

Stone arch bridges

A strong & cost effective technology for rural roads



A practical manual for Local Governments

Foreword

This manual was developed based on the experience of the Belgian Technical Cooperation (BTC) supported **Kasese District Poverty Reduction Programme** (KDPRP) in Western Uganda, during the period 2009-2013. The programme piloted stone arch culverts and bridges in rural areas, where low labour costs and high cost of industrial building materials favour this technology. The construction of stone arch bridges in Uganda, Tanzania & Rwanda has demonstrated its overall feasibility in East Africa.

How to use this manual

The purpose of this manual is to provide supervisors of stone arch bridge works with an easy step by step guide. The stepwise approach ensures adherence to quality requirements and construction methodology. The main target audience of this manual is the road works supervisors and engineers employed by District Local Governments in East Africa. However, the manual remains relevant in the context of many other developing countries.

Acknowledgements

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1. Chapter One: Introduction to stone arch bridges

1.1 Background and justification.

Stone arch bridges are amongst the strongest in the world. The technology has stood the test of time. The Romans built stone arch bridges and aqueducts with lime mortar more than twenty centuries ago. Arches and vaults were also the determining structural design element of churches and castles in the Middle Ages (*fig 1&2*). There are stone arch bridges which have survived for hundreds and even thousands of years, and are still as strong today as when they were first constructed (*see fig. 5*).



*Fig 1: Vaults built in churches 14th century
Santiago de Compostela cathedral, Spain
Picture: courtesy Wikipedia.*



*Fig 2: Ancient stone arches street
medieval town of San Gimignano, Italy*

The main reason that western countries moved away from stone arch bridges is because of the high labour costs involved in their construction. In industrialised countries, it is cheaper to use pre-stressed concrete rather than employ a lot of masons and casual labourers. In the economic environment of East Africa and the majority of developing countries, with low labour costs and high costs of industrial building materials, stone arch bridges provide a more affordable and practical option.

Technology choice	Adapted to following economic context	Typical example
Reinforced/ pre-stressed concrete bridges	<ul style="list-style-type: none">• High labour costs• Low cost of industrial building materials	<ul style="list-style-type: none">• Industrialised countries.• Highway contractors.
Stone arch bridges	<ul style="list-style-type: none">• Low labour costs• High cost of industrial building materials	<ul style="list-style-type: none">• Rural areas in developing countries.• Community road projects

Each financial year, districts and lower local governments are faced with funding constraints while the challenges in the rural transport sector are overwhelming. The limited available road funds are spent on costly public procurement of a few structures and road repair while most of the grassroots requests remain without support. Rural roads are often designed with an insufficient number of culverts due to the high cost of concrete culverts. It causes inadequate drainage and premature erosion, leading to increased maintenance costs of the road network. On the other hand, due to budget constraints, timber bridges are constructed with a limited lifespan of 4-10 years and the need for constant repairs. The adoption of stone arch bridges enables districts and lower local governments to improve the access to social services and markets of more village communities at 70% lower investment costs. Stone arch bridges offer a low-cost but strong technology that is appropriate for rural areas in developing countries.



Fig 3: Eroded road due to insufficient drainage capacity of the culverts



Fig 4: Timber log bridges have limited span (10 to 12m) and lifespan (4 to 10 years).

1.2 The stone arch bridge technology

Arch bridges are among the oldest types of bridges. Dating back to ancient China, Rome and Persia, this bridge structure has been in use for thousands of years. Because of the strength, many ancient bridges can still be seen today in cities of Europe and Asia. The Romans were the first to fully realize the potential of arches for bridge construction and built many spectacular arch bridges, over 2000 years ago (*fig 5*)!

For local masons first exposed to arches, the concept remains abstract and shaky. The structure is completely unstable until the two spans meet in the middle and the arch is closed. From a layman's perspective, it is hard to see how a bridge merely built with stones will support heavy traffic. However, the structure is ultimately rendered robust by the wedging principle of the stones that distribute the load as compression along the whole arch to the foundations. Tensile stresses are omitted.



*Fig 5: Roman stone arch bridge built over the Tagus River at Alcántara, Spain between 104 and 106.AD (Total length: 194m, longest span: 28m)
Picture: courtesy Wikipedia.*

While there is quite some variety in arch bridge construction, the basic structure does not change. They can be architecturally different; but they are structurally the same. The simplest shape of an arch bridge is a semicircular design with abutments on each end. Its structure distributes compression through its entire form and diverts weight onto its two abutments. Tensional force in arch bridges, on the other hand is virtually negligible. Arch bridges do not need additional supports of reinforced steel. They are particularly suitable for building in stone because each of the elements in the arch will be under compression (*fig 6*).

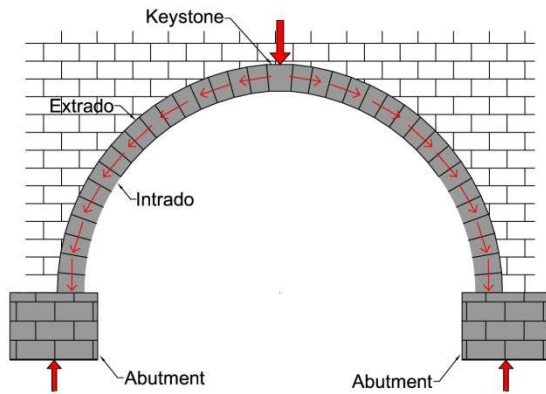


Fig 6: Load distribution in a semi-circular arch: the weight on top of the arch is diverted to the abutments through the arch. The arch is almost entirely under compression without any tensile stresses.

Single stone arch bridges can cover spans up to 20 meters. For larger spans, steel and pre-stressed concrete is required. Steel arches typically span between 50 and 250 meters, but West Virginia's New River Gorge Bridge built in 1977 has an impressive span of 518 meters (fig 7).



*Fig 7: New River Gorge Bridge, a steel arch bridge West Virginia, USA
Picture courtesy Wikipedia.*

The construction of arch bridges all follow the same basic principle (fig 8), which is simple but requires some experience and training to ensure strong and long lasting structures. Stone arches are built over a temporary wooden formwork which holds the masonry in place during construction. The temporary form is needed since the structure is not stable until the arch is closed. The paragraph 3.2 gives more details about the different steps of the construction

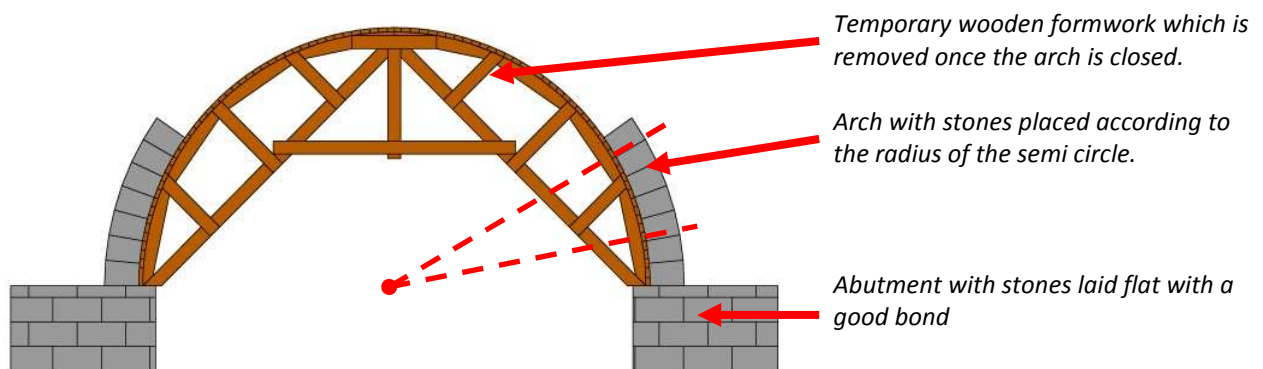


Fig 8: Basic elements of arch bridge construction. The arch is constructed symmetrically over a temporary formwork. Note that the arrangement of the stones differs entirely between the arch and the abutment. Stones of the abutments are placed in a flat and horizontal position while the ones forming the arch follow the radius of the circle. This arrangement is the key principle for the stability of the bridge.

1.3 Advantages & limitations.

When compared to concrete bridges, stone arch bridges offer several advantages.

A larger proportion of locally available resources are used in stone bridges as they can be built with local labour and stones. In contrast, raw materials and machines have to be imported for the construction of concrete bridges and specialized technical expertise is required. Compared to expensive aggregates, local stones are a strong, affordable material and they are often available in the vicinity (10-15 km) of the construction site. There is no need for expensive steel bars, aggregates, concrete or galvanised pipes that have to be hauled over long distances.



Fig 9: Construction of a multiple-arch culverts with stones found in the vicinity

As regards to the construction cost, concrete bridges require more capital and equipment (poker, concrete mixers). The cost of additional man-days required for the construction of stone arch bridges in rural areas is usually much lower than the higher cost of industrial materials and equipment used in concrete bridges as the table below illustrates.

