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SUSPENSION FOOTBRIDGE CONSTRUCTION IN ETHIOPIA AND RWANDA: A COMPARATIVE STUDY

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ABSTRACT: Trail bridges are vital for improving rural connectivity and living standards. Their construction minimally impacts the environment and causes less disruption. These bridges are crucial for safe river crossing, reducing travel time, and aiding in education, healthcare, and market access. This research aimed to identify best practices by evaluate and compare the design and construction of trail bridges in Ethiopia and Rwanda. The study used data from focus group discussions, expert interviews, and on-site observations in both Rwanda and Ethiopia. Significant distinctions in N-type suspension bridges constrcution noted, particularly in the simplicity of the steel tower, its foundation connections, and main cable anchorage in Rwanda compared to Ethiopia. Ethiopia's bridges, however, were praised for bridge tower and suspenders easely adjustable, maintenable and local material use. The results from the expert questionnaires reveal a strong consensus on the importance of integrating bridge users or community input into the creation of design codes and standards to enhance bridge functionality and user-friendliness. The case study and field observation reveled that, the construction of trail bridges in Ethiopia is more costly than in Rwanda. In Conclusion, the research identified both deficiencies and strengths within the Ethiopian and Rwanda Trail Bridge constrcution practices. The study recommends updating the design manuals by integrating the most effective elements and best practices from each country.

KEYWORDS: Cable bridge; Eco-friendly construction; Rural access; Suspension footbridge; Trail bridges.

1 INTRODUCTION

Poverty remains one of the most significant global issues, with a well-documented link to accessibility. It's widely recognized that areas with limited access often face higher levels of poverty [1,2]. The relationship between access and poverty is deeply intertwined. In their study, Li and colleagues utilized satellite imagery to quantify rural access by measuring the Non-Served Rural Population (NSRP). This metric offers an alternative to the Rural Access Index (RAI), providing a count of the population unreached by transportation infrastructure. The research highlighted that Nigeria, Ethiopia, and the Democratic Republic of the Congo each have an NSRP exceeding 30 million [3]. Given that Congo and Ethiopia rank among the world's poorest, this raises the question of whether inadequate infrastructure is a contributing factor. In Rwanda, however, trail bridges significantly enhance rural connectivity, thereby elevating the standard of living in rural areas [1]. Constructing trail bridges is one of the most effective strategies to improve both rural access and the quality of life for those living in disadvantaged rural areas [4]. These bridges enable thousands to safely traverse rivers, drastically reducing travel time, facilitating children's education, providing villages with access to healthcare, and helping farmers reach their fields and markets. Trail bridges present a cost-effective alternative to the more expensive medium and large-sized concrete or steel bridges, offering a viable solution for regions with limited infrastructure funding. Juji D. et al highlighted the infrastructure deficit in Sub-Saharan countries, underscoring the need for affordable solutions [5]. The challenging topography and absence of narrow riverbanks often make the construction of conventional bridges impractical. Moreover, for the purposes of pedestrians, cyclists, motorbike and carts, heavy-duty materials such as big concrete mass are not necessary. Therefore, a lightweight and economical bridge system is the preferred choice. Trail bridges stand out as the optimal solution for rural connectivity, being not only affordable and lightweight but also environmentally friendly with a minimal carbon footprint [6].

The construction of trail bridges in both Ethiopia and Rwanda is based on Nepalese models. Bridges to Prosperity (an NGO working in rural access in Rwanda and other African countries) has adapted the Nepalese practices to suit the unique requirements in Rwanda and other African countries [7]; while Ethiopia's trail bridge design manual is a direct adoption of the Nepalese system [8]. This study aims to evaluate trail bridge designs and construction methods in Ethiopia and Rwanda to recommend best practices. The criteria for "best practices" include construction & maintenance ease, local material use, construction time efficiency, and cost-effectiveness. The research identifies areas for enhancement and uncovers gaps in current design and construction approaches to foster improvement. It also documents good practices from a two-country comparison, serving as a learning resource and a foundation for updating design manuals.

2 LITRATURE REVIEW

2.1 Trail bridges construction in Ethiopia & Rwanda

In many countries, the ropes of creepers, vines, and other trailing plants are the natural sources that gave rise to the concept of a suspension bridge. It's likely that nature fashioned the earliest bridges for river crossings, such as a tree limb extending over to the opposite bank, trees that had unintentionally fallen to form a connection between two stream sides, or the natural arches created by the erosion of soil underneath, among various other conceivable natural formations. It is widely acknowledged that rural residents benefit from having a safe route to cross rivers. Such crossing sites would improve communities' access to services, markets, and jobs, boosting their standard of living in the process [9]. In order to achieve this goal, Rwanda and Ethiopia have been encouraging the development of trail bridges in rural areas. Various trail bridges have previously been built with various partners.

Rwanda has a land area of 26,337 square kilometers, of which 11,880 square kilometers are water, and is situated along the Great Rift Valley in the mountains of east central Africa. The Virunga Mountains, a range of volcanoes that form the western frontier of the nation in the Congo/Nile watershed, rise high from the landscape [10]. With its geographical condition Rwanda is committed to addressing the issue of a lack of footbridges in rural areas. For the past ten years, districts in Rwanda have worked with German Engineers without Borders and the international non-governmental organization Bridge to Prosperity (B2P), which specializes in the design and construction of pedestrian footbridges, to design and construction of trail bridges. Over 150 trail bridges constructed in different districts of Rwanda, including suspension and suspended trail bridges. So far, the longest trail bridge built in the country is spanning 150m.

Ethiopia has Flat-topped plateaus, high and rugged mountains, deep river gorges and vast plains. Ethiopia's topography is remarkably diverse, with altitudes stretching from 125 meters below sea level at the Kobar Sink to the towering peak of Mount Ras Dashen, which rises 4,620 meters above sea level and stands as Africa's fourth tallest mountain. The nation is aptly named 'The Roof of East Africa,' given that over half of its terrain exceeds 1,000 meters in elevation, and a substantial 44% of the country lies above 1,500 meters [11]. This topographic feature dictates the need for the construction of trail bridges in Ethiopia. In 2003, Ethiopia government in collaboration with HELVETAS Ethiopia (Swiss based international NGO) started constructing trail bridges. So far over 130 trail bridges constructed in various parts of Ethiopia, including suspension (N-type) and suspended (D-type) trail bridges. The longest trail bridge built in Ethiopia is spanning 120m [2].

According to Bridges to Prosperity trail bridge design manual, 3 types of trail bridges are built in Rwanda [7] whereas in Ethiopia only two type (suspended (D-type) and suspension (N-type) are constructed [8].

Suspended trail bridge: for which the cables supporting the walkway surface hang from masonry abutments on each bank of the river. These bridges are suitable for short to mid spans in gentle sloping valleys and short to long spans in gorges. It is commonly referred to as D-type, named after the final letter in "suspended." Suspended bridge: “often referred to as the catwalk, which is a modern version of the traditional chain bridge. The walkway is unstiffened and directly fixed on the main cables lying underneath. The sagging walkway is anchored directly to the main anchorage blocks without using any tower structures” [12,13].

