1.1. MATERIALS SHALL CONSIST OF ROCKFILL, CONCRETE MASONRY BLOCKS, OR CLAY BRICK.

3.1.1.1. ROCKFILL SHALL CONSIST OF LARGE, DURABLE ROCK FRAGMENTS, WELL GRADED BETWEEN 6 AND 36 INCHES IN DIAMETER.

3.1.1.2. LARGER BOULDERS, ROCKS, AND STONES CAN BE HAMMERED TO CREATE SMALLER ANGULAR ROCK FRAGMENTS TO GENERATE A WELL GRADED MIXTURE.

3.1.1.3. CLAY BRICKS SHALL BE UNIFORM WITH STANDARD DIMENSIONS OF 8 BY 4 BY 3 INCHES. MORTAR BETWEEN BRICKS MAY BE USED AT THE MASON'S DISCRETION TO MAINTAIN THE STABILITY AND PATTERN OF BRICK LAYING.

3.1.1.4. CONCRETE MASONRY BLOCKS SHALL BE UNIFORM WITH DIMENSIONS OF 17 BY 8 BY 6 INCHES. MORTAR BETWEEN BLOCKS SHALL BE USED AT THE AT THE DISCRETION OF THE MASON TO MAINTAIN THE STABILITY AND PATTERN OF BRICK LAYING.

3.1.2. ALL MATERIALS SHOULD BE PLACED AND COMPACTED TO ENSURE THEIR STABILITY.

3.2. DRAINAGE BLANKET & TOE DRAIN

3.2.1. THE DRAINAGE BLANKET SHALL CONSIST OF PERMEABLE, WOVEN OR BURLAP SACKS FILLED WITH GRAVEL AND SMALL ROCKS 2IN OR SMALLER PLACED AGAINST THE IMPERVIOUS CORE.

3.2.2. THE TOE DRAIN SHALL CONSIST OF ROCKFILL (AS DEFINED IN 3.1.1.1) ALONGSIDE THE DRAINAGE BLANKETS IN THE DOWNSTREAM TOE OF THE DAM.

3.3. PERVIOUS SHELL

3.3.1. THE PERVIOUS ZONES MAY CONSIST OF SOIL CLASSIFICATIONS OF TYPE B&C CONTAINING SAND, SILT, GRAVEL, COBBLES, ROCK, AND OTHER COARSE-GRAINED, PERVIOUS MATERIAL. SUITABLE EARTH FILL MATERIAL FROM EXCAVATION CAN BE USED FOR PERVIOUS ZONES.

3.3.2. UNSUITABLE MATERIAL IS DEFINED AS LOOSE, SOFT, OR DISINTEGRATED MATERIALS, DEBRIS, AND VEGETATION.

3.3.3. CLAYEY SAND IS PREFERABLE TO LOOSEN SOIL AND FORMATION MATERIAL.

3.4. IMPERVIOUS CORE

3.4.1. THE IMPERVIOUS CORE SHALL CONSIST OF CLAY OF SOIL CLASSIFICATION TYPE A AND OTHER FINE-GRAINED IMPERVIOUS MATERIAL.

3.5. SPILLWAY

3.5.1. THE SPILLWAY SHALL BE LINED WITH CLAY BRICKS TOTALING A DEPTH OF MINIMUM 4". MORTAR MAY BE USED IN BETWEEN BRICKS TO MAINTAIN THE STABILITY AND PATTERN OF BRICK MAKING.

3.5.2. CONCRETE SHALL BE LAYER AS A BASE LAYER UNDERNEATH THE LAYER OF CLAY BRICKS AT A THICKNESS OF MINIMUM 4"

4. MATERIALS RECOMMENDATIONS

4.1. MATERIALS MAY BE LOCALLY SOURCED PROVIDED A LOCAL ENGINEER CONFIRMS THE MATERIAL MEETS THE SPECIFICATIONS PROVIDED.

4.1.1. CONSIDERATIONS OF PROXIMITY, ACCESSIBILITY, NATURAL MOISTURE CONTENT, INFILTRATION RATES, PERMEABILITY, AND WORKABILITY OF THE MATERIALS SHALL BE USED TO DETERMINE THEIR SUITABILITY.

4.2. ROCKFILL IS THE PREFERRED MATERIAL FOR SLOPE PROTECTION.

4.2.1. CLAY BRICKS ARE THE SECOND OPTION BUT IT IS RECOMMENDED THAT CLAY SHOULD BE PRIORITIZED FOR THE CONSTRUCTION OF THE IMPERVIOUS CORE.