Construction	Cost in Ush 2012	Cost in US\$ 2012	Cost saving arch technology
Bridge box culvert - public procurement span 4m	116,000,000	44,000	
Stone arch bridge - forced account span 4 m	20,000,000	8,000	83%
Reinforced concrete bridge – public procurement span 8m	250,000,000	95,000	
Stone arch bridge - forced account span 8 m	39,000,000	15,000	84%
Culvert 3 lines 75 cm diameter - public procurement	28,000,000	11,000	
Triple culvert 80 cm diameter - forced account	5,900,000	3,000	79%

Examples of cost comparison stone arch/concrete bridges, rural Uganda 2012- 1 US\$= 2.650 Ush.

The weight of the stone arch culverts reduces the risk of floods washing them away. The interconnecting arch and the heavy weight also prevent the tilting and sliding exerted by the backfilled soil mass - typical technical challenges related to concrete bridge abutments. Moreover, stone culverts cannot be stolen and resold, unlike galvanised or concrete pipe culverts.

Compared to bridges made from tree logs, the stone arch bridges are more durable. They do not need to be re-built every 3 to 5 years. This makes the investment and community effort more effective, while the safety standard and traffic load capacity increase drastically.

However, concrete bridges will be the right technology choice where labour costs are high and where large spans are involved. The maximum single span of stone bridges is usually less than 20 meters. For larger single spans, the volume of stone masonry becomes too massive and reinforced concrete is a better option.

SUSTAINABILITY CRITERIA	STRENGTHS	WEAKNESSES
ECONOMICAL	<ul style="list-style-type: none"> No need for expensive equipment Long lifetime Low cost Easy to maintain at local level 	<ul style="list-style-type: none"> More expensive where labour and local stones are expensive.
TECHNICAL	<ul style="list-style-type: none"> Stronger Adjustable to local conditions 	<ul style="list-style-type: none"> No traditional skills for arches, requiring prior training of masons
SOCIAL/ POLITICAL/ CULTURAL	<ul style="list-style-type: none"> Technology manageable at community level. 	<ul style="list-style-type: none"> New technology requires a change of mind-set and the sensitisation of the community and local governments.
ENERGY BALANCE	<ul style="list-style-type: none"> Use of local materials, reduced use of industrial materials and dependence on long distance transportation 	<ul style="list-style-type: none"> Higher energy cost than timber bridges due to use of cement but lifespan also 30 times longer.
ECOLOGICAL	<ul style="list-style-type: none"> Limited use of timber as forests are under threat. Maintains the beauty of the landscape as natural stone blends in well with the environment. 	<ul style="list-style-type: none"> borrow pits for stone and sand might affect landscape and accelerate erosion but same applies to concrete bridges.

There are some limitations to constructing stone arch bridges. It is important to assess the local context to make sure a stone arch bridge is the right solution. Where the cost of labour is high or where large quantities of stones cannot be found in the vicinity, the construction cost of a stone arch bridge could exceed the one of a concrete bridge. Another challenge is the capacity building of local craftsmen and contractors. Where no stone masonry tradition exists, masons need to be trained to master this technology and adhere to technical specifications.



Fig 10. Vocabulary of arch bridges

1. Wing wall
2. Head wall
3. Spring
4. Key stone
5. Ring stone
6. Abutment
7. Shoulder

1.4 Stone arch bridges: implications of labour-based technology.

Apart from the requirement of crossing a river, job creation is one of the objectives that this kind of construction can meet perfectly. The beneficiary community can indeed be integrated in the construction of stone arch bridges. Unemployment is usually high in rural areas of developing countries. Due to the high labour input required for the construction of stone arch bridges, seasonal employment can be increased. As the construction is simple, low-skilled labour can be used to implement the work. Unskilled workers from the villages collect stones and sand, masons build the bridges, and village carpenters make the simple scaffolding that is needed. It promotes employment, focusing on people and their skills rather than machines and imported diesel.



Fig. 11: The community can be involved in the construction of a stone arch bridge.

This approach enables also the involvement of the rural communities and district councils during the planning and execution of road works and results in a greater sense of ownership, self-reliance and community cooperation. The execution of the works can be delegated to village road committees. Villages can potentially access donor and government funding for road works through the matching of local resources. This approach favours the adoption of stone arch bridge technology by communities and also by local governments. The allocation of road funds based on effective community contribution is a more just principle than electoral campaign considerations based on patronage networks.

Involving the community in the construction process is usually also one of the main challenges of the construction project. Successful bridge construction depends on a committed leadership and whether the bridge was identified as a top community priority. Without these preconditions, it is difficult to mobilise the community on a voluntary basis, especially where public procurement demonstrated a wasteful use of resources in the past.

Next to the “force on account” approach, stone arch bridges can also be tendered through the public procurement system and contracted to construction firms. Still cost advantages will be important, as steel and concrete unit costs of conventional bridges are replaced by the much lower unit costs for stone masonry.

2. Chapter Two: Design of stone arch bridges

2.1 Quick scan: assessment of the grassroots request and site

During the local government participatory planning and budgeting cycle, there are many demands for the construction of bridges. Some requests are politically motivated; others have strong socio-economic drivers. In the context of limited budgets, it is important to select the most economically relevant bridges which are strongly supported by the community. A preliminary survey will give a quick insight into the cost of the construction and the willingness of the community to contribute. Based on this data, the number of bridges in terms of the cost and the priority sites can be identified. Priority bridges can then be selected by the relevant local government bodies.



Fig. 12: Site assessment

The preliminary assessment should be carried with regards to:

- Existing building skills and experiences of local craftsmen.
- Demand analysis, acceptability amongst local inhabitants and community commitment. Is the bridge really a development priority of the local community?
- Costs of labour and materials – vicinity of borrow pits for stones, sand and murram.
- Technical site characteristics:
 - Hydrology (Flood, discharge, river profile, risk of erosion, etc)
 - Sub-soil - test pits to assess bearing capacity
 - Previous bridge and road works by the community
- Level of skills & means of local contractors and craftsmen
- Economic activities of the area – socio economic justification for the construction as compared to mere political demands.
 - Crop production: cash and food crops.
 - Existing markets and trade centres
 - Improved access to schools and health facilities
 - Population density – number of village benefiting
 - Expected future traffic

A checklist intended to help planners and technicians assess the feasibility of a proposed bridge construction project can be found in the annex 6.

2.2 Planning and stakeholders involved.

Multiple stakeholders are involved in a construction project.

The benefiting community will actively participate in the construction. They are organized in a road committee. An entrepreneur can be contracted to implement the construction, or a mason, assisted by casual labourers from the community. Local governments at sub-county / ward and district levels are involved at every step of the process. Each stakeholder has its responsibility to ensure the implementation of the project. The structural analysis and drawings are prepared by the district works department. Entrepreneurs or qualified mason are trained and contracted for the implementation of the works. Tools and cement are provided by the district. Local building materials like stones, sand and murram can be collected by the community, coordinated by their road committee. They can also provide labour for the site clearance, excavation, trenching, compacting and backfilling, under the supervision of the works department. The lower Local Government is responsible for the mobilization of the community. The construction is monitored by the District Works Department, assisted by the lower local government. The road committee reports to the district in case of problems with the quality and quantity of the works provided by the masons and/ or contractor.

A Memorandum of Understanding (see annex 4) is signed between the lower local government, the community and the district. It gives more details about the possible responsibilities of each stakeholder and the implementation modalities. It is an important tool for improved communication and planning.

2.3 Design

The following recommendations aim at helping planners and technicians with the design of a stone arch bridge on rural feeder roads.

Standard design tables were adopted as outlined in the tables of paragraph 2.6. These design parameters are based on the work of architect Paul Dequeker in the Democratic Republic of Congo (reading reference 14) and the design manual of the French Ministry of Works (reading reference 9). For further strength analysis, the doctor thesis of Alix Grandjean (Lausanne 2010 - reading reference 1) gives an excellent background.

2.4 Site conditions and arch types.

Site conditions determine the type of the arch:

- Roman arches (i.e. half circle) are the strongest and the simplest to construct. They are the favoured option where gully or riverbanks are high enough to allow for large radiuses within the bridge span.
- Segmental arch bridges (only a circular segment) are the necessary design option in lowlands and flat valleys. They avoid that the bridge will stick out as a large hump and that large quantities of murram will have to be hauled for the road approaches. Segmental bridges are structurally less strong than roman arches.

Fig. 13: Recommended bridge type in function of the landscape and river crossing.

Site conditions	Recommended arch type	
High riverbanks & gullies (Height of the riverbank is larger than 1/3 of the bridge span)	Roman arch	
Flat areas Low river banks Valley grounds	Segmental arch	
Wide rivers with rock formations in the river bed	Multiple roman arches with piers on the rocks in the river bed	
Wide rivers >15 metres	Segmental arch	
Road drainage. Narrow brook and gullies < 1 metre	Single arch culvert	
Swamps and brooks. Irrigation canals. Sub soil with weak bearing capacity.	Multiple culverts & vented drifts	

2.5 Calculation of the flow and the bridge span

The opening of the arch bridge should allow the river to pass through it. By examining the riverbanks and asking local residents the highest flood water levels they have observed, the maximum discharge of the river can be calculated. The section of the opening should be equal to the surface of the trapezoid outlined by the highest water level (*fig. 14*). From there, the required span of the bridge can be calculated, taking into account the site conditions. The opening should be wide enough to minimize constriction of the natural channel. But it should not be too wide, as this could encourage river deposits likely to modify the flow of the river. In addition, there is no advantage of constructing a bridge taller than the highest flood level. Beyond that point, no water will be evacuated unless the road is raised and the bridge span increased.

