Cite this article

Towler I, Mills B, Lofts M et al. (2019)
Rutaka footbridge in Rwanda: a low-technology deck launch.
Proceedings of the Institution of Civil Engineers – Civil Engineering **172**(3): 137–143,
<https://doi.org/10.1680/jcien.18.00045>

Research Article

Paper 1800045
Received 24/09/2018
Accepted 20/12/2018
Published online 30/01/2019

Keywords: developing countries;
footbridges; sustainability

ICE Publishing: All rights reserved

Civil Engineering

ice Publishing

Rutaka footbridge in Rwanda: a low-technology deck launch

- 1 Ian Towler** MEng, CEng, MICE
Senior Civil Engineer, Mott MacDonald, Manchester,
UK (corresponding author: ian.towler@mottmac.com)
(Orcid:0000-0002-6392-4855)
- 2 Brandon Mills** BSc, MSc, CEng, MIStructE
Senior Bridge Engineer, Mott MacDonald, London, UK
(Orcid:0000-0002-3302-5330)
- 3 Matthew Lofts** IEng, MICE
Balfour Beatty, Langley, Berkshire, UK (Orcid:0000-0002-0017-4030)
- 4 Benjamin Mills** IEng, MICE
Construction Manager, Jacobs, London, UK
(Orcid:0000-0002-1850-1554)
- 5 Peter Crosthwaite** MEng, GMICE
Civil Engineer, Mott MacDonald, Glasgow, UK (Orcid: 0000-0002-7687-5538)
- 6 Divesh Mistry** BSc, MSc
Hydrologist and Photographer, Environment Agency, Worthing, UK
(Orcid:0000-0002-4731-0132)

US charity Bridges to Prosperity has delivered over 250 simply designed and built footbridges around the world to provide rural communities with year-round safe access to markets, farms, schools, health clinics and other critical services. This paper describes the innovative design and construction of a 40 m suspended footbridge in Rutaka, Rwanda, which was completed in 2017. To reduce time working at height, the volunteer engineering team developed and trialled a low-technology method for launching the deck from a temporary platform, significantly improving safety and quality control. A photography-based community initiative also helped to convey the importance of maintaining the structure.

Notation

F	force required to pull the deck
g	acceleration due to gravity
m	mass
θ	angle of incline
μ_s	static coefficient of friction, assumed to be 0.8 for dry steel on steel

1. Introduction

In the developed world it is often taken for granted that one can travel directly and safely to a desired destination without undue risk to life or limb. In developing nations, rural communities often lack year-round safe access to local markets, farms, schools, health clinics and other critical services.

Bridges to Prosperity is a US-based non-profit organisation which is helping to solve the issue by building footbridges in partnership with local communities, sponsor companies and professionals. The charity has so far delivered over 250 footbridges in developing countries since 2001, serving over 1 million community members worldwide.

It has developed standard footbridge designs and construction methods. Industry partners bring best practice, knowledge and experience to the project, which in turn facilitates the transfer of knowledge to the charity, its site engineers and community workers. The construction methods have seen incremental improvements following lessons learned from earlier projects, which has led to construction, safety and programme enhancements.

This paper presents a case study of the Rutaka cable-supported footbridge in Rwanda, which was completed in June 2017. A team of ten volunteers from industry partners Balfour Beatty and Mott MacDonald in the UK pioneered an innovative deck-launch methodology, the first time the method had been attempted on one of the charity's footbridges.

The 40 m long structure crosses the Nyagako River and serves the communities of Nyamirama and Kanyinya, with a combined population of 10 000, in Muhanga District 70 km west of the capital Kigali (Figure 1). For 8 weeks a year during the rainy season the

Figure 1. View of Rutaka river valley in Rwanda

river swells up to and over the river banks. In the 3 years prior to the footbridge's construction, four people had died attempting to cross.

2. Conventional construction methodology

The charity has two standard footbridge designs selected for specific sites depending on site characteristics: a suspension span footbridge and a suspended span footbridge. The Rutaka footbridge is a suspended span footbridge. Handrail and walkway cables

Figure 2. Typical half-span elevation (a) and deck cross-section (b) of suspended span footbridge

are slung across the span and anchored into reinforced concrete anchor beams buried beneath each approach ramp (Figure 2(a)). The anchor beams are fixed in place by the abutment walls and the weight of the stone backfill, grout infill and concrete ramps. Before backfilling and installation of the bridge deck, the sag of the cables is set to the desired level by tensioning with a winch and secured with clamps.