4.2.2. CONCRETE MASONRY BRICKS ARE CONSIDERED THE LEAST DESIRABLE OPTION DUE TO COST.

5. CONSTRUCTION

5.1. FOUNDATION

5.1.1. FOUNDATION PREPARATION OF THE DAM INCLUDES REMOVING VEGETATION, STRIPPING THE SANDY LAYER, AND DIGGING OUT THE OUTER TOPSOIL.

5.1.2. THE TOP 12 INCHES OF THE FOUNDATION WILL BE COMPACTED TO PROVIDE A SATISFACTORY BONDING SURFACE WITH THE FIRST LAYER OF THE EARTH FILL.

5.2. EARTH FILL

5.2.1. EARTH FILL MATERIAL FOR THE PERVIOUS SHELL AND IMPERVIOUS CORE SHALL BE SPREAD IN LEVEL, CONTINUOUS, HORIZONTAL 8-12IN LIFTS TO ACHIEVE A DESIRED 6IN THICKNESS AFTER BEING COMPACTED.

5.2.2. AFTER A LAYER OF EARTH FILL HAS BEEN DUMPED AND SPREAD, IT SHALL BE DISKED OR TILLED TO BREAK UP AND BLEND THE EARTH FILL MATERIALS.

5.3. SLOPE PROTECTION

5.3.1. CLAY BRICKS SHALL BE PLACED IN A RUNNING BOND PATTERN ON TOP OF THE EARTH FILL. THE CLAY BRICKS SHALL BE AT LEAST 2 LAYERS OR MORE IF THERE IS NOT ENOUGH ROCKFILL TO MEET THE THICKNESS REQUIREMENTS.

5.3.2. ROCKFILL IS PLACED IN LIFTS AROUND 1-2FT THICK. THE OUTER PORTION OF A ROCKFILL ZONE SHOULD CONTAIN THE LARGEST AVAILABLE ROCK TO SECURE SLOPE PROTECTION AND SHALL BE PLACED IN CONTINUOUS, HORIZONTAL LAYERS ON TOP OF THE CLAY BRICKS. RIPRAP SHALL BE DUMPED OR PLACED ON TOP OF THE BOULDERS TO INTERLOCK THE ANGULAR FRAGMENTS AND FILL IN THE VOIDS.

5.4. COMPACTION

5.4.1. COMPACTION SHALL BE COMPLETED BETWEEN EVERY LIFT OF MATERIAL.

5.4.2. THE DESIRED PERCENT COMPACTION IS AT LEAST 95%. AROUND 4-12 SUCCESSIVE PASSES OF COMPACTION ARE NEEDED TO ACHIEVE THE DESIRED PERCENT COMPACTION.

5.4.3. COMPACTION SLOPES SHOULD BE 0.5:1 (HORIZONTAL TO VERTICAL) OR FLATTER.

5.4.4. COMPACTION TECHNIQUES CAN INCLUDE HAND TAMPING WITH SOIL TAMPERS, ROLLERS, OR THE CONTROLLED TRAMPLING OF FEET CAUSED BY HUMANS OR ANIMALS. RUBBER-TIRED EQUIPMENT MAY BE USED IF OPERATING SPEEDS DO NOT EXCEED 2MPH. ROLLERS CAN BE MADE BY FILLING BUCKETS WITH LIQUID AND ROLLING THEM ON THEIR SIDES.

Maji Marwa
A Sustainable Resilient Communities Project
KIHO KILLIMANJARO HOPE ORGANIZATION P.O. BOX 250 SAME KILLIMANJARO TANZANIA
OSU 281 W. LANE AVE. COLUMBUS, OH, 43210