Figure 1. 109 meters long suspended bridge Constructed in Chole woreda, Oromia region Ethiopia

Figure 2. 120m long suspension Bridge under construction in Ethiopia

Suspension trail bridge: that is a cable bridge which utilizes load bearing cables above the deck that are strung across high towers with an arching walkway. This design is most suitable for use in flat river terrain or in flood plains where achieving freeboard could be difficult. It is commonly referred to as N-type, named after the final letter in "suspension." The suspension bridge is a light bridge construction with an un-stiffened walkway, towers, and generally gravity anchorages on both river banks. The walkway is suspended by adjustable hangers, which are connected to the overhead main cables.

Hybrid trail bridge: this is a type of bridge that combine both suspended and suspension due to the high difference in elevation between the banks.

2.2 Trail bridge components

Trail bridge components are the parts that make up a bridge. Some of trail bridge components are indicated in the above fig. 6 Suspension type and in fig 7 Suspended type, i.e. N-type & D-type, respectively. The major trail bridge components are then discussed below.

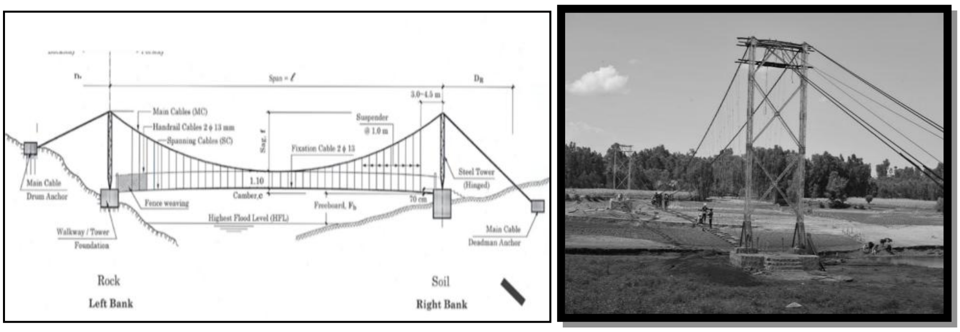

Figure 3. Suspension foot bridge layout and photo

Main cables: are the main load bearing element in a trail bridge. In N-type bridge, the main cables are the cables that run along the top part of the bridge which are supported over the tower and are anchored at the ends. They support the weight of the bridge and the loads on it. In D-type bridge, the main cable run below the walkway and supported over the walkway saddles and anchored at the end on the dead man concrete block anchorage.

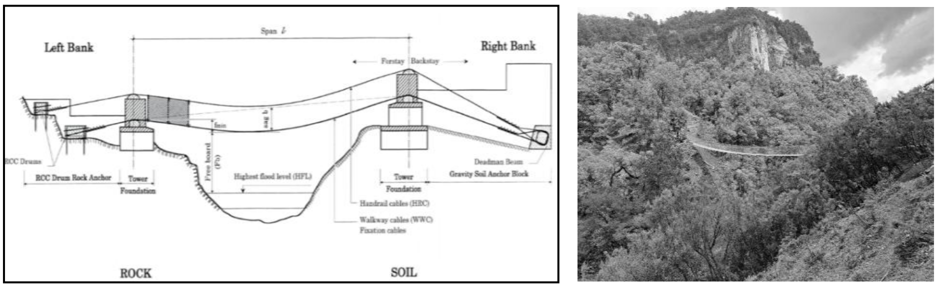

Figure 4. Suspended (D-type) foot bridge layout and photo

Handrail cables: are cables that serve as a handrail in D- type bridge. They run along the top of the masonry tower and anchored at the end on the same place as the main cable in D-type bridge. These cables are designed to carry some load during ultimate loading in D -type bridge. Whereas in N -type bridge, they do not carry loads, only serve as a handrail.

Spanner Cable: - are cables used in N-type bridge, below the walking decks. They are used to add stability to the bridge.

Fixation cable: - these are cables used to fix the wire mesh over the walkway decks.

Suspender cables: are the cables that hang vertically from the main cables and connect them to the deck cross beam in case of the N- type bridge. They transfer the loads from the deck to the main cables. In the case of D-type bridges, they hang from the handrail to the cross beam. At full load, in D-type also they transfer load from the deck to the handrail cable [12].

Deck: The deck is the surface of the bridge where people walk and ride. It is usually made of wood, steel, or concrete planks.
Cross Beams: they support the decking and are load transferring element to the main cable.

Towers: The towers are vertical structures made of steel and support the main cables in N- type bridge and hold them at a certain height and distance. The towers are masonry in the case of D-type bridge, and they support the handrail cables.

Foundation of the tower (or piers): is the base of the tower that is fixed to the ground or the riverbed. It provides stability and strength to the tower.

Anchors: are the devices that secure the cables to the ground or the bridge itself. They prevent the cables from slipping or moving. Based on the ground soil type these can be dead man or drum anchorage.

3 MATERIALS AND METHODS

A structured questionnaire was distributed to various trail bridge experts, including designers, builders, and government officials involved in construction. The technical questionnaires were prepared using Google Docs and distributed through various means to contractors, consultants & government engineers engaged in the sector. The questions categorized into different sections under design codes & standard, Trail bridge design features & Construction.

In the questionnaire, design & construction related questions are made conditional. For example, if the technical person who is filling the questionnaire does not have experience related to cable bridge design, then the following question skips him, and the system directs the respondent to the next section. This ensures inter-rater reliability. To validity & to avoid missing aspects, the questions are designed in such a way that they capture most of the measures and in case anything is missing, the respondents are offered freedom to add. In this way content validity has been given due emphasis. In this study, 98 experts are involved and responded to this questionnaire. 88% of the respondents confirmed that they took adequate training on Trail Bridges. Out of the total 98 respondents, 70 are from Ethiopia whereas 28 are from Rwanda. According to the data, 53% of the Ethiopian experts are already involved in the study and design of Trail Bridges in addition to 31% involved in different construction and/or Supervision works at site. Whereas 32% of the Rwandese experts were involved in the study and design works of Trail Bridges in addition to 79% confirmed their involvement in different construction and/or supervision works. Thus, this makes the respondent capable of answering the questionaries and giving reliable responses.

The research team undertook field observations of trail bridge sites across various regions of Ethiopia from August 14-18, in Rwanda the western, southern, and eastern districts from August 28 to September 2 in 2023, capturing a variety of informative photographs. The filed observation helped to discern the differences in construction and design approaches between Rwanda and Ethiopia.

Additionally, two focus group discussions conducted with key stakeholders and participants, including university representatives, road administration officials, regional/district road authorities, and members from design and construction firms, as well as engineering associations & institute of engineers. The initial focus group discussion took place in Kigali at the Great Seasons Hotel on September 4, 2023. The subsequent discussion was hosted in Addis Ababa at the Jupiter Hotel on September 21, 2023, centering on a reflection workshop regarding the revision and adaptation of the Ethiopian Trail Bridge Design Manual. During the focus group discussions, clarity of purpose was provided to the participants as each lead author elucidated the content and goals of the research areas, which was then followed by a period for discussion. The discourse was structured around various questions that fell into three main categories: design, construction, and maintenance & sustanaibilty of Trail bridges.