The established deck construction method involves working at height using harnesses fitted with a fall-arrest system. 'Swing' assemblies to support the deck are fashioned at height while standing on the front tiers of the abutment (Figure 3). The assemblies usually consist of cross-beams made from steel hollow sections with a timber nailer attached (Figure 2(b)). The cross-beams bear on the walkway cables as well as being partially suspended from the handrail cables by 10 mm steel reinforcing bars. The suspender bars are bent around both the walkway cable and the handrail cable at either end of the cross-beam. This involves using a steel tube and considerable physical effort, while working at height.

Once installed, the swing assemblies are slid into position either using ropes or, more typically, by an operative balancing on the structural cables. To prevent the first swing assembly from moving it is fixed at the main tower with clamps on the walkway cables; however, further suspended cross-beams are not fixed and can swing or slide. This movement is only prevented once decking planks are laid and screwed down.

When the swing assemblies are in place, timber deck planks, which can each weigh up to 18 kg each, are carried out and screwed to the timber nailers in sequence, working from one abutment to the other. The deck comprises five 200 mm wide planks, which are staggered along the span of the structure. The planks are laid out, drilled and screwed into place (Figure 4).

As the team lay the deck, they each wear a harness clipped onto the handrail cable and balance on the 200 mm wide timber nailers or on the walkway cables. It is not until the deck is complete and the mesh fencing between deck and handrail is in place that the harnesses are no longer required.

Figure 3. Established method for installation of swing assemblies at the front edge of the abutment

Figure 4. Established method for installation of deck planks on loose swing assemblies

3. Development of launch method

3.1 The proposal

The industry volunteer team was motivated to utilise their knowledge, experience and ingenuity to deliver additional value. The team reviewed the established construction method and felt that it could be improved.

Working at height was identified as the major safety risk during construction of the deck. The work undertaken at height is also labour intensive, involving a large amount of manual handling of materials along the span of the bridge and physical exertion to bend the suspenders to fix the swings to the cables. The team set itself a challenge to reduce significantly the amount of working at height during this phase of construction.

Influenced by long-span bridge construction, where bridge launching is a common construction method, the team explored whether a suitable launching method could be developed to suit the charity's suspended footbridge construction. A model of the 40 m span Rutaka footbridge and site was prepared using Sketchup software to help visualise the construction process and understand the site constraints (Figure 5).

An area of level ground was identified in front of the east abutment where a temporary works platform could be built. If a suitable method to launch the deck could be devised, it would be possible to install the swing assemblies and connect the deck planks from the temporary platform. This would provide a safer working environment without the need for harnesses and allow greater quality control during installation.

The tools and equipment available to the team were limited to what was available on-site provided by the charity, and what the team members could bring with them on commercial flights from the UK to Rwanda. It was proposed that the winch used to set the sag of the cables could also be used to pull the deck across the span.

The model was updated and used to visualise the process to aid understanding and stimulate discussion within the team (Figure 6). The model was also used to demonstrate staging and clash detection, to brief and gain approval from the Bridges to Prosperity in-country team, and provided measurements for the design of a temporary platform with edge protection.

3.2 Construction planning

The volunteers were selected in April 2017, allowing only 3 months to plan for the project. This included logistics, resourcing and developing a safe method in a foreign country, and using a new system of work for the deck construction.

A product breakdown structure (PBS) was produced which captured what had to be constructed by the volunteer and in-country team together. This along with outline sequence sketches was shared with the charity's team to clarify the elements the team would construct. The PBS was used to split the team into manageable sections, provide focus on each activity and help develop individuals' planning and knowledge of the construction method. A detailed construction programme was produced using as-built data from previous charity teams.

Breaking the work into packages ensured that activities and hazards were identified in sufficient detail to reduce risks to as low as reasonably practicable, and risk assessments and site briefing documentation were prepared. This was used on site to

Figure 5. Digital model of the Rutaka footbridge

Figure 6. Model showing launched deck installation from temporary platform

communicate the activities to the site team, most of whom would not know how to speak English.