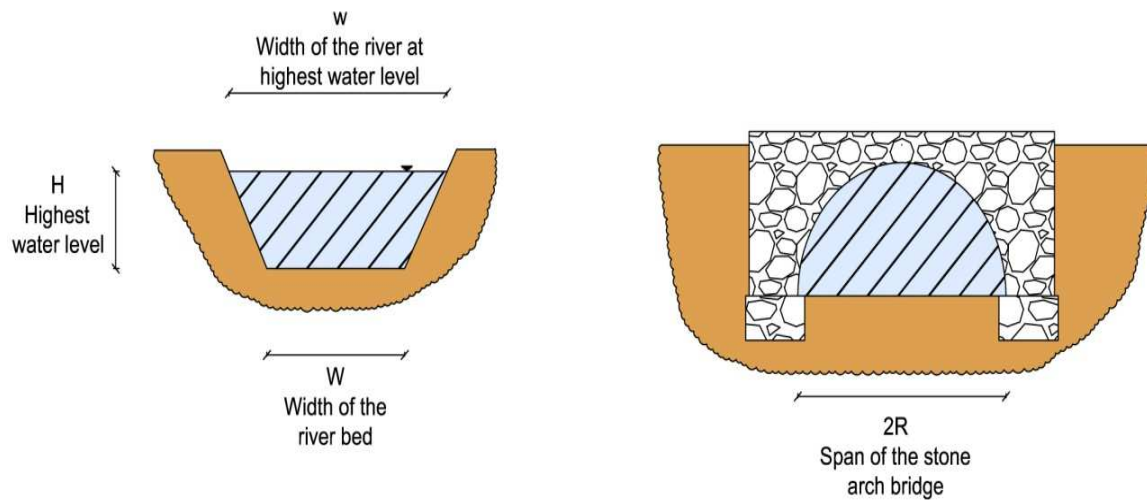


Fig. 14: Left side: river profile at highest water level. Right side: Roman stone arch bridge with an equivalent opening. Hatched surfaces have the same area, i.e. the area of the river section at highest water level. The radius of the required roman bridge can easily be calculated:

$$R = \sqrt{\frac{(w+W) \times H}{\pi}}$$

The construction of sufficient large bridges to allow for the discharge of floods will not be a problem for rivers with high banks. However, in low laying valleys with small river banks, there is usually a conceptual problem. On one hand, the areas flood and large bridge openings are required to absorb the water flow. On the other hand, a large bridge will constitute a high hump that will be an obstacle to traffic and require a lot of costly backfilling. A balance needs to be struck between the two construction considerations.

Low valleys will often entirely flood during the peak of the rainy season. Under these conditions, the road level needs to be raised considerably, which is often more expensive than a bridge structure itself. Alternatively, the bridge can be relocated to a more suitable site or several bridges can be built in series over existing river arms or a vented drift should be designed.

Due to their heavy weight, stone arch bridges resist well floods provided that their foundations are protected against erosion. During the torrential floods in Kasese in May 2013, none of the arch bridges was damaged while many other conventional structures were damaged.

2.6 Bridge dimensions

Roman arch bridge

The dimensions of a Roman arch bridge can be determined from the table below, as a function of the required span (2R). The dimensions are for a maximum traffic load of 40 tons. The roman arch bridge is the strongest design.

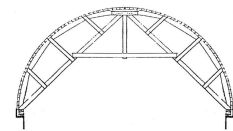
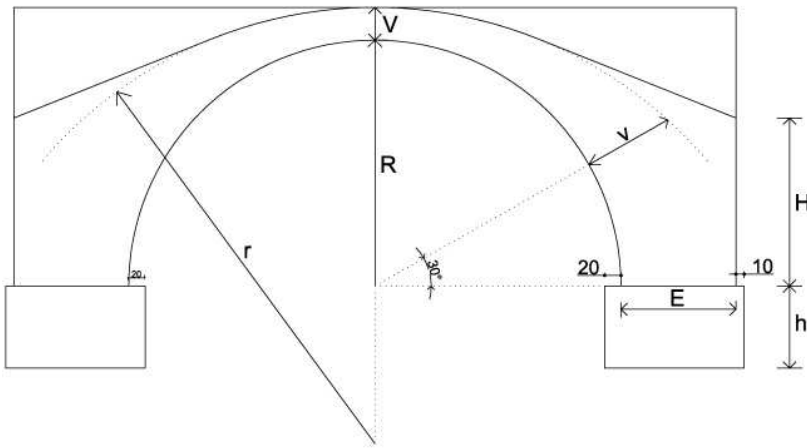


Fig. 15: diagram, formwork and example of a roman arch bridge

Span (m)	Thickness keystone	Thickness at 30°	Radius extrados	Thickness abutments	Height abutments	Min. Depth foundations	Masonry volume (incl. foundations) /m	Masonry volume (incl. foundations) for 3m width
2R	V	v	r	E	H	h	m ³	m ³
1	0.28	0.75	4.00	0.44	0.63	0.50	2.32	6.97
2	0.30	0.82	3.38	0.63	0.91	0.60	3.79	11.36
3	0.33	0.89	3.70	0.83	1.19	0.70	5.40	16.19
4	0.35	0.96	4.19	1.02	1.48	0.80	7.16	21.47
5	0.38	1.02	4.74	1.21	1.76	0.90	9.07	27.20
6	0.40	1.09	5.32	1.40	2.05	1.00	11.13	33.38
7	0.43	1.16	5.91	1.59	2.33	1.10	13.33	40.00
8	0.45	1.23	6.51	1.78	2.61	1.20	15.69	47.07
9	0.48	1.30	7.11	1.98	2.90	1.30	18.20	54.59
10	0.50	1.37	7.72	2.17	3.18	1.40	20.85	62.55
11	0.53	1.43	8.33	2.36	3.47	1.50	23.66	70.97
12	0.55	1.50	8.94	2.55	3.75	1.60	26.61	79.83
13	0.58	1.57	9.56	2.74	4.04	1.70	29.71	89.14
14	0.60	1.64	10.17	2.93	4.32	1.80	32.97	98.90
15	0.63	1.70	10.79	3.13	4.60	1.90	36.37	109.11

Source: Dequeker Paul, Architect

Width

For rural feeder roads, the standard width of a bridge is 3.6 meters, which allows for single lane crossing of lorries.

Height

The roadway should be above the flood level, which can usually be determined by examining the riverbank and asking local people the highest water level they have observed. If necessary, the bridge must also provide an adequate clearance for boat passage.

Segmental arch bridge

It is possible to increase the span up to 20m by using another arch shape. The segmental arch bridge is practical for flat valleys and larger spans. The segmental arch is less strong than the roman arch. The bridge dimensions for a maximum traffic load of 15 tons are given in the table below.

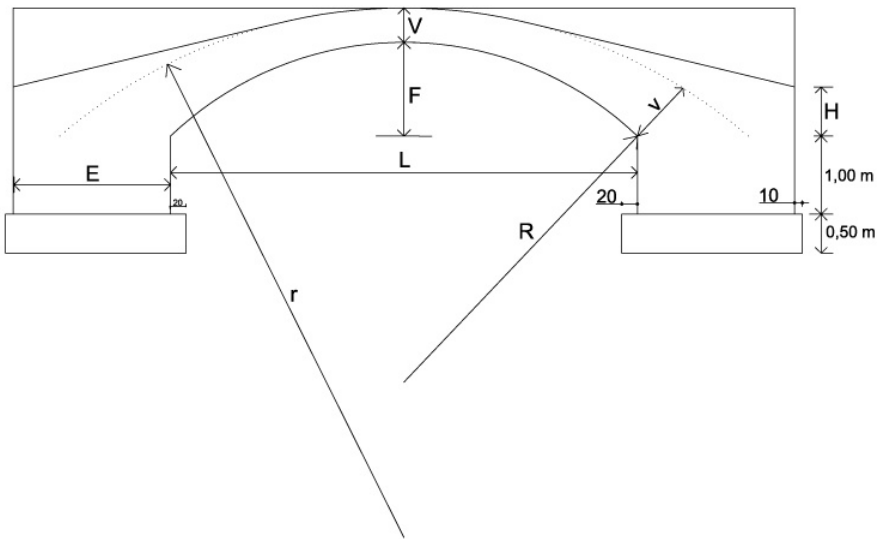


Fig. 16: Diagram, formwork and example of a segmental arch bridge.