Moreover, comparative evaluations of bridges in each country focused on material weight and size done. For a direct comparison, two trail bridges (one suspension and one suspended) with similar spans were randomly selected to analyze material use and the relative cost efficiency of each country's construction methods.

4 FINDING, RESULTS AND DISCUSSION

This section presents the findings from site observations, focus group discussions, and expert questionnaires. The results and discussions are organized into subsections, each addressing specific components and design features.

4.1 Bridge components: anchorage, foundation & tower

The result of the filed observation shows that in Rwanda, the steel tower is made from two vertical legs and diagonal members connected to the legs as shown in the figure below. The legs are simply pipe sections of 220mm filled with concrete. The diagonal and top horizontal members are angle iron 76/76/6 connected to the vertical members using bolt connections. The B2P manual gives standard drawings of different tower heights from 4.50m to 9.0 m for bridge spans varying from 30.0m to 84.0m.

Whereas in Ethiopia, the vertical legs are made from four angle irons 65/65/6 arranged as shown below and connected using steel rods of dia. 16mm to form a truss like structure. These vertical legs are manufactured at workshops to a standard height of 1800mm each and connected and assembled at site using bolt connections. The standard heights of the tower are 5.50m, 7.35m, 9.20m, 11.05m depending on the span of the bridges varying from 30.0m to 120.0m. From the focus group discussion on the tower selection, the participant compared the two kind of practices and assigned qualitative criteria to compare both. As a result, the following qualitative comparative table anenoumsly agreed by the participant.

From the filed observation & focus group discussion, it is easy to conclude that Rwanda tower selection and construction practice is simpler in the overall design and construction procedure and less time taking than the one adopted by Ethiopian. However, part by part maintenance and replacement is difficult for Rwanda style tower.

Figure 5. Steel tower, Rwanda style

Figure 6. Steel tower, Ethiopian style

Table 4.1. Focus group discussion result: qualitative comparison of N-type trail bridge tower in Rwanda Vs Ethiopia

Comparison Criteria	Rwanda Tower style	Ethiopia Tower Stype
Material availability	Difficult (imported)	Easy (locally manufactured & imported available)
Time of Construction	Short (1 week – including fabrication time),	Long (3 weeks for fabrication, 2 -3 weeks for assembly)
Ease of Construction	Easy & simple errection tehniques	Difficult & laborous method of erection
Maintenance	Difficulty of parts replacement as the materials are imported. Monolothic construction.	Replacement is easy, materials are accessible from local market. It is not monolithic, part by part maintenance and replacement possible.
Aesthetics	The focus group participants showed different opinion on the aesthetics of each bridge. The result is 1:1, half of the participant favoured the Ethiopian style and others favour the Rwanda tower.	

Likewise, the focus group participant discussed on the symmetrical and assemtric design practice of tower in Ethiopia and Rwanda respectively. This is due to whether allowing high differentials for the tower foundation or not. The height difference “h” between the two foundation blocks not only has adverse structural effects, such as excessive eccentricity on the abutment tower, but also decreases serviceability by producing steep walkways. In the suspended (D-type) of the trail bridge, both B2P and the Ethiopian manual gives similar recommendations limiting the height difference to four percent.

However, the difference in the recommendation arise in the suspension (N-Type) trail bridge where the B2P manual allows a maximum height difference of 2% of the span (l/50) whereas the Ethiopian and Nepali manuals don’t allow any height difference between the two cable saddles on the left and right banks. Table 4.2 presents the qualitative comparison resulted from the focus group discussion.

While both guidelines have their merits, it is important to ensure that the recommended height difference is appropriate for the specific environmental conditions, materials, and construction methods used in each country. Safety, stability, and serviceability should be the primary concern when designing and constructing bridges.

It is true that the standardized manual followed by Ethiopia has its own pros and cons. This standardized manual has simplified the design task where the designers are engaged in deciding the design parameters and selecting the respective detailed drawings as required satisfying certain site conditions and code recommendations. Any offset from the code provisions and limits will result in a complete shift from the manual.

Table 4.2. Focus group discussion Results of qualtative comparision Tower foundations of N-type bridge

Criteria	B2P – Rwanda practice	Ethiopia practice
Foundation at the two banks	Allow up to 2% height difference between two bank tower foundation	No height differential allowed
Cost	Low cost as it tries to avoid high excavation or masonry work	High construction cost related to excavation & masonry work to avoid high differentials
Constructability	The substructure is easy to construct. But superstructure need carful calculation and assembly of suspenders	The substructure may take more time of excavation or masonry construction. The superstructure is symmetric and suspenders are easy to assemble.
Design	As it is asymmetric and as a result suspender assembly is difficult and needs separate calculation for each suspender. Design complication. Loads may not be uniformly distributed resulting differential stress.	The superstructure is symmetric and this gives freedom of replicating suspenders. Loads are uniformly distributed and thus stress are distributed uniformly. Design is simple and mirror copy of one side to the other is possible.
Maintenance	It is not easy to maintain	Maintenance of suspenders is relatively easy.
Aesthetics	There are people who favour symmetric construction and said it is more attractive than the asymmetric. And there are also advocates of the asymmetry considering the condition 'fit to the natural ground condition', claiming that it gives more aesthetics if the natural ground condition is reflected on the foundation high differentials. 60% of the participant favoured the symmetric Ethiopian experience against 40% that favoured the asymmetric Rwnada experience.	

On the other hand, depending on the site conditions, ensuring no height difference as per the standardized Ethiopian manual can either force changing the site location which can impact the use of the bridge or increasing the tower foundation height which can implicate additional cost or increase in budget.

The next point the focus group discussed was about main cable anchorage & transition arm in N-type Bridge. An anchor block is a large concrete structure that anchors the main cables of the bridge to the ground. In N- type suspension bridges, the main cables are attached to the anchor block and are then stretched across the span of the bridge, providing the primary support for the deck and pedestrians. The anchor block must be able to withstand the uplifting, sliding and/or overturning effect generated from the tension forces of the main cables, as well as any additional loads placed on the bridge by wind, traffic, or other external factors. The anchor block consists of the dead man and the transition arm. See the figure below.

Figure 7. Anchor block, left B2P construction in Rwanda, right Ethiopia practice

Figure 8. Anchor block transition arm, right B2P construction in Rwanda, left Ethiopia practice

The focus group participants evaluated two types of anchorage systems, considering factors such as cost, ease of construction, and material availability. The consensus favored the B2P construction method used in Rwanda, noting the use of reinforced bars and concrete for transition arms, as opposed to the steel plates employed in Ethiopia. The cost comparison revealed that reinforced bars are priced approximately at 150 birr (1.5 USD) per kg, significantly higher than steel plates at 280 birr (2.8USD) per kg. Additionally, steel plates require further fabrication—such as hole making, bolting, and cutting—performed in metal workshops, whereas reinforced bars can be processed directly at the construction site, eliminating the need for workshop activities and associated costs.