The process also identified additional permanent works design to reduce risk, such as adding handrails on the approach ramps. It ensured a good base of knowledge for the entire team and made sure the tight preparation timescales were achieved. The use of models, diagrams and regular contact among the volunteer team as well as with the in-country team improved understanding and helped to ensure success.

3.3 Developing the detail

The launching method required a temporary platform constructed of timber, sourced locally for a small cost, with full edge protection (Poulson *et al.*, 2019). The platform allowed the decking to be installed in 2 m sections and pulled over the span using a series of ropes connected to a winch secured to the anchor beam at the far abutment (Figure 7).

High-strength yachting rope made from braided polyester was selected as the pull rope based on its high tensile strength, low elasticity and weather resistance. The rope was purchased in the UK and transported to Rwanda by the team as part of their check-in luggage.

It was determined that the anchor beam should be backfilled to mitigate movement and the winch secured to it by way of a spare cable and D-shackle. On the other end of the winch, the winching cable was connected to the high-strength rope using a figure-of-eight loop. This rope passed over the top of the abutment and was attached to the deck.

Figure 7. Pulling winch set up at the far abutment

Once the winching cable hook reached the winch and could not be pulled any further, the tension from the winch was released and the cable was pulled through and connected to the high-strength rope at the top of the abutment using a new figure-of-eight loop. A spare length of ducting was used to reduce friction of the rope on the top of the abutment and to avoid damage to the rope due to the rough concrete surface.

The high-strength ropes were connected to the swing assemblies (Figure 8). The line of action of the pull was parallel to the walkway cables as the load in the structure is mostly supported by the walkway cables under permanent load conditions. A sling was used to connect to the first swing assembly and a shackle used to connect this sling to the high-strength rope.

The lower rope connecting the swing assemblies together was tied tightly and under tension. The team determined that it was vital that the load transfer between cross-beams was by way of the rope rather than the deck, to avoid the risk of deck screws shearing. The high-level rope connecting the suspenders ensured that the suspenders did not trail behind the cross-beams.

The sag of the suspension cables is a catenary, so the deck panels undergo a change of curvature as they move across the cables. To avoid introducing additional friction and to allow as much movement as possible it was proposed that only the plank ends be fixed prior to launching. The planks' centres were fixed after the deck pull was complete.

3.4 Technical assurance

The key to the launch method was the analysis of the forces needed to be overcome by pulling the bridge deck over the steel cables. The calculations undertaken to determine the suitability of the deck-pulling method were simplistic and were determined from first principles.

The outline steps are as follows.

- (i) The permanent load of the deck per metre length was calculated.
- (ii) The dead load sag and maximum angle of the cable were calculated at the abutment tower of the side from which the winching was to be undertaken. Example calculations were referenced from the charity's Bridge Builder Manual (Bridges to Prosperity, 2016).

Figure 8. Details of how pulling system is connected to deck

- (iii) The angle found in (ii) was used to calculate the pulling force required using Equation 1.

$$1. \quad F = \mu_s mg \cos \theta + mg \sin \theta$$

In Equation 1 F is the pulling force, μ_s is the static coefficient of friction (conservatively assumed to be 0.8 for dry steel on steel), m is mass, g is acceleration due to gravity and θ is the angle of incline.

- (iv) There will be some friction as the pulling rope passes over the saddle to the location of the winch and this was accounted for in the total pulling force required of the winch. By treating the pulling rope and saddle as a friction pulley, the resultant normal force on the saddle was calculated. By multiplying this by an appropriate friction coefficient, the force to overcome the friction over the saddle was found. This highlighted the importance of providing a low-friction surface for the rope to slide over to reduce friction and wear. The forces found in (iii) and (iv) were added to provide a total force F_t of 27.3 kN.
- (v) The total pulling force was checked against the pulling capacity of the winch. The calculation for the required pulling force is conservative in that it assumes that the entirety of the deck is pulled up the angle of incline. Clearly, this is not the case as the cables are in sag and the angle of incline changes over the length of the cable. Factors of safety are also built into the equipment ratings. The winch used had a 3 t lifting capacity and a 5 t pulling capacity, while slings, shackles and ropes were rated for 4 t. The calculated magnitude of the required pulling force was less than 3 t.