EARTHEN DAM MARWA SCHOOL

GENERAL NOTES

NOT FOR CONSTRUCTION

SCALE	1/8" = 1'
DRAWN	SNL
CHECKED	--
DATE	MAY 2023
REVISION	--
PROJECT	1
DRAWING	G000

Figure D3: General Notes3

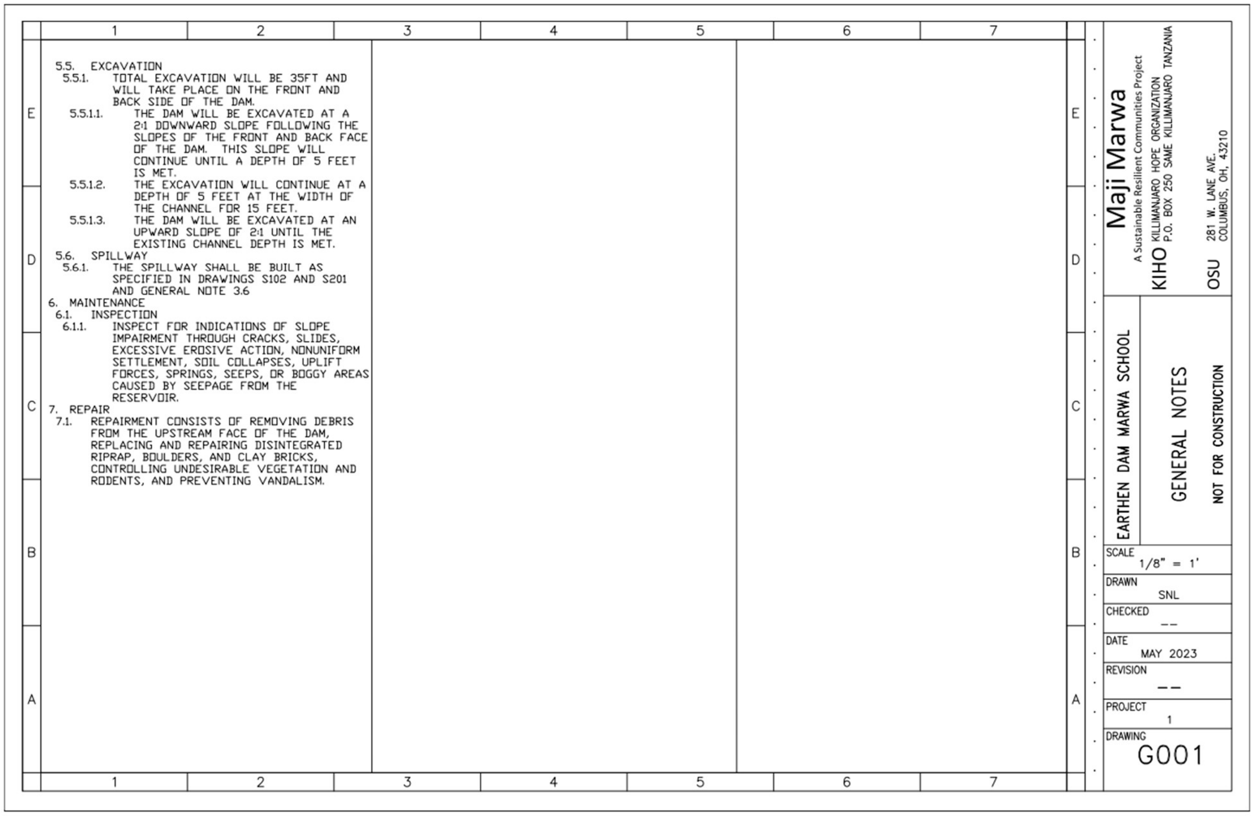

Figure D44: General Notes Cont'd

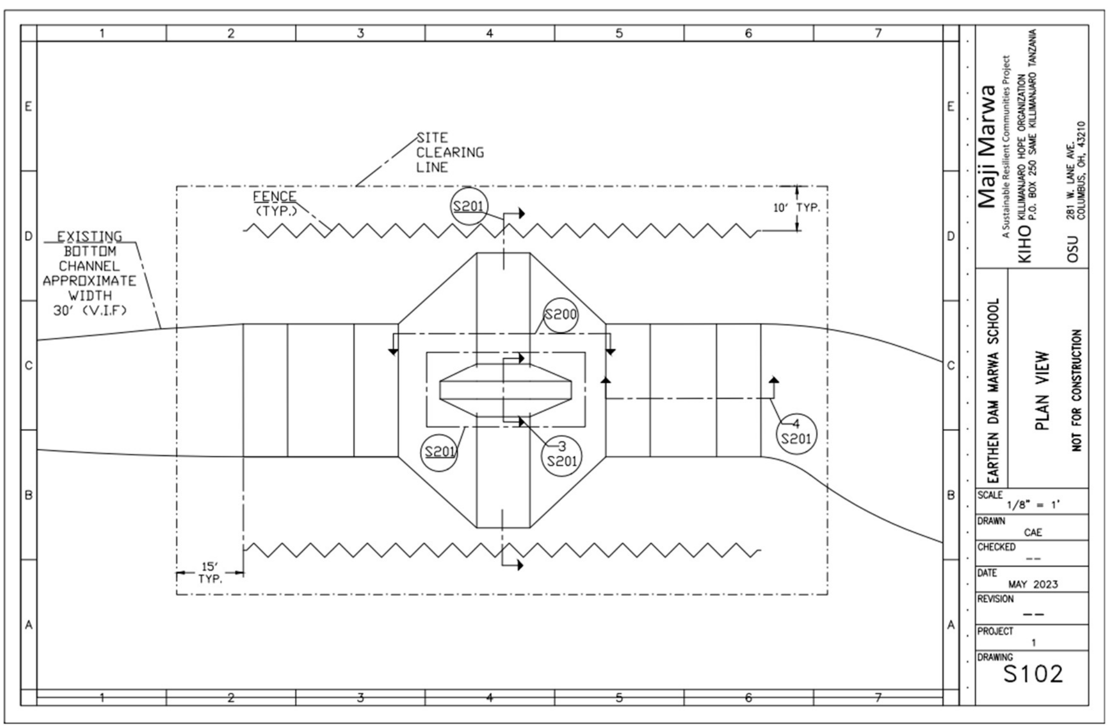

Figure D5: Plan View

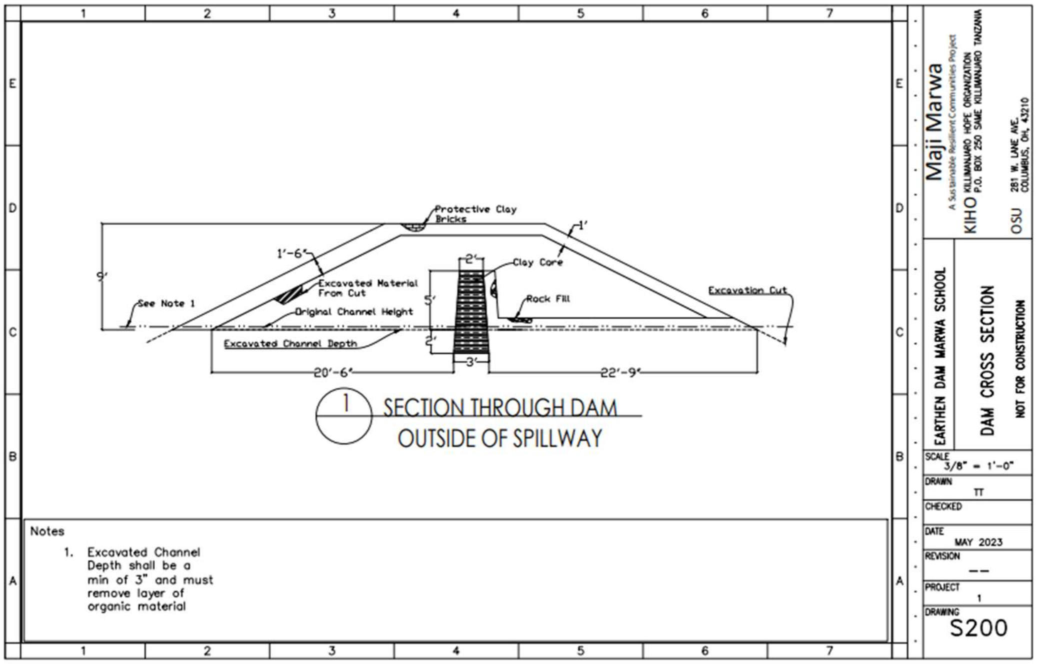

Figure D6: Section Through Dam Outside of Spillway

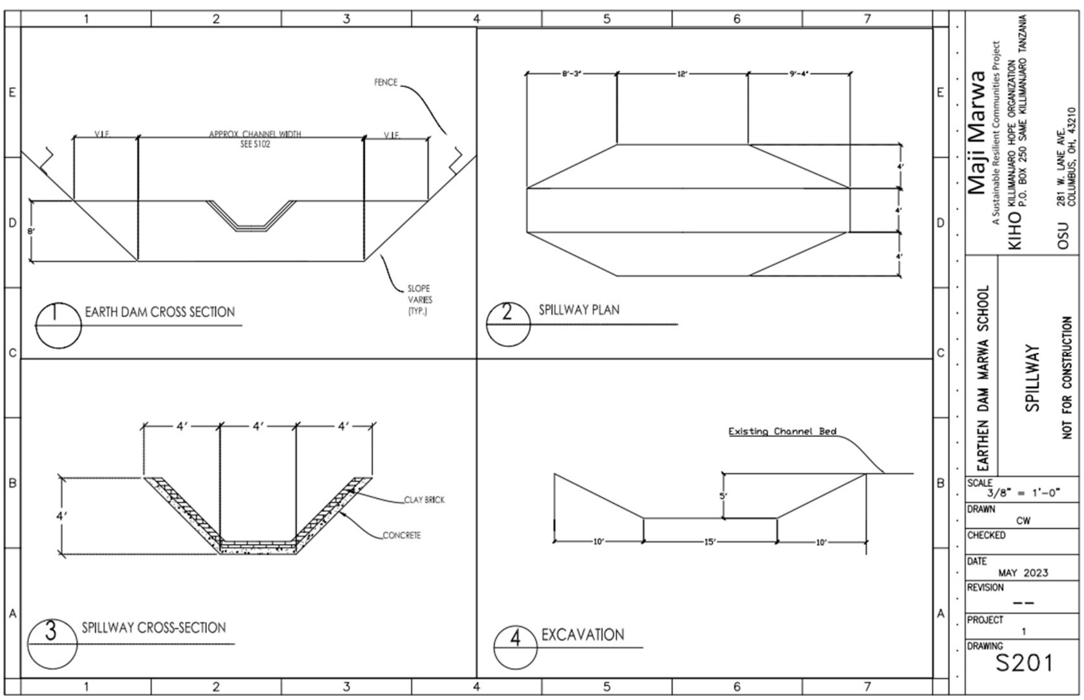

Figure D7: Isometric Spillway Details – Excavation Cross Section

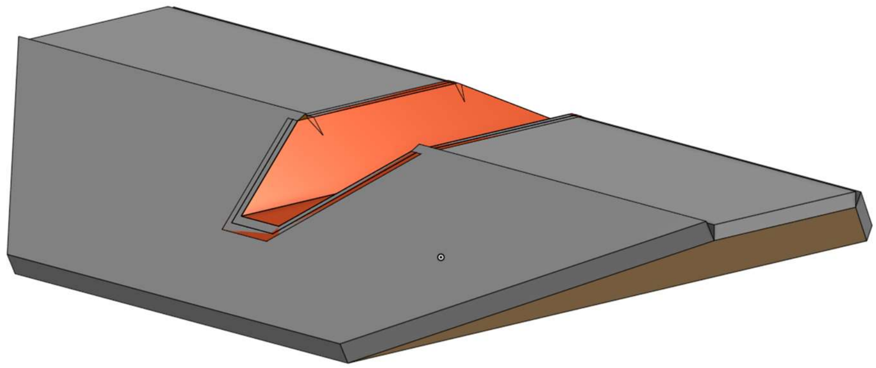

Figure D8: 3D Onshape Model

E – Calculations

```
%{
** DISCLAIMER **
THIS CODE IS A WORK-IN-PROGRESS AND SHOULD NOT BE USED IN ANY ENGINEERING DESIGN WORK.
%}

%{
** ABOUT THIS SCRIPT FILE **
This code is written for the design of a a small earthen dam in rural Tanzania.
The purpose of the script file is to produce dam dimensions based on constants observed in the field.
The methodology used in this design is from the book 'Design of Small Dams' written by the United States Bureau of Reclamation.