The focus group participants commended the turnbuckle system used in the Ethiopia/Nepal suspension bridge anchorage block system, which is absent in the Rwandan B2P construction method. Turnbuckles are instrumental in retightening loose cables during construction, allowing for adjustments and fine-tuning, a feature not available with the Rwandan method.

The group, including experts, proposed a hybrid anchorage approach—integrating the B2P system with the turnbuckle arrangement from the Ethiopia/Nepal model. This hybridization aims to optimize costs and enhance the efficiency of the anchorage system.

4.2 Loadings: Maximum distributed loads, point loads & wind

Design load is another crucial aspect that is considered at different stages of the design. Distribute load "w" is considered when designing the cables and point loads arranged in certain way is considered when designing the steel decks. The difference in the distributed live load in the two manual is very small. The Ethiopian manual suggests a distributed load of

$$w = \begin{cases} 4kN/m^2 \dots\dots\dots\dots\dots\dots for \quad l \leq 50m \\ (3 + 50/l)kN/m^2 \dots\dots for \quad l > 50m \end{cases} \tag{1}$$

Whereas the B2P manual recommends

$$w = \left\{4.07 * \left(0.25 + \frac{4.57}{\sqrt{A_1}}\right)\right\} kN/m^2 \tag{2}$$

Where: w the design live load (kN/m2)

l span length (m)

A_1 = the walkway area (m2)

However, regarding the point load, the Ethiopian manual considers two porters passing each other with each P = 150kg of point load spaced laterally at half the walkway width and along the bridge span at 0.6m as shown below.

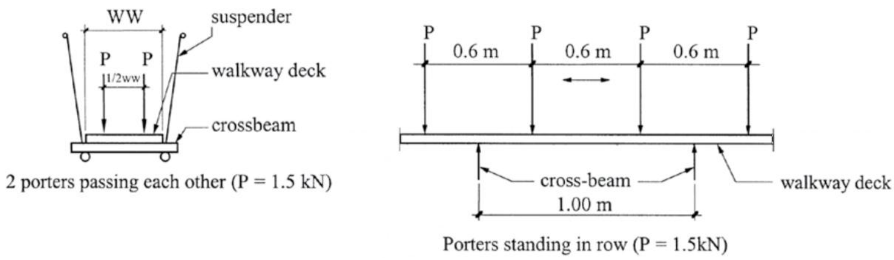

Figure 9. Point load arrangement in Ethiopian design manual [9]

Whereas the B2P manual considers a point live load imposed from livestock, horses, and motorbikes represented by a single point load of 2.22 kN (226.3 kg) located anywhere across the bridge width.

Eighty percent of participants in the focus group were satisfied with the current load capacity, but 20% suggested increasing it to 5KN/m2 to account for the average weight of an individual carrying goods. In Rwanda, about 85% of participants in the focus group discussion expressed satisfaction with the point load, considering that the heaviest livestock that may cross the trail bridge is a cow that varies up to 600kg, means maximum of 150 kg per leg. On the other hand, 15 % suggested increasing the point load considering the heaviest cow. From the Focus group Discussion held in Ethiopia, about 90% suggested to increase the point load considering different way of transportation of goods within Ethiopia. For Example, the camel is used for transportation in some regions. A camel can comfortably carry around 200kg and its weight varies up to 900 kg. This means it can weigh together with carry loads up to 1,100kg, or 275kg per leg.

The suggestion to increase the point load in Ethiopia raised important questions about safety, and durability. It is essential to consider the factors driving this suggestion, such us Way and mode of transportation, Camel weight, and how frequency the livestock can cross the trail bridge. This can help in understanding the evolving needs and challenges faced in each country. As the live load governs the cost and safety of trail bridge, it is particularly important to examine well the loading patterns. It is recommended to conduct further detailed research on the loading on trail bridges to better understand and helping the local engineering practicing to make decisions.

Wind loads are crucial design considerations for cable-supported bridges, as these structures dynamically respond to wind forces [14,15]. In the two countries Rwanda and Ethiopia, the design of Trail Bridges considers the wind load, which is assumed to be uniformly distributed based on a wind speed of 160km/h acting horizontally to the walkway. This results in a wind load of 0.50 KN per meter span. It is assumed that wind loads do not significantly affect trail bridges with spans up to 120m. The focus group discussions in Ethiopia and Rwanda revealed interesting insights regarding the design wind speed and its impact on Trail bridges. Approximately 70% of the Rwandan participants strongly suggested that the design wind speed of 160km/h may be too high. They argued that the open surface of the trail bridge allows wind to pass through without significantly affecting the structure. Therefore, they proposed considering the local conditions for each specific country when determining the design wind speed. On the other hand, about 30% of the participants recommended keeping the current design wind loads, emphasizing that the flexibility of the trail bridge allows it to absorb the impact of wind loads and may compromise its structural integrity. They expressed concerns that reducing the design wind speed could lead to potential failure of the bridge under extreme wind conditions. The suggestion to consider the local wind design speed raised important questions about the cost-effectiveness of trail bridges. It is crucial to consider factors such as local conditions and standards when designing trail bridge projects. This approach can help in understanding the evolving needs and challenges faced in each country, leading to more sustainable and resilient trail bridges. The focus group discussions in Ethiopia and Rwanda highlighted the importance of considering local conditions when designing trail bridges. By incorporating feedback from stakeholders and adapting design parameters to suit specific environments, it is possible to ensure the safety and longevity of trail bridge structure in diverse geographical locations.

The design of cable bridges requires careful consideration of various load combinations to ensure the structural integrity and safety of the bridge. The two countries have different approaches to determining load combinations based on local conditions and structural requirements. In Rwanda, the standard load combination for cable bridges is taken as:

$$DL + EH + LL \tag{3}$$

Where: DL Dead Load
EH Lateral Earth Pressure, and
LL Live Load.

This load combination is suitable for standard cable bridges where wind does not significantly affect lateral movement. However, for long span bridges in Rwanda where wind is a significant factor affecting lateral movement, lateral stabilizers are required. In this case, the load combination becomes

$$DL + EH + LL + 0.3WL \tag{4}$$

Where: DL Dead Load
EH Lateral Earth Pressure, and
LL Live Load.
WL Wind Load.

The temperature effect, seismic, and ice or snow load are ignored in Rwanda due to their low probability of occurrence. On the other hand, in Ethiopia, the full load case is considered when designing the foundations and steel parts, including cable structures. Wind load is only considered when designing steel towers and wind guy cables. Currently, three load cases are considered in Ethiopia including live load, dead load, and wind loads. Like Rwanda, the temperature effects, seismic, and ice or snow load are not considered in these countries. Based on the data collected from focus group discussions in Rwanda and Ethiopia, all participants supported the load considerations and combinations being used in their respective countries. The participants emphasized the importance of considering local conditions and structural requirements when determining load combinations for cable bridge design. The load combinations used in Rwanda were deemed appropriate due to the presence of long span bridges where wind significantly affects lateral movement. The data analysis of load combinations in cable bridge design in Rwanda, and Ethiopia, highlights the importance of considering local conditions and structural requirements when determining load combinations. The load combinations used in these countries should be tailored to their specific needs and ensure the structural integrity and safety of cable bridges. Further research and analysis may be needed to explore additional factors such as temperature effects & seismic load in future cable bridge designs.