L (m)	F	R	V	r	v	E	H	Vol. m ³ /m	Vol. m ³ for 3m width
1	0.20	0.72	0.28	3.37	0.52	0.64	0.38	2.77	8.31
2	0.40	1.45	0.31	3.59	0.60	0.94	0.43	4.54	13.62
3	0.60	2.17	0.34	4.29	0.67	1.23	0.48	6.36	19.08
4	0.80	2.90	0.38	5.09	0.74	1.50	0.53	8.28	24.84
5	1.00	3.62	0.41	5.93	0.80	1.76	0.58	10.33	30.99
6	1.20	4.35	0.44	6.78	0.87	2.02	0.63	12.50	37.50
7	1.40	5.07	0.47	7.65	0.93	2.28	0.67	14.80	44.40
8	1.60	5.80	0.51	8.52	0.99	2.54	0.72	17.25	51.75
9	1.80	6.52	0.54	9.39	1.06	2.79	0.77	19.83	59.49
10	2.00	7.25	0.57	10.26	1.12	3.05	0.81	22.55	67.65
11	2.20	7.97	0.61	11.14	1.19	3.30	0.86	25.41	76.23
12	2.40	8.70	0.64	12.02	1.25	3.56	0.91	28.42	85.26
13	2.60	9.42	0.67	12.90	1.32	3.81	0.95	31.57	94.71
14	2.80	10.15	0.70	13.78	1.38	4.06	1.00	34.86	104.58
15	3.00	10.87	0.74	14.66	1.44	4.32	1.04	38.29	114.87
16	3.20	11.60	0.77	15.54	1.51	4.57	1.09	41.86	125.58
17	3.40	12.32	0.80	16.42	1.64	5.08	1.18	45.65	136.94
18	3.60	13.05	0.83	17.30	1.64	5.08	1.18	49.43	148.29
19	3.80	13.77	0.87	18.19	1.70	5.33	1.23	53.44	160.32
20	4.00	14.50	0.90	19.07	1.77	5.58	1.28	57.58	172.74

Source: Dequeker Paul, Architect

Culverts.

Expensive and fragile concrete culverts can be easily replaced by stone arch culverts. They are usually >60% cheaper than conventional galvanised or concrete culverts. They cannot be stolen and do not break during construction or transport. In valleys, they do not need a large soil buffer as concrete pipes. It is recommended to use a standard mould of 80 cm span that can be re-used. The height of the culvert is adjusted to suit the discharge and river banks. For ease of access, an 80 cm semi-circular span with 60 – 80 cm height abutments is a convenient size. The width of the abutments should not be smaller than 30 cm. The depth of the foundations should not be smaller than 40 cm. The setting out of the abutments should be done with the moulds in place. A gap of about 2 cm is left between the mould and the abutments. The gap will allow for the swift removal of the moulds once the arch is finalised. A gradient of 2% of the base will facilitate the self-desilting of the culvert. Drawings of some culverts can be found in annex 2.

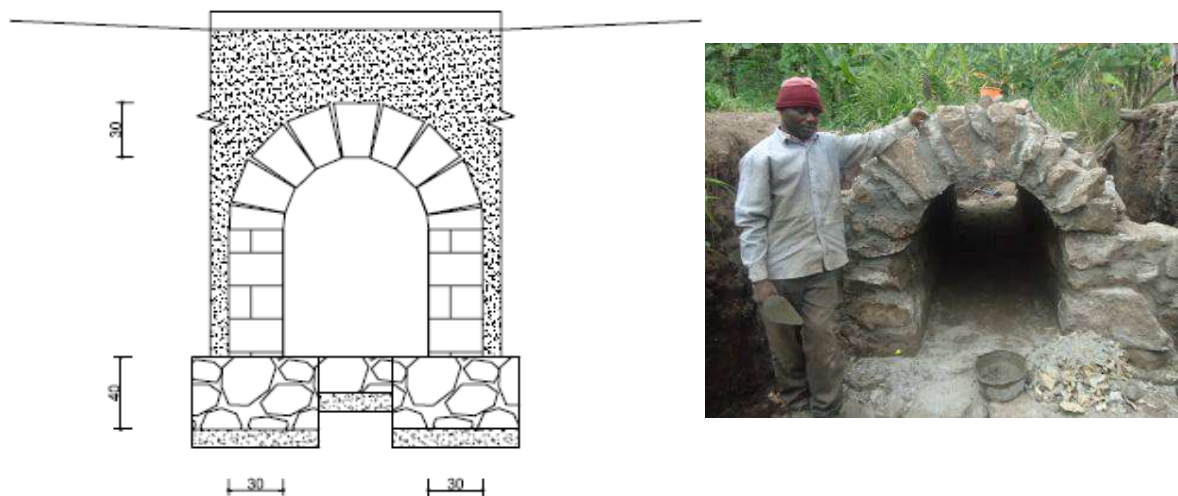


Fig. 17: Single stone arch culvert - dimensions in cm.

Multiple arch culverts can also be used for spans bigger than 1m, where a stone arch bridge would be much higher than the level of the road, requiring an excessive quantity of backfilling for the road approaches. This is usually the case in flat valleys and swamps. During flooding the small diameters of the culverts will be blocked with logs and debris. They need frequent cleaning.

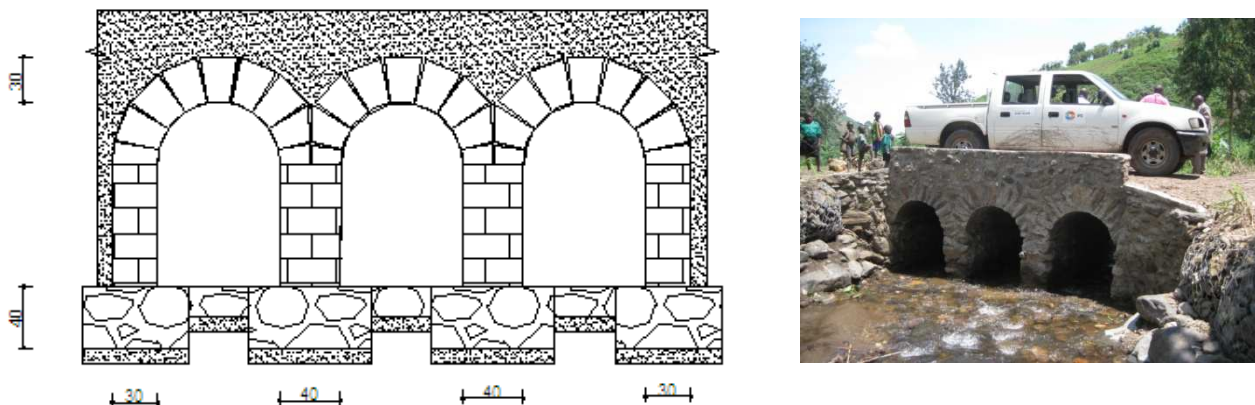


Fig. 18: Multiple stone arch culvert- - dimensions in cm.

2.7 Calculation of the quantities of materials.

Materials are calculated in order to make a Bill of Quantities and estimate the cost of the construction. It can be done with the Excel spreadsheet given in the annex 1, as a function of the design parameters. The cost can also be estimated. Unit prices need to be adjusted according to the local prices. The volume of stone masonry for the arch, abutment and foundations of roman arch bridge and segmental bridge are also given in the last columns of the above tables.

Basic quantity guidelines:

- Stone requirement: theoretical volume of the structure +10%. A 7 tons lorry carries 3.5 m³ of stones.
- Cement requirement: 1.5 - 1.8 bags per m³ stone masonry for 1:3 mix.
- Water requirement: less than 20 lt per bag of cement. In addition, large amounts of water are required for curing of the stone masonry.
- Labour: 1 mason with 2 casual labourers construct 1.3- 1.6 m³ stone masonry per day

There are large variations to the above recommended data:

- Well organised and skilled masons will construct larger volumes per day.
- The cement requirement will be much higher if small stones are used or the mason is not filling the gaps with small pebbles but only with mortar.
- Large stones help to reduce cost, speed up the work and increase the strength of the bridge.

2.8 Drawings

Examples of AutoCAD drawings are given in annex 2. They can be used as models and be modified to suit the design parameters. Other elements can of course also be added depending on local conditions (concrete cap when no soil buffer, stone pitching in the river bed, etc).