4. In Rutaka

4.1 Construction

The deck launch from a temporary platform was a resounding success as the team were able to pull the entirety of the deck across

the 40m span, achieving their aim of significantly reducing the amount of working at height using harnesses. The use of high-strength rope, shackles and lifting sling allowed for a flexible installation because the elements were simple to put together using conventional rope knots. The construction of the temporary platform was simply and successfully installed by the in-country team, with only minor alterations from the original plan required once the volunteer team arrived on-site.

The temporary platform allowed the team to complete the assembly of the bridge deck in a safe and controlled environment (Figure 9), removing the requirement for working at height from this stage of the process. A specific briefing on the use of the temporary platform was established. The platform was limited to a maximum of six people at a time and signage was used to clearly convey this safety protocol. This approach reinforced safety behaviours that the team emphasised on-site.

A further benefit of the innovations to the construction method was that it helped in the cultivation of a safety culture on-site. This approach demonstrated the team's commitment to safety, reinforcing safe behaviours site-wide by the volunteer and in-country team members.

4.2 Community engagement

During the construction period, the volunteer team had a multi-faceted approach to community engagement. Community members of the construction team were integrated into the volunteer and charity team. They were involved with each element of construction to provide the greatest level of skills transfer, with a focus on health and safety and sharing industry best practice.

Ongoing monitoring and maintenance of the bridge is crucial to the longevity of the structure. Individuals from the community were therefore selected to form a bridge maintenance committee. Most had been involved in the construction. Formal training was completed on bridge maintenance, including the provision of manuals and equipment, and practical skills to enable essential maintenance such as replacing deck planks. The charity's in-country team will continue to be available should any major issues be identified.

Off-site, building on community engagement initiatives developed during previous builds, the team ran a participatory photography project with ten community members. The individuals were each provided with three disposable cameras over the construction period. The purpose was to provide the community with an opportunity to show how the lack of a safe crossing impacts their daily journeys. The first batch of photographs were developed, then a meeting was held where participants were given copies of all their photographs and invited to discuss and review them.

Guidance was provided on photographic composition and common mistakes (i.e. camera shake), then individuals were provided with another camera to develop stories related to their daily journeys. The wider community would gather and listen to these discussions and provide feedback based on the illustrated stories (Figure 10). This allowed the team to gain a level of engagement and mutual learning that otherwise would not have been possible. The stories provided a first-hand account of the impact that a lack of safe crossing can have on the community. Photographs are a rare commodity in the valley and were shared and enjoyed by the community.

Figure 9. View of deck being launched with deck installation within temporary platform

Figure 10. Participatory photography project community meeting

5. Fulfilling sustainable development goals

The charity's design used sustainable materials throughout the structure: retired crane cables were reused as the primary support elements; car wheel rims were repurposed to provide low-friction saddles for the cables; and locally sourced stone formed the abutment walls and backfill. Local community members were employed to provide labour at a fair wage.

By providing safe year-round access to employment, markets, crops, healthcare and schools, the bridge contributes positively to seven of the 17 UN sustainable development goals (UN, 2019)

- no poverty
- zero hunger
- good health and well-being
- quality education
- reduced inequalities
- responsible consumption and production
- industry innovation and infrastructure.

The Rutaka footbridge made a specific impact to the last goal by partnering with industry to improve the construction method. It is an example of how infrastructure that provides safe access for communities empowers people to advance their own prosperity in a sustainable way.

6. Discussion

The process highlighted differences in working practices between commercial Western construction teams and charities operating in developing countries. In developed countries, hazards such as working at height are eliminated from the process wherever possible. For charities operating in the developing world, the cost and availability of extra materials and risk prevention can be prohibitive. Construction methods must be sustainable, affordable and replicable at other bridge sites and in other countries.

The experience of the industry team enabled them to apply their knowledge to innovate on the construction method. In

addition to facilitating the deck pull, the temporary platform provided a safe working space to fix the swing assemblies and the ability to rotate the construction team and tasks. The successful completion of the bridge deck pull opens the opportunity for the method to be applied on future suspended footbridge builds by the charity.

A potential risk with the deck-pull method is that excessive load could be directed through the deck as opposed to the high-strength rope. This has the potential to shear the screws that fix the deck planks. Had the method failed, the construction would have had to revert to the conventional method of construction. Calculations with conservative assumptions were produced to provide confidence that the pulling apparatus was sufficient for the task. An additional risk was the deck snagging on frayed cable strands. The team monitored this during the pull and, while frayed strands were noted, they were easily overcome by the pulling force.