4.3 Miscellaneous design features: Bridge width, access structure & free board

Trail bridges are often constructed with fenced walkways to prevent people from falling, ensuring the safety of users. However, the design of these bridges can sometimes limit the width of the walking path, which may pose challenges for individuals carrying wider loads. During site visits in Rwanda, and Ethiopia, it became apparent that people in these countries have different styles of carrying loads. In Rwanda, for example, it is common for individuals to carry goods on their heads, a method that is not significantly affected by the width of the bridge walkway, as the fencing is typically less than 1.3 meters high. However, the use of bicycles as a mode of transport in Rwanda presents a challenge, as the width of the walkway (typically around 1.7 meters) may not accommodate the wider load of a bicycle, which can be up to 2.5 meters in width.

Figure 10. Loading style in rural Rwanda

In Ethiopia, people often carry loads on their backs in a horizontal position, which have an impacted on determining the bridge walkway width. In some cases, individuals may need to navigate the bridge in an inclined position to accommodate a wider load. These observations highlight the importance of considering the specific loading styles and needs of users when designing trail bridges. By considering the unique characteristics of each country or region, bridge designers can ensure that the walkway width is sufficient to accommodate a variety of loads and carrying methods. This approach not only enhances the usability and safety of trail bridges but also helps to meet the diverse needs and expectations of bridge users. The design of trail bridges should be tailored to the loading styles and requirements of the local population. By incorporating these considerations into the design process, bridge engineers can create structures that are functional, safe, and accessible to a wide range of users.

Figure 11. Loading style in rural Ethiopia

Results from expert questionaries also supported the above field observation. When dealing with the width of the bridge, a crucial factor the come to the front is the lifestyle of the community and how they carry and/or transport their goods/products to the market. The below figure 12 refers to the load transportation habit of the communities in Rwanda and Ethiopia

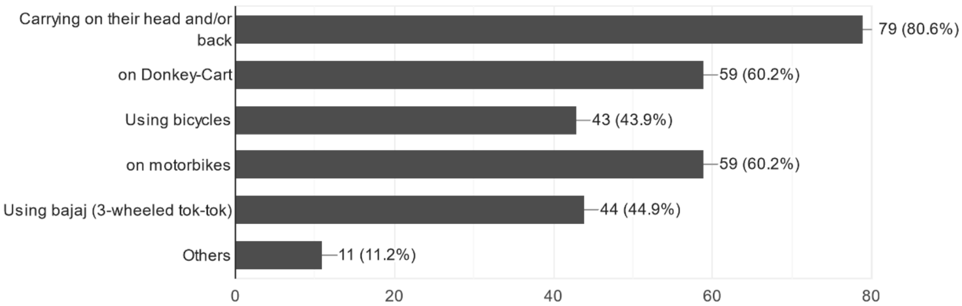

Figure 12. Common way of load transportation in the research countries

As has been shown in the above figure, the community uses various methods and means for transporting goods. A significant majority, 81%, indicated that people carrying goods on their head or back is the prevalent mode of transport among rural communities. In Ethiopia, about 60% of respondents acknowledging the use of donkeys and motorcycles for the purpose of transporting goods. This shows that both the fields' observations and the questionaries analysis revealed the need for accommodating different modes of transportation, including pedestrian and non-motorized load transporting systems. In addition, a significant number of experts participated in the questionaries suggested that the width of the bridge need reconsideration (see fig 13). The recommended width according to the experts should be greater than 1.06m. The revision process could involve incorporating the research findings on the bridge users' way of carrying and/or transporting their goods and products to the market. Considering these facts, 88% of the respondents suggested increasing the bridge width to 1.20m (10%), 1.50m (34.7%) and 2.0m (43%). This unusually high weighting could indicate that the current guidance on bridge width design is either insufficient or not comprehensive enough for the variety of bridge applications encountered in practice.

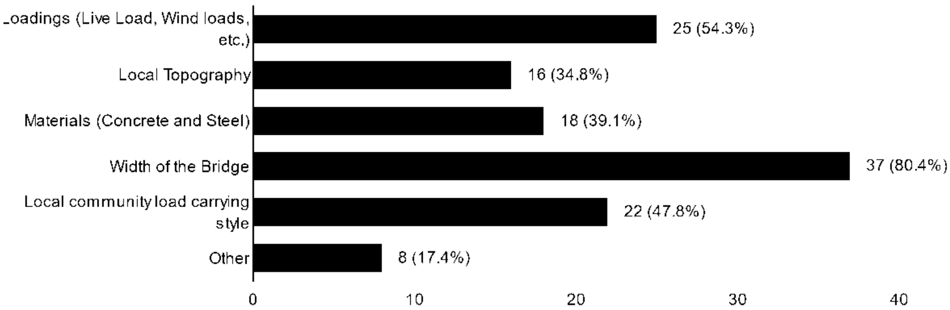

Figure 13. Design features need revision in the manual

Based on the gathered data, a substantial 80% of respondents highlighted the "Width of the Bridge" as an aspect in need of significant updates in the manuals. Additionally, 54% of respondents recommended revising the load specifications, while 48% pointed out the local community's load-carrying practices, further emphasizing the importance of reassessing the adequacy of bridge width. Observations from Nepal revealed a flexible approach, with the adoption of trail bridges up to 1.5 meters in width. In areas where Motorbike and Bajaj predominate, they use 1.5m wide steel trusses bridge and even D- & N-Type trail bridges. This adaptability has facilitated the use of three-wheelers (Bajaj). This practice suggests that there is potential to expand the current design standards to accommodate wider bridge specifications in both Ethiopia and Rwanda. In Rwanda, there are few bridges constructed by Germans with 1.5m width in Rwanda too.

Access structure: Ramp Vs staircase

Modern bridge design emphasizes adherence to universal design principles, aiming to create accessible infrastructure for all users. Ethiopian manuals stated a staircase as the access structure to bridge whereas the B2P manual provided a ramp instead. The collected data regarding user preference for access structures on the TRAIL Bridge reveals a strong preference for ramps (81%) over staircases (19%).