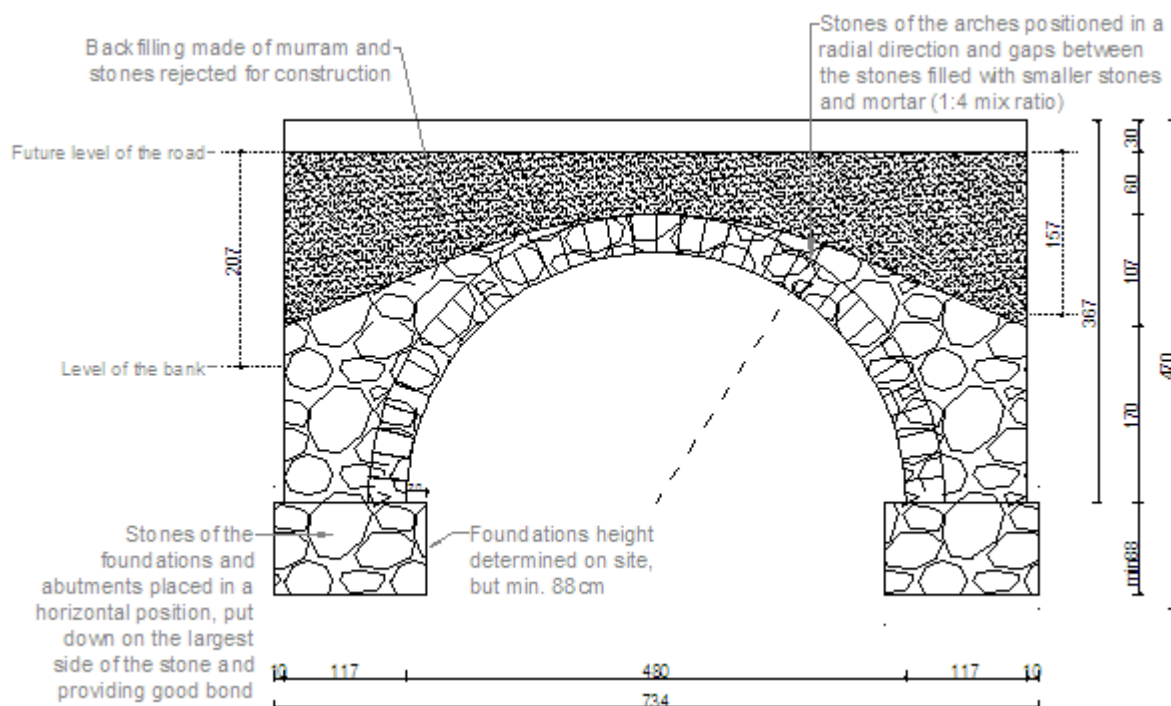


Fig. 19: diagram stone arch bridge with components

3. Chapter Three: Construction of stone arch bridges

3.1 Principle: wedging - only compression forces

A simple beam will bend as a reaction to a load. This change in the beam's shape causes the bottom of the beam to become stretched in tension, the top of the beam to be squashed in compression. These opposite forces in the beam can cause the beam to tear apart with relatively small forces when materials with low tensile strength are used, such as stones or plain concrete. The arch form is one of the earliest and historically ingenious solutions of dealing with tensile stresses.

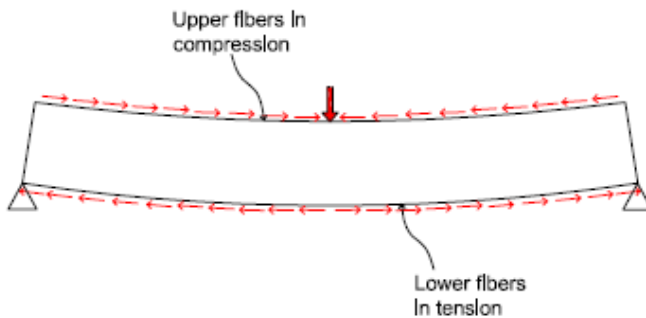


Fig. 20: beam bending under a load.

The semicircular arch developed by the Romans was a great technological achievement in bridge design. The strength of the arch bridge comes from its shape. The shape of the arch is designed so that, when loaded, every component is in compression, and ideally there is almost no part of the structure in tension. Instead of pushing straight down, its semicircular structure carries the load outward along the curve through its entire form and diverts weight onto its two abutments. The supports at each end of the bridge directly take on pressure. These abutments and well compacted backfilling prevent the arch from bending outwards when heavy loads press down on it. As a result, the arch is always under compression, maintaining its shape and stability.

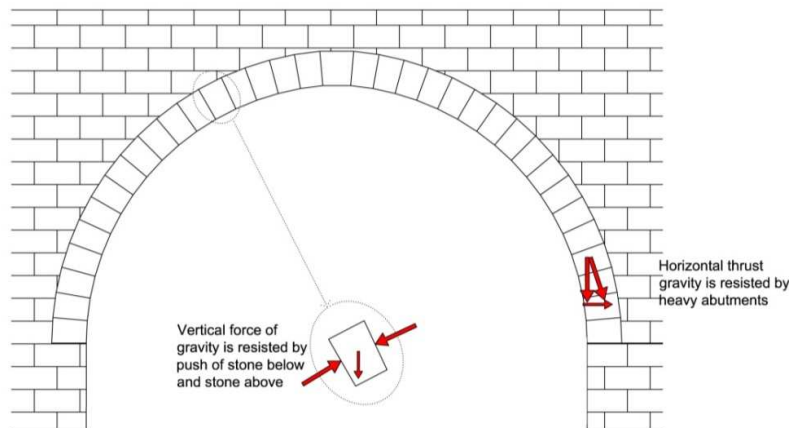


Fig. 21: Forces in an arch bridge.

An arch can carry a greater load than a horizontal beam of the same size and material, because downward pressure forces the stones together instead of trying to force them apart. All the compressive forces hold it together in a state of equilibrium. By using the arch configuration, significant spans can be achieved. However, an arch pushes outward at the base, and this needs to be restrained with heavy abutments and well compacted backfilling. Masonry arch bridges need backfilling material above the arch in order to increase the dead-weight on the bridge and prevent tensile stresses from occurring in the arch ring as loads move across the bridge. Loaded bridges with plenty of backfilling are the strongest.

3.2 Steps of construction process

3.2.1 Site selection

It is recommended that the existing bridge site is thoroughly examined. Traditional pole bridges are often located at the narrowest river crossings which are not necessarily the best construction sites for permanent bridges. The following factors are taken into consideration for the site selection:

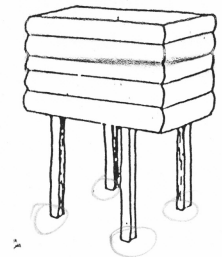
The bearing capacity of the subsoil.

Sites with rock layers provide important advantages, as the cost for the foundation will decrease considerably and future erosion damage will be prevented. It is usually more cost effective to move an earth road rather than building a bridge on an existing site that has no firm sub soil or that is prone to erosion. Sandy and clay soils and sites with springs, muddy ground and swampy terrain should be avoided as they will require improved reinforced or sometimes even piled foundations.

Small trial pits are dug to assess the bearing capacity of the sub soil. The bearing capacity varies in function of the moisture level and soil type. Laboratory test to establish the shear strength and consolidation of the soil are recommended. Alternatively, in the absence of such services, the chair test can be used. This method consists of adding cement bags on a stool (with a known surface area of its legs) till the legs enter the soil by 2-3 cm. The test is done in a trial pit at foundation level. The bearing capacity of the soil in kg/cm^2 is then calculated by:

$$\frac{0.33 * \text{number bags} * 50\text{Kg}}{\text{Cross-section legs in cm}^2}$$

0.33 is the safety factor 3. The conversion rate from kg/cm^2 to kN/m^2 is about 9.8.



Minimum required bearing capacity of sub soil as function of the bridge span & traffic load – values at foundation level

Span bridge L(m)	traffic load 40 tons		traffic load 20 tons	
	in kN/m^2	In kg/cm^2	in kN/m^2	In kg/cm^2
1	132	1.35	77	0.79
2	113	1.15	72	0.73
3	108	1.1	74	0.75
4	109	1.11	80	0.81
5	113	1.16	88	0.9
6	121	1.23	98	1
7	129	1.32	109	1.11
8	139	1.42	121	1.23
9	150	1.53	133	1.36
10	161	1.64	146	1.49
11	173	1.77	159	1.62
12	185	1.89	172	1.75
13	198	2.02	186	1.89
14	211	2.15	200	2.03
15	224	2.29	213	2.17
16	238	2.42	227	2.32
17	246	2.5	236	2.41
18	265	2.7	256	2.6
19	279	2.85	270	2.75
20	293	2.99	284	2.9

Source: Cornet 2013

Bearing capacity of some soil types in Kasese District

Soil type	depth	av. allowable bearing capacity kN/m ²	area
clayey sands	2.5	210	Nkoko / Karusandara
clayey & silty gravels	3.0	340	
clayey gravels	3.0	110	Kyempara / Isango
clayey sands	4.0	155	
poorly graded gravel & silty gravel	2.5	635	Kyabayenze/ Karambi
silty sands	3.0	740	
inorganic silt	3.5	770	
silty sands	2.0	735	Katumba / Bugoye
silty sands	3.0	>1000	
clayey sand and clays	3.5	400	Kanyamunyu / Kitholhu
silty gravels	2.0	450	Kaghema / Kyarumba
silty gravels	2.5	695	
silty gravels	3.0	845	
silty gravels	4.0	730	
clayey sands and poorly graded sands	3.0	730	Kabuiiri / Maliba
clay	3.5	695	
poorly graded sands	4.0	755	

Source: MBW 2012 – safety factor 3 applied.

Flood prevention

It is advisable to construct a bridge on a slight sloping terrain in the landscape rather than on the edge of the valley where water accumulates and risk of floods and meandering is higher. High river banks reduce the risks of flood levels exceeding the bridge and of the by-passing the structure by the river.

Avoid river bends

The crossing must ideally be located where the river is straight, stable, and not meandering. This will reduce the maintenance costs considerably. In a curve, the river will cause heavy scouring or will break through its banks and by-pass the bridge.

Road approaches

For low rural traffic densities, the best position of the bridge vis-à-vis the river (i.e. square on the river axis) is more important than the alignment with the existing road approaches. The site for the bridge is selected in such way that no large quantities of backfilling are required for raising the level of the road. Backfilling of road approaches can be very costly as it often requires heavy machinery.

High river banks

For arch bridges where tilting force of the soil mass has no effect on the stability of the structure, high river banks usually offer important advantages:

- The roman arch type can be adopted which is a stronger design than the segmental one.
- Larger bridges can be constructed to absorb the full discharge of even the largest floods.
- Less material is required for backfilling and the construction of road approaches.
- With high river banks, the probability of a meandering river or bursting banks is lower.
- Usually easier traffic access, as the approaches will not be on a steep slope.