The equipment and materials used for the Rutaka build could be reused for bridge builds of a similar span in Rwanda if they are carefully looked after and stored appropriately. The deck launch rate could be increased by constructing a larger temporary platform to allow longer deck sections to be installed for each incremental pull.

As the length of spans increase, the force required to be pulled by the winch and high-strength rope will also increase. The limiting span is likely to be determined by the capacity of the winch available on-site or the availability of rope with sufficient tensile strength to provide an acceptable factor of safety. For substantially longer span lengths, the deck could be pulled in multiple sections which are then connected above the river.

While most construction materials used on the charity's projects are sourced locally and sustainably, the high-strength yachting rope used at Rutaka was imported from the UK. Consideration of the sustainability aspect of this choice is necessary in future. Alternative local options, or a method to reduce the length of rope required, could be considered.

The parapet mesh cannot be installed until the suspenders have been clamped to the handrail cables. The result of this is that some work at height is still required to complete these elements. An alternative fencing detail could be derived to eliminate this hazard. This could be in the form of a series of smaller low-level cables to create a restraint system to allow the mesh to be installed without harnesses.

7. Post-construction

In June 2018, almost a year after the bridge opened (Figure 11), the charity revisited the bridge to review its condition and to speak to the community and the bridge committee. The bridge was in good condition (Figure 12) and the community members enthused that it had had a significant positive impact on the community (personal communication from L Walter, 2018).

Students can now cross the bridge safely and year-round to get to schools on both sides of the river valley (Figure 13). The community can reach the local hospital safely, including pregnant women. Farmers can reach crops and transport the harvest home and to market. The bridge committee advised that no issues had been reported and that the community took the care and condition of the bridge seriously.

Figure 11. Footbridge inauguration day in June 2017

Figure 12. Footbridge still in good condition in June 2018 (courtesy of Andrew Nash)

Figure 13. Footbridge being used by schoolchildren in June 2018 (courtesy of Andrew Nash)

8. Conclusion

One of the key successes for the Rutaka footbridge project was the innovative use of temporary works to improve construction efficiency, safety and quality. The team was commended by the charity for the success of the methods used and its community engagement.

The team focused on people, particularly local workers and community leaders, recognising that the ultimate client was the local community which the footbridge would serve. By focusing on people, the team enabled the community and its workers to deliver their own footbridge.

The deck-launch technique is now available for adoption on future projects dependent on local site conditions. To assist future projects, the volunteer team produced a technical note detailing the deck launch methodology.

The ongoing success of the charity's footbridge building programme demonstrates the significant positive impact that something as simple as a footbridge can have for individuals and communities. Involvement in a Bridges to Prosperity footbridge build provides a powerful reminder that, in essence, engineering is about people and improving lives. It is also a reminder that bridges provide connection, and connection is the critical foundation for economic opportunity, healthcare and education (Bridges to Prosperity, 2019).

Acknowledgements

The authors would like to acknowledge Bridges to Prosperity for the outstanding work it undertakes and the opportunity to be involved; Balfour Beatty and Mott MacDonald for their support and contributions to the project; and Andrew Nash and Brian Duguid of Balfour Beatty and Mott MacDonald, respectively, for championing involvement with the charity's industry partnership programme.

References

- Bridges to Prosperity (2016) *Bridges to Prosperity Bridge Builder Manual*, vol. 2, 5th ed. Bridges to Prosperity, Denver, CO, USA.
- Bridges to Prosperity (2019) *Why Bridges?* Bridges to Prosperity, Denver, CO, USA. See <https://bridgestoprosperity.org/why-bridges/> (accessed 11/01/2019).
- Poulson S, Mills BP, Mills BJ and Towler IR (2019) *Rutaka Footbridge: Suspended Footbridge Launching Methodology*. Bridges to Prosperity, Denver, CO, USA, Technical Note, in press.
- UN (United Nations) (2019) *About the Sustainable Development Goals*. United Nations, New York, NY, USA. See <https://www.un.org/sustainabledevelopment/sustainable-development-goals/> (accessed 11/01/2019).

How can you contribute?

If you would like to comment on this paper, please email up to 200 words to the editor at journals@ice.org.uk.

If you would like to write a paper of 2000 to 3500 words about your own experience in this or any related area of civil engineering, the editor will be happy to provide any help or advice you need.