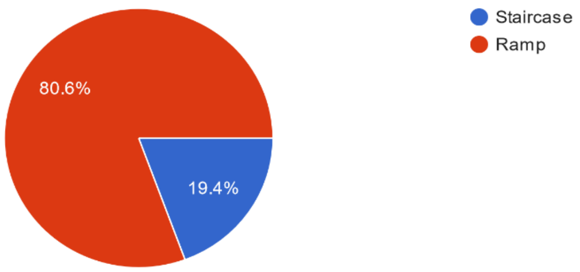

Figure 14. Access structure Ramp Vs Stair

Ramps offer a significantly gentler incline compared to staircases, making them easier to navigate for individuals with mobility limitations, using wheelchairs, bicycles, motorbikes or pushing strollers. In addition, ramps provide a more stable walking surface compared to staircases, potentially reducing the risk of slips and falls, particularly for elderly users, children, and those with balance issues. Furthermore, Ramps allow for a more gradual ascent and descent, enhancing user comfort, especially for those with physical limitations or carrying heavy loads. However, there are opinions from a few experts and community members that ramps tend to be slippery for their cattle's especially when higher slopes are used and thus tends to prefer stairs. In such locations, dual systems are preferably used incorporating both staircase and ramps side-by-side in the access system.

While the data suggests a clear preference for ramps, it is important to acknowledge the potential drawbacks such as space requirements compared to staircases where ramps require more horizontal space for construction, which might be a limitation on bridges with tight spatial constraints. In summary, the B2P manual seems to adhere to the users' preference than the Ethiopian and Nepali's manual.

Free board

The free board, which is the elevation difference between the highest flood level to the lowest point of the bridge, is another important parameter addressed in this study. The Ethiopian manual state a minimum free board of 5.0 m with some allowance to reduce in exceptional cases of flat and wide riverbanks.

Whereas the B2P manual provides a minimum of 2.0m with the possibility of increasing it to 3.0m in locations with steeper slopes.

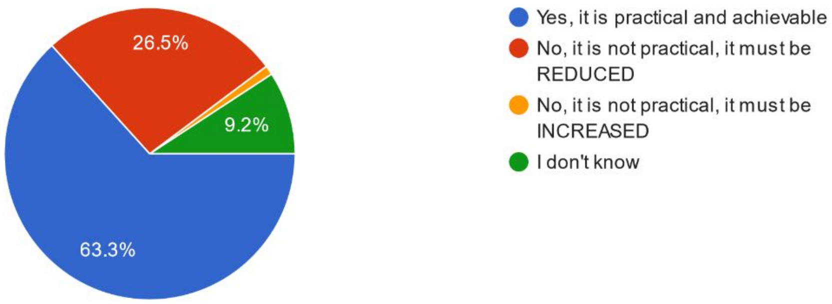

Figure 15. Respondent opinion on the Free board specified in the Ethiopia & B2P design standard

Even though the collected data shows that 63% of respondents responded that the current free board specified in the code is adequate. A significant percentage (27%) of the participants believe that the freeboard of 5.0m should be reduced. Whereas other participants suggested to treat each site considering in respective local conditions.

Analysis results on 19 sample bridges from Amhara region and field observation experiences shows the need to further study and contextualize the standard free board requirement under the Ethiopia's prevailing geographic, topographic, river flow, bridge type and other factors. Out of the bridges observed, only 37% meet the standard requirement stated in Ethiopian Trail bridge design manual. 42% of the bridges have free board less than 3.5m and 21% of the bridges have free board ranging from 3.5 – 5.0m.

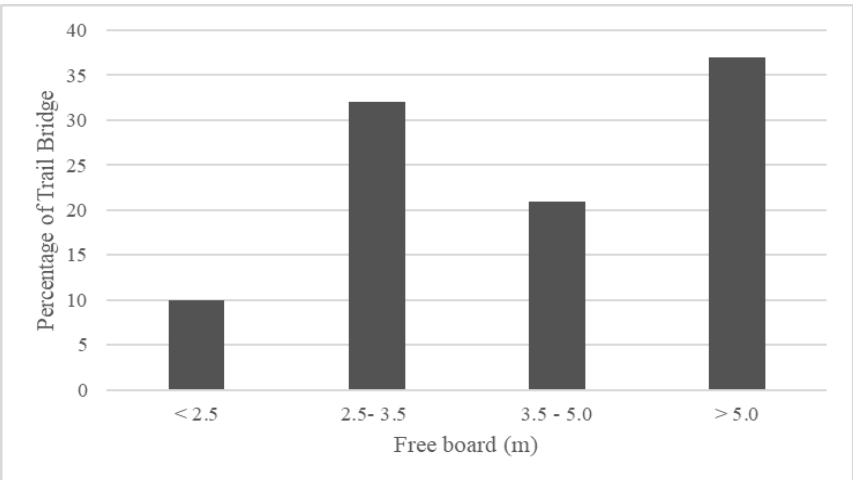

Figure 16. Freeboard as observed from constructed trail bridges in Amhara region, Ethiopia

4.4 Design code and standard

It is customary that countries adopt design codes and standards from other developed countries and customize it according to their local conditions. Ethiopia adopted “The European Committee for Standardization and the European Committee for Electrotechnical Standardization (CEN/CENELEC)” the European code while developing its Building code standard named Ethiopian Standard based on European Norm (ESEN). This is clearly declared in the National forewords of the Ethiopian building codes. It also states that the normative part of the code is chosen based on the local needs and construction practice [16].

Similarly, the Ethiopian Road Authority (ERA) Bridge design manual is based on the American Association of State Highway and Transportation Officials-Load and Resistance Factor Design (AASHTO) LRFD Bridge Design Specifications, 2nd edition, 1998, with modifications to Ethiopian conditions. This manual also acknowledges the Ethiopian building code as complement to its specifications. The case with the ‘Ethiopian Design Manual for Low Volume Roads Trail Bridges Manual - Part F’ is somewhat different. The code is adopted from the Nepali manual and maintained it without adjusting it to the actual local conditions and requirements. This is posing great challenges at design level as well as on the construction site. Some of these challenges are such as achieving the stated free board in so many regions of Ethiopia because of the terrain type difference between the two countries.

In the context of Rwanda, the trail bridges are being constructed by the adoption of the Bridges to Prosperity design, Manuals which were originally developed based on the experience of Helvetas Nepal. These Manuals have been customized to better suit the local conditions, ensuring that the trail bridges remain a sustainable option for communities in different topographic and geographic regions.

When designing any structure, design codes and standards must be followed to ensure the safety and quality of the structure. Ethiopian manual is adopted from the Nepali Short Span TB manual. The data from the expert questionaries (see fig 17) revealed that in Ethiopia most of the trail bridge designer use the Ethiopian trail bridge design manual, and most of them also refer the Nepali manual. However, in Rwanda, they use the design manual prepared by Bridges to Prosperity (B2P).

A deep observation to the Ethiopian manual shows that the actual site conditions and users’ opinions were not considered. This will eventually lead to inefficient use of the bridge. According to the data below in fig 14, 76% of the participants strongly agreed to include the users’/community’s opinion when drafting the code or design standards. This will surely increase the level of the serviceability of the bridge and increase the comfort of the users.