%}

% CONSTRAINING VARIABLES
channel_width_bottom = 30; %(ft) measured in field with pacing
channel_side_grade = 26.6; %(degrees) estimated 2:1 slope using site photo/video
protection_thickness_front = 1.5; %(ft) small dams book and own analysis
protection_thickness_top = 1;%(ft) small dams book and own analysis
protection_thickness_back = 1; %(ft) small dams book and own analysis
dam_foundation_height = 8; %(ft) height of the dam without top slope protection
min_freeboard = 4; %(ft) from small dams book
excavation_depth = 5; %(ft) based on OSHA safety



% geometric calculations
dam_full_height = dam_foundation_height + protection_thickness_top; %(ft)
crest_width = round(dam_foundation_height / 5 + 10); %(ft) round to nearest foot for simplicity
dam_width_bottom = channel_width_bottom; % (ft) measured at toes of dam
excavation_width = channel_width_bottom; % (ft)
dam_width_top = round(dam_width_bottom + 2 * (dam_foundation_height / tand(channel_side_grade))); %(ft) (crest length)
freeboard_height = dam_full_height - min_freeboard; %(ft)

% (ft) how far the spillway extends past the edge of the crest on the front
%side. Used for dimensioning purposes in plan view
sw_ext_front = ((min_freeboard - protection_thickness_top) / tand(channel_side_grade)) + (protection_thickness_front / sind(channel_side_grade));

% (ft) how far the spillway extends past the edge of the crest on the front
%side. Used for dimensioning purposes in plan view
sw_ext_back = ((min_freeboard - protection_thickness_top) / tand(channel_side_grade)) + (protection_thickness_back / sind(channel_side_grade));

foundation_volume = 9315; %(ft^3) calculated in onshape 3D model

%(ft) approx needed length for two excavations to fufill foundation soil
%reqs. Rounding to 35 to account for slope at ends of cuts.
excavation_length = (foundation_volume / excavation_depth / excavation_width)/2;
```

Figure E1: Matlab Script used for Geometric Dam Calculations