High river banks are sometimes an indicator for increased erosion risk and adequate mitigation measures should then be put in place (see 3.2.9).

3.2.2. Site preparation

For large bridges, the community will need time to deliver the materials before the actual construction starts. It is good practice to peg out already the actual site of the bridge. In addition, the technician should peg out the locations where sand and stones should be delivered by the village. The site plan is discussed with the village so that building materials are dumped in a systematic way without hindering access to the site and optimising transport cost during construction.

Construction is best done during the dry season. Transport of building materials is then easier and costs for river diversion, digging the foundation pith of sufficient depth and flood prevention can be minimised. Village labour is also more available during the dry months. It is good to avoid construction during the rainy season; as flood risks are hard to control.

Site preparation starts with site clearing (stripping topsoil, slashing the vegetation, cutting down trees and removing the roots). Clearing vegetation is a basic task performed by the community. On the river banks, heavy bush clearing and the unnecessary cutting down of trees should be avoided as they will help to prevent erosion in the future. Existing grass tufts should not be destroyed. They will be planted on the steeps riverbanks to stabilize the soil after construction.

If possible, the existing local bridge is left intact to facilitate the movement of building materials. Alternatively, a temporary bridge might need to be constructed where the traffic cannot be interrupted. It can be made with logs placed across the river.

If necessary, the river will be diverted with coffer dams, notably to allow for foundations of sufficient depth and provide for stone pitching of the river bed where required to prevent scouring. Cofferdams are usually erected to prevent the flooding of the excavation pits. Cofferdams will be made of bags filled with soil and stones. In function of its height, the bottom of the coffer dam will be 2-3 bags wide to improve stability. In case of flood risk of large rivers, the bags will be supported by spiked poles and heaped stones walls or temporally placed gabions. The size of the diversion canal is a function of the river flow. The verge of the canal is dug at 60% degrees to avoid the collapse of the walls. Excavated soil is "stored" properly to facilitate the filling of the diversion after construction. If possible, the dam is made at sufficient distance from the construction site to prevent flooding. River diversions are best avoided during the rainy season as the floods can make deep gullies causing the stream to by-pass the bridge altogether. To prevent scouring of the diversion canal during floods, gabions can put across the canal bed to obtain a stepwise discharge. Alternatively, galvanised culverts are temporary used to avoid erosion.

3.2.3. Setting out and excavation

Once the location of the bridge has been determined, the river banks and the foundation trenches are excavated. During excavation, it is important to ensure that any water which may enter the trench can run off or should be pumped out. After digging, the bottom of the pit shall be compacted with a heavy steel compactor or a jumping compactor. The excavation pit will provide for an allowance of about 1 metre each side to enable the access of the craftsmen. In most cases, a water pump is required to remove the excess water and reach the required foundation depth.

To avoid the river banks collapsing, the slope of the excavation should be at least 60 degrees. For unstable soils, the excavation should be done in steps or the walls should be temporally shored by timbering and struts.

For larger rivers that cannot be diverted, the excavation is usually done in 2 phases. Only one bank of the river is shut off with a coffer dam to reduce the water level and allow for excavation. Then the foundation and abutment at that bank are built. The coffer dam is then moved to the opposite river side and the process repeated. Shutting off both river banks at the same time drastically increases the risk for flooding of the excavation pit and foundations and should be avoided unless construction is done in the middle of the dry season.

The bridge foundations must be carefully set out. Measurements are made and checked with two measuring tapes and a calculator (*see figure 22*). Based on the Pythagoras' theorem (squared hypotenuse equals the sum of the squared length and squared width), the diagonal can be calculated and square angle obtained. To make sure that a corner is a right angle, the 3-4-5 method can also be used, but it is a bit more time consuming. Pegs are put in the ground and string or cord is tied to them, to show the mason the width of the foundations. These marks must be durable, so that they remain accurate for a long period of time and are not destroyed by rain or workers activities.

A straight trench is dug out between the lines. Before digging, it is necessary to check the orientation of the lines, the dimensions and the right-angles using a measuring tape and a square.

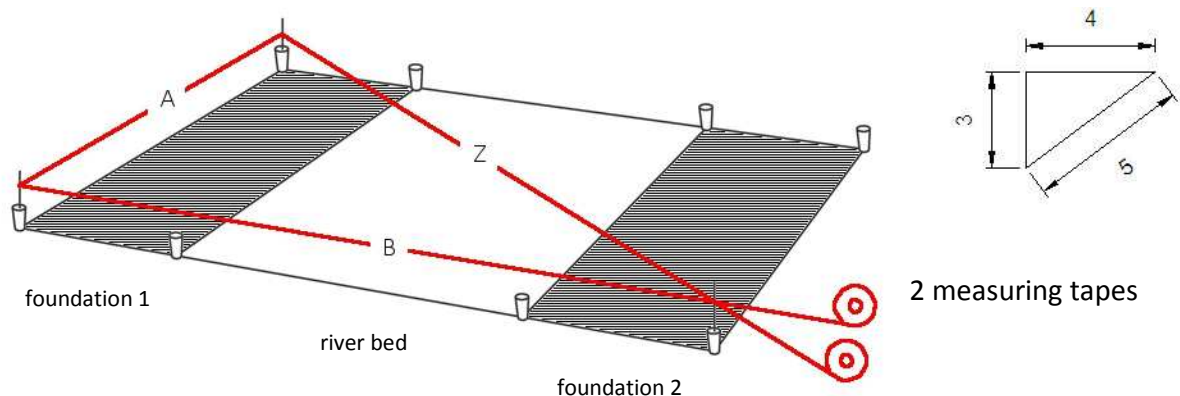


Fig. 22: Setting out the foundations with 2 measuring tapes speeds up the work. The measuring tapes will help to get the right angle based on the Pythagorean Theorem. $Z^2 = A^2 + B^2$. In a triangle of 90 degrees: the square of the hypotenuse is equal to the sum of the squares of the other two sides. Alternatively, use the 3-4-5 method which is more labour intensive: $5^2 = 3^2 + 4^2$.

Excavation, loading and hauling tasks can be performed by the community, using shovels, pick axes and wheelbarrows. The workers are instructed not to dump the excavated soil in the river. Excavated materials will be kept near the construction site so as to be re-used later for backfilling, although more material will usually be needed. The excavated soil should be dumped where the road approach. To prevent collapse of the construction pit, excavated soil is dumped at least 6 metres from the trenches so that no extra weight is added to the earth wall.

3.2.3. Foundations and abutments

The lifespan of a bridge depends essentially on the strength of its foundations. The strongest bridge will have a short lifespan if its foundations are eroded by the river. Masonry work for foundations will be carried out with particular care and under strict supervision. The substandard work of many local masons (low dosage cement in mortar mix, no use of batch box, excessive water amount in mix, poor bonding of stones, air gaps, no stone washing...) should not be tolerated. The technical

specifications and quality will be strictly enforced, as the structural strength of the bridge depends on it. Masons not able to adhere to higher quality requirements should be replaced immediately.

With stable sub soils, foundations are made of stone masonry. Their height should be determined on site once firm subsoil is reached. The design tables (*figures 15 & 16*) give only minimum depths. Apart from sites with solid rock beds, the foundation depth will exceed the depth of the river bed. On sites with poor bearing capacity (permanent waterlogged places, sites with high content of clay and sand), a reinforced foundation slab or footing will be necessary. On muddy and unstable sites, different techniques exist of constructing piles of mass concrete. One of them is the use of well foundations: a well is built with bricks. A base ring made of reinforced concrete and is bevelled to facilitate the penetration of the cylinder into the ground. Another solution is the construction of concrete rings. They are dug into the ground until a firm sub soil layer is encountered. The rings are then filled with mass concrete as foundation pillars. Reinforced concrete boxes can also be constructed upstream on the riverbanks, and moved by floating. However, this requires specialised skills beyond the scope of this manual.



*Fig. 23 a: The quality of stone masonry is essential. A good bond of stones and tight gap filling will provide for a strong abutment. In addition, at the river corners dents are left for a good link with the wing-walls.
Fig. 23 b: Extremely poor masonry works – no bond at all, plenty of gaps between the stones, no embedding of stones with mortar. Sections like those need to be demolished immediately and the mason replaced.*

Stones for the foundations and the abutments are placed in a horizontal position (*see fig. 8, fig. 23 a, fig. 24*), laid down on the largest side of the stones enabling a good bond. The selection of the well shaped stones is important in order to minimize the quantity of mortar and improve the strength of the bridge. Stones are wedged against each other to reduce the number and size of holes to be filled in with mortar.

The foundation and abutments require large stones – ideally rectangular shaped. Masons will work with “stone spotters”. From the stone piles, these casual labourers specialise in identifying the stones of the right shape and size that fit in the existing masonry gap. The stones are washed with a hard brush and wedged against each other to reduce the number of holes to be filled in with mortar. Gaps between the stones need to be filled with crushed stones and mortar. Mortar is laid where necessary, rather than just poured over the stones. All stones should be well embedded in mortar. The practice of local masons to allow some dry touching of stones should not be tolerated.

As the foundation and sections of the abutment are permanently exposed to damp conditions, a mortar mix of 1:3 is a must. For the sections of the foundation under the water table, a 1:2 mix is required. Poor quality sand will require a higher cement dosage. Untrained craftsmen will usually

put too much water in the mortar to enhance workability. However, wet mortar mixes will lead to poor strength. The maximum amount of water is 20 litres per 50 kg cement bag.



Fig. 24: Different positioning of stones in the structure

Arch = stones along radius of the semi-circle

Abutment & foundation = stones are laid flat

3.2.4. Formwork

For building an arch, a semi-circular formwork of the same shape as its interior curve (intrados) is required to support both spans until they lock together at the top (*see fig. 8, fig. 24 and fig. 25*). The frame, called centring, is removed after the stones are in position. The formwork is usually made of wood; but soil on a wooden platform is also possible. The wooden formwork is used with wedges so that it can be easily removed once the arch is complete. The formwork resembles the trusses of a roof, only that its top shape is circular and that usually it is made of 2 parts.

The wooden formwork is made up of 2 individual trusses (*see fig. 25.b*) that are linked in the middle. The trusses are usually made of 2*4" timber (50*100 mm). For longer spans 2*6" (50*150 mm) will be required. The trusses are supported by transverse struts and poles. For the average bridge width of 3.6 metres, 5 "double" trusses are required. The trusses are covered by 1*3 timber purlins. The purlins are jointed tightly without gaps to avoid mortar being wasted.



Fig. 25: Each truss of the form work consists of 2 pre-fabricated quarter circles that are assembled at site.

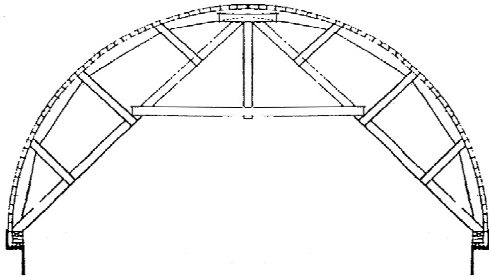


Fig.26: The wooden formwork is made up of 2 individual trusses that are then connected in the middle with a tie-beam. The floorboards are placed directly on the trusses. Each wooden structure rests on 2 wedges easing the removal of the formwork.

Fig 26 a: formwork for a roman arch.

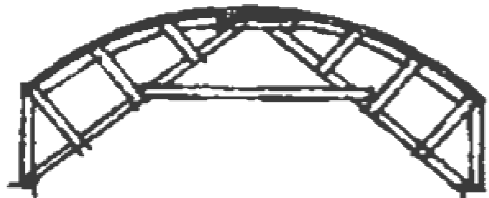


Fig 26 b: formwork for a segmental arch for large spans.



Fig. 27: The correct curve of the truss in a function of the span and the type of arch is important. Many carpenters struggle with the principle and the process will need technical guidance. A: correct shaped formwork. B: wrong formwork consisting of a set of straight lines. This latter formwork had to be demolished.

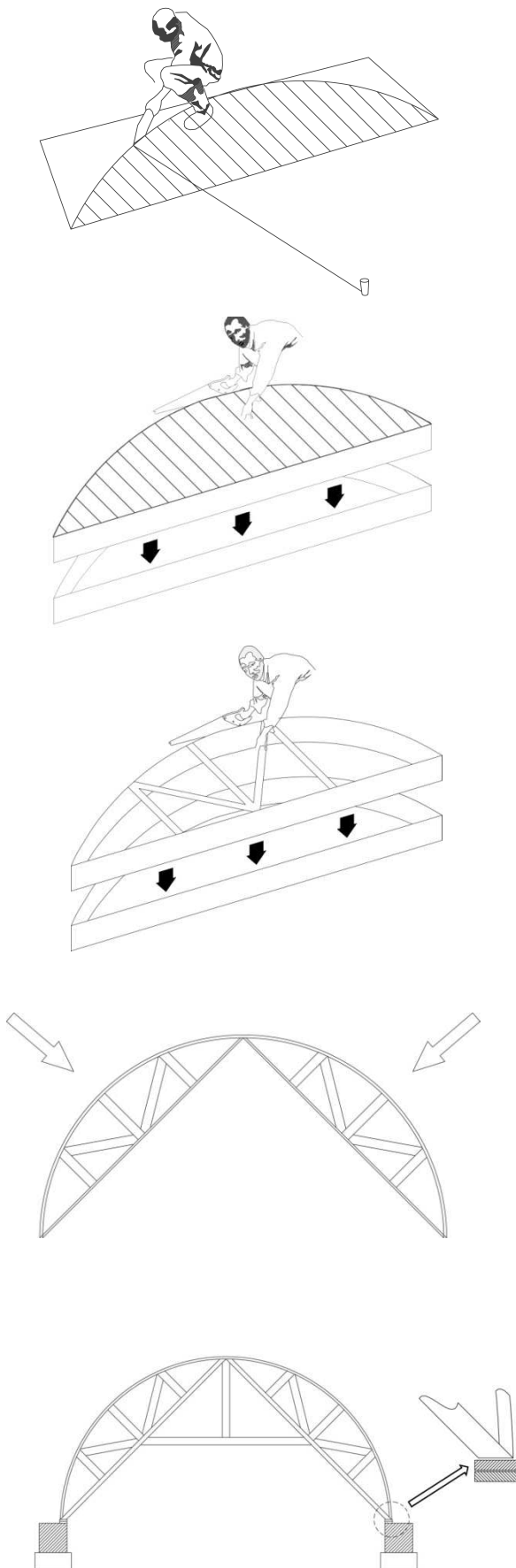


Fig. 28: Once the first mould is constructed, the others are easily copied and shaped with a machete.



Fig 29: five trusses are required for a standard width of 3.6 m. The trusses are supported by struts.

Fig. 30: Steps of assembling the formwork



1. With help of rope and pencil, $\frac{1}{4}$ of a circle curve is drawn on newspaper sheets that were pasted together. The paper mould is then cut out and will be used for the first wooden mould. The radius for the curve can be found in the design tables – figures 14-15. The rope will have the length of $2R$ of the design tables. For larger spans, the formwork will consist of 2 moulds.
2. The timber frame is constructed by putting the timber struts along the paper mould. The curved shape can be obtained with a saw or by hand with a machete/ chisel. It is critical that the shape of the arch mould is a curve and not a set of straight lines at different angles. Untrained carpenters will initially construct the latter which should be immediately corrected.
3. Once the first mould is obtained, the others are simply copied by drawing the original shape on the consecutive trusses.
4. On site, the quarter trusses are assembled into a half circle by struts. This formwork is levelled and supported by poles. Purlins are nailed on the trusses to finish the formwork.
5. It is important that the trusses rest on 2-3 wedges. Without the wedges, it will be impossible to remove the formwork without damaging the timber once the stone arch is constructed.

The drawings were produced by Neil Noble - Practical Action/ UK



Fig 31.: Left: If there is a risk of heavy flooding, additional anchoring of the scaffold is required. Timber poles (A) stretching across from one abutment to the other will hold the scaffold together. They are the basis for additional poles which are nailed parallel with the abutments in the river bed. A large opening (B) should be left in the middle where the debris can pass. Right: The poles of the formwork in the middle caught the debris of the first seasonal floods. The water flow was blocked leading to serious damage and the river by-passing the structure.



Fig 32: This formwork was constructed on site during the dry season. The span of the bridge was 50 metres and consisted of 5 arches. A rope was used to get the curved shape. The pictures are a courtesy of Rashid Mtamila/Tz.

Formwork for culverts



Fig. 33: The moulds for culverts are standard (here 80 cm diameter and 2 metres long). They can be re-used many times. The culvert size can be adjusted in function of the site conditions (banks, water flow) by increasing the abutment height or having multiple structures.

The formwork can be removed immediately after closing the arch – there is no need to wait for the curing of the mortar. The scaffold can therefore be reused straightaway for culverts or multiple arches. It makes sense to construct a precise and robust formwork so it can be re-used. The district works office can store the trusses and culvert moulds so that they are available for future use. Painting the timber with used engine oil will increase the life span.

Alternative types of formwork

Where carpentry skills are not sufficient to build trusses, a full panel system can be used, but it consumes more timber (see fig 34). Building up bricks or blocks with dry joints and shaping the curve with a layer of mortar is a very economical way of making a formwork. When timber is too expensive, a further alternative is to use the “lost soil method”. The abutments are first built up and a platform is built between them. Then the inside of the culvert is filled with earth shaped on top to the correct profile for the underside of the arch (intrados). The earth provides temporary support for the arch stones during construction and is removed later (see fig 35).



Fig 34 a full panel form work is easier to construct but more expensive and less strong. To reduce construction costs, the formwork was removed to build the 3 arches consecutively.

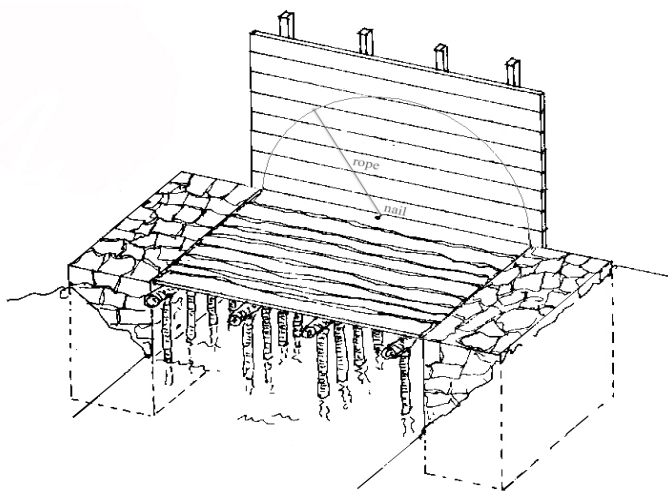


Fig. 35: Making of formwork with the “lost earth method”: A platform is built between the abutments. Wooden panels at both sides cut along the intern curve of the arch, drawn thanks to a rope fixed to a nail in the circle centre. The inside of the culvert is then filled with earth contained by two wooden panels, and shaped on top to the correct profile.

3.2.5. Arch – the wedging principle.

The arch shape is made from a series of wedge-shaped stones carefully chosen to fit together. These stones are set side by side on the formwork, and gradually take the curve of the arch from the outermost horizontal springs, the two points where the arch rests on its supports, up to the central and vertical 'keystone'. Stones of the arch are placed in a radial position. Stones should act like a wedge: the small end should be on the inner radius of the arch and the larger end at the outer. Once the stones are in position, it is recommended to tap with a hammer so that they slide tightly into place and mortar is better spread in the gaps between the stones.

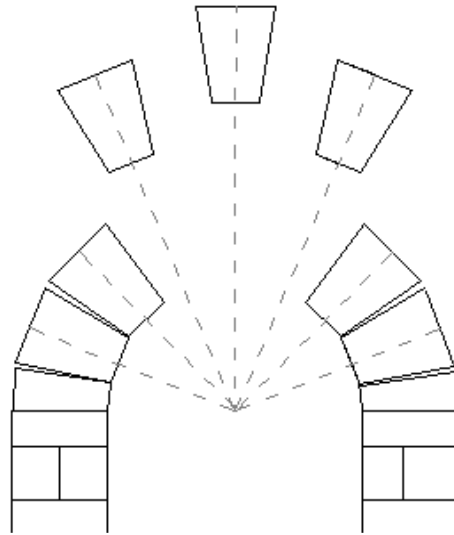


Fig 36: Stones of the arches are placed along the radius of the arch, the small base down and the larger base up, while stones of the abutments are set in a horizontal position, put down on the largest side of the stones.

It is usually not necessary to chisel the stones, but the selection of well shaped stones is crucial. They should be flat and long especially in the upper section of the arch. More details about the required quality of the stones are given in section 3.3.

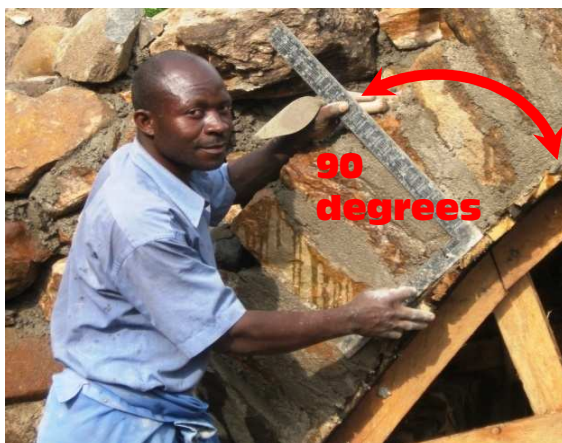


Fig. 37: Correct position of the stones along the radius of the arch.

Stones of the arch are placed in a radial position, squared to the scaffold.

A mason square indicates the correct position of each stone, provided the formwork is even.

For culverts, a rope fixed in the centre of the circle can be used to show the right direction.

During the closure of the arch at the top, it is essential that:

- The best shaped stones (long & flat) are preserved for closing the arch (*see fig 44*). They should not be used in early construction stages, as they are essential later.
- Stones are laid along the radius of the circle. Building squares help to get the right position.
- The stones are tightly wedged-in with a hammer and all gaps are filled with mortar (*see fig 38*).
- The minimum key stone dimensions (*see tables 15 & 16*) must be respected.



Fig 38: Left: Building squares show the right position of the stones during each phase of the arch construction. Right: It is of utmost importance to fill all gaps between the stones. Small stones will be added to the mortar to reduce cement costs and increase strength.



Fig 39. The quality of the craftsmanship is of extreme importance for the strength of the arch. Left: Good bond and proper positioning of stones. Right: poor stone masonry that will result in a weak structure.



Fig. 40: a: Stones are tightly put together. They should act as a wedge with the narrow base pointing downwards.
Fig 40 b: The keystone is wrongly placed. As the large base is at the bottom, the stone will fall out over time.

The arch construction must start from both sides at the same time, and is assembled symmetrically up to the keystone, which is positioned last. The formwork can be removed as soon as the arch is closed. It is easy to remove the formwork that was placed on simple wedges of timber cut-offs. The formwork can be re-used.



Fig. 41: For stability reasons, the bridge is built symmetrically, stepwise from both sides at the same time (a). It is dangerous to construct only one side first (b). The structure is not secure until the arch is closed in the middle.

3.2.6. Headwalls

Head walls are constructed to protect the backfilling from water damage and guide traffic along the crossing. They are made of stone masonry and are positioned downstream and upstream sides of the bridge. They are made of 30cm thick stone masonry. For bridges of a long span, rain water drainage holes at the right level should be provided for.

3.2.7. Wing walls

The wing walls act as retaining walls for the riverbanks and protection against scouring. They are interlocked with the masonry work of the abutment. Wing walls are provided at both ends of the abutments to provide smooth entry of water into the bridge site and to retain the backfilling of the approaches. Their design (position, orientation and length) is determined on site, in function of the natural landscape. They are preferably constructed in steps, at the same time as the abutments. It is not recommended to build wing-walls higher than 2 metres in one go. This would require a heavier base than the usual 40 cm thickness of the stones. Wing-walls with deep foundations are often a better investment than gabions which usually sag and tumble after minor under scouring.

3.2.8. Backfilling: an underestimated construction step.

The strongest arch bridges are those that are permanently loaded with compacted backfilling material. Ideally, there is a soil buffer above the arch to cushion the impact of moving heavy traffic and increase the load. Backfilling material (typically compacted gravel or laterite soil) is compacted above the arch in order to increase this dead-weight on the bridge and prevent tensile stresses occurring in the arch ring as loads move across the bridge. A minimum of 30cm of filling should be added on top of the arch, but the quantity will vary as a function of the site conditions (level of the road and height river banks). If insufficient backfilling can be provided (to avoid large humps in flat valleys for instance), it is recommended that a concrete cap of 10 cm thick and 2 metres in length is cast on the top of the middle section arch. .



The backfilling should be placed in 10 cm layers of murram and then heavily compacted. The workers will use an iron compactor, a tractor axle or a long handle with a cast iron weight at the end. The usual timber or light metal compactors are not effective at all and should be banned. Even an eucalyptus pole will do better than those.

A lot of manpower and direct supervision is needed to produce a compaction of reasonable quality. The soil layers should have the right moisture content and should not be too thick. A jumping compactor will provide for the best compaction. A common construction mistake is that soil is just dumped in large quantities behind the wing-walls and abutment and then only compacted on top. Soil dumped in this way will exert a big sliding pressure on the wing-walls, leading to cracks. In addition, it will not further strengthen the structural stability of the arch bridge.

A moderate moisture level allows for the best compaction and the soil strength. The backfilling is usually from a dry stockpile of excavation materials. It needs to be slightly moistened. If the soil is too wet or too dry, it will simply not compress

A layer of gravel or laterite soil will be used to be rammed in the last layer of the wearing surface of the road. Surfacing improves the structural support and reduces road surface erosion. Soil of high organic matter should not be put close to the surface of the approaches or road.

Rain water should not be standing on top of the culvert or bridge. Therefore, this section of road should be slightly higher and the water should gently be drained away from the wearing surface to the shoulders. The headwalls can also have some drainage holes.

3.2.9. Erosion protection

As the population is growing, more floods can be anticipated, due to deforestation, poor land use, destruction of the catchment area, quarrying in the river bed, etc. Global warming has also increased considerably the risk of extreme flooding. High flow velocities often lead to bank erosion and the formation of gullies. Therefore, it is important to plan for long term erosion protection. Scouring of the foundations and wing-walls will compromise the lifespan of the structure.

Site selection

Future erosion can be prevented by selecting the correct site. The bridge is ideally located where the river is straight, stable, and does not change its course. The opening should be wide enough to minimize constriction of the natural channel. Whenever possible, a bridge should be constructed at a narrow channel location at a straight angle with the river. Where the bridge restricts the river flow, higher water velocities downstream will require erosion protection. For more details about the site selection, see the first paragraph about construction steps.

Foundation depth

Bridge foundations should preferably be placed on bedrock. Alternatively, foundations are constructed well below the expected future maximum depth of scour – usually 1.5 - 2 metres. A water pump is required to reach that depth.

Structure protection

The in- and outlet will be protected with masonry wing walls or gabions where the