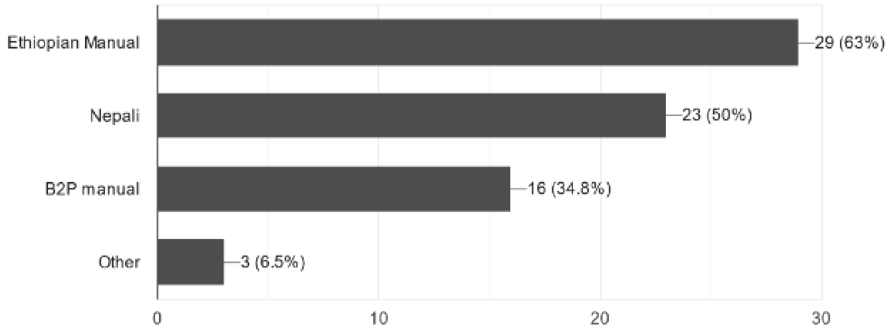

Figure 17. Design codes used for trail bridge design in Ethiopia and Rwanda

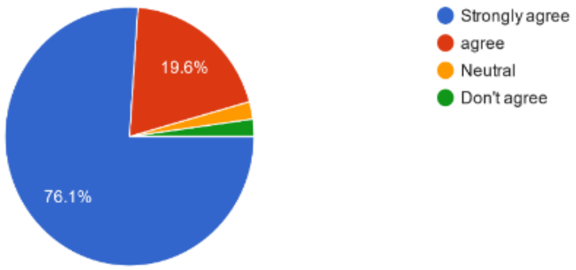

Figure 18. Opinion of designers to include community feedback during Design

Most Ethiopian design manuals are derived from international standards such as the Eurocode, and AASHTO, leading to a preference for these over Indian codes. For instance, the Ethiopian Roads Authority (ERA) manual is based on AASHTO, while the Ethiopian building design codes for reinforced concrete structures primarily follow the Eurocode. When designers were surveyed about their preferred codes for concrete structures, with the option to select more than one, Eurocode and AASHTO emerged as the top choices. The considerable influence of these codes poses challenges in integrating the Indian code.

Additionally, a survey revealed that Ethiopian experts are not remarkably familiar with the Ethiopian Trail Bridge Design Manual, which is limited in use to Helvetas Ethiopia [17, 18]. This lack of familiarity may stem from Ethiopian engineers' exposure to the Eurocode, whereas the Trail Bridge Manual, adopted from Nepal, utilizes Indian codes, which are less familiar to Ethiopian engineers. The expert questionnaires revealed that engineers are comfortable utilizing design codes from AASHTO and European standards.

However, the material provisions and certain design features outlined in the Ethiopian Trail Bridge Manual were somewhat unfamiliar to Ethiopian design engineers.

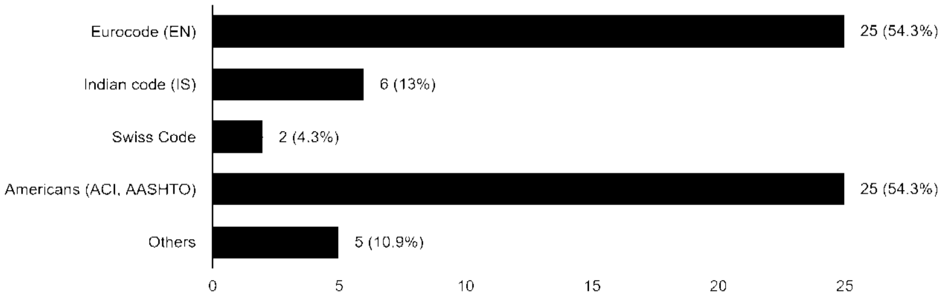

Figure 19. Design code preference of engineers during steel & concrete structure design exercises

4.5 Construction completion time, cost & materials

Experts who are involved in the construction and/or Supervision of Trail Bridge projects requested to specify the construction completion period in each country. Fifty-seven percent of the Rwandese experts expressed that the N-type bridges take less than 3 months to complete. Whereas the 65% of the Ethiopian experts have confirmed that a similar project may take up to 6 months. This difference can emanate from the difference in the construction methodology (i.e., the erection of the steel towers, the installation system of the walkways and suspenders, etc.) followed in the two countries.

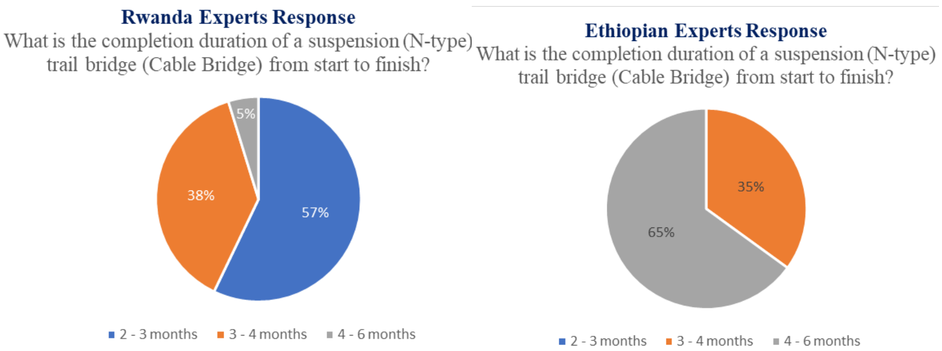

Figure 20. Suspension bridge construction time, Rwanda Vs Ethiopia

The simple steel tower made from vertical circular pipes filled with concrete connected by simple diagonal and horizontal steel angles members make it simple to assemble, install and errect in place in a very short period of time, in case of Rwanda. Whereas the Ethiopian steel towers are standard prefabricated truss like structure that is assembled on site. The complexity of the structure and accuracy needed during the assemply and erection makes it to take longer period of time.

Materails & Cost

The literature review & field observation have revealed that the construction & design of trail bridge vary between the two countries. For its completeness, two case studies undertaken, encompassing both a comparison and analysis of the Bill of Quantities for the N and D type bridges. This study aimed to quantitatively demonstrate the differences in trail bridge construction practices in the two countries. The findings of this case study offer a concise overview of the material differences and, by extension, the relative cost-effectiveness of each design. The tables provided below detail the project's quantity comparisons that were considered in this study. It is important to note that excavation and masonry foundation work were omitted from this comparison due to their dependence on topographical factors.

a) Case 1: D-type Bridge Construction Material comparison

To this case, in Ethiopia the research considered Wabe Trail bridge, a D type 108m sapn bridge constructed over wabe river in west Arsi zone of Oromia region. While similar bridge is considered from Rwanda, Rusayo Bridge over Muregeya river having 108 m span. The details of the bridge are presented in the following table 4.3.

Table 4.3. Details of the Bridge under comparison (Materials & overall cost)

Item Description	Unit	Quantity	
		Ethiopia	Rwanda
Steel Deck width	M	1.06	1
Number of walkway cable	No	4	4
Size of the walkway cable	Mm	32	28
Number of handrail cables	No	2	2
Size of handrail cable	Mm	32	28
Fixation Cable	Mm	2pcs, 13mm	2 pcs. 10mm
Bulldog Grips,	Pcs	32mm, 12x4=48 32mm, 12x2=24 13mm, 12x2=24	29mm, 6x8=48 29mm, 6x4 =24 10mm, 2x4=8
Anchor size/Deadman	m3	10	5
Reinforcement bar	Kg	249	680
Suspenders (10mm dia.)	Lm	310 (8mm)	432
Saddle parts (angle iron and flats)	Kg	27	24
Total Cable	Kg	3,300	3250
Cross beam	Kg	1,360	1,395
Walkway Panel	Kg	3927	2,722
Fencing in m2	Lm	216	216
Deck Bolts	Pcs	1300	1,300
Construction Cost/m	$	850	500

From the above table 4.3 one can generalize that Ethiopia trail bridge is heavier using additional steel weight on the walkway pannel (1000kg more than Rwanda) and higher cable size; as a result the cost of trail bridge construction is Ethiopia is 75% higher than Rwanda; Thought the cost factors are not only using higher quantity of steel materials. However, the stability of Ethiopian bridges are better than Rwanda. This might correspond to the use of higher cable size and more self-loads of the decking materials. Since Ethiopia manual did not consider the overburden load from the soil, it uses higher concrete volume for the Deadman anchorage than B2P Rwanda.

b) Case 2: N-type Bridge Construction Material comparison

In the second case, in Ethiopia the research considered Baro Trail bridge, N type 120m sapn suspended bridge under constructed over Baro river in Ilubabor zone of Oromia region; and similar bridge is considered from Rwanda, Gihororo Bridge over Nyabarongo river having 120 m span. The details of the bridge are presented in the following table 4.4.

Table 4.4. Details of N type bridge under comparison

Item Description	Unit	Quantity	
		Ethiopia	Rwanda
Steel Deck width	M	1.06	1
Main Cable	No	4	4
Size of Main cable (mm)	Mm	32	32
Handrail & Fixation cable	Pcs	4pcs, 13mm	4 pcs, 10mm
Spanner Cable	Pcs	2pcs, 32mm	2pcs, 13mm
Bulldog Grips, Main cable	Pcs	32mm, 12x4=48 32mm, 12x2=24 13mm, 6x4=24	32mm, 7x8=56 14mm, 120x2=240 10mm, 2x4=8
Anchor size	m3	44	15
Suspenders	Lm	1,220	1,680
Total Cable	Kg	4,723	
Cross beam	Kg	1,595	1,549
Walkway Panels	Kg	4,357	3,024
Anchorage flats, angles	Kg	1075	0
Reinforcement Bar	Kg	1,188	4,170
Tower foundation Anchorage	Kg/	805	21.7
Steel Tower	Kg	2,700	2,645
2” GI pipe	Lm	234	240
Fencing	Lm	240	240
Construction Cost/m	$	>1500	935

In general, trail bridge construction in Ethiopia is expensive as compared to Rwanda. Even if the cost of materials in Rwanda and Ethiopia are comparable the cost has a difference up to 70% for D-type bridge and more 80% of Rwanda in case of N- type bridge. This is mainly because of using too much weight steel decking and other materials in the Ethiopian case. In addition, B2P uses lesser size of spanning cable and lesser weights of other cables in general. Moreover, the spanning cable end connection is not fixed on the tower foundation. This might have resulted in lesser stability of B2P Rwanda cable as compared to Ethiopia bridge.

4.6 Health & safety in construction sites

Health and safety in construction sites is a critical aspect that cannot be overlooked in any construction project. It is essential to ensure the safety of workers, as well as the tools and equipment being used on site. In Rwanda, the importance of safety in construction sites, particularly in trail bridge construction sites, has been recognized and implemented as a culture. Workers at these sites are provided with all necessary personal protective equipment, site hazards are identified and mitigated, and safety training is provided to all workers.

However, in Ethiopia, safety in trail bridge construction sites is still substandard. Workers are not adequately protected, and there are numerous risks present on these sites. The data analysis from the expert questionnaire, revealed that the health and safety measures are not fully practiced at some trail bridge construction sites as reported by a sizable number of respondents (around 30%). Data analysis from focus group discussions and site visits has shown that most participants support the idea of building a safety culture in all trail bridge construction sites. They believe that safety measures are essential to protect workers and others from potential risks and hazards, especially when working at heights above water bodies.

On the other hand, a minority of participants argue against investing in safety culture, citing concerns about increased costs for trail bridge projects. It is crucial to consider both perspectives when addressing safety in construction sites. While safety measures may increase the overall cost of a project, it is essential to prioritize the well-being of workers and the community. By investing in cost-effective safety measures and utilizing local methodologies where possible, it is possible to maintain safety standards without significantly increasing project costs. The debate surrounding safety culture in trail bridge construction sites highlights the need for a balanced approach that considers both safety and cost implications. It is essential to prioritize the safety of workers and the community while also exploring cost-effective solutions to ensure that safety standards are met.

5 CONCLUSIONS

The research identified both deficiencies and strengths within the Ethiopian and B2P Rwanda Trail Bridge design and construction practices. The team recommends updating the design manuals by integrating the most effective elements and best practices from each country. It is crucial to consider the community and expert feedback in finalizing the design manual, avoiding a top-down approach that assumes what is best for the community without their input. The updated manuals should align with the design codes commonly used for concrete and steel within the country, or clearly indicate any deviations to prevent user confusion.

Furthermore, from the focus group the need for user centered design approach for sustainability. The focus group recommended that the bridges should fit the purpose, the needs of the community must be considered. Such as considering new loading configuration such as loading motor bike and Bajaj (three wheelers). The design codes must provide provisions (loading, width) that are flexibly able to change based on the need of the locality. Design in case of high-water table need to consider both saturated and unsaturated condition to balance the bouncy effect. Free board value of 5m should be reconsidered and improved as per Ethiopia context. Factors like construction simplicity, material availability and ease of transport must be considered and contextualized. The research concludes the need for revisions in both the Ethiopian and B2P manuals to address various parameters, including bridge width, load capacities, and stability requirements, to better meet the community's needs.

The influence of spanner cables on mitigating vibrations and lateral movements has not been formally recorded, indicating the need for a dedicated study to ascertain their substantial effect on bridge stability. Furthermore, the correct technique for end connection of cables remains a contentious issue that research must resolve. While both Ethiopian and Rwandan practices employ GI pipes to reduce vibrations in suspension bridges, there is a notable divergence in the methodologies they adopt for end connections, which warrants further investigation. Ensuring the stability of pedestrian suspension bridges is essential for their functionality and service quality.

However, challenges such as traffic-induced vibrations, swaying, and lateral shifts can compromise their stability. Specifically, cable pedestrian bridges are vulnerable to these vibrations, which arise from the energy transferred by pedestrians walking on the bridge. Such vibrations can cause discomfort for users, raise safety issues, and potentially lead to the degradation of bridge components over time.

Moreover, excessive movement may hinder animal crossings and discourage usage, diminishing the bridge's serviceability. Therefore, a more comprehensive investigation and detailed study are necessary to address these concerns. To reduce the cost of construction steel optimization research are also required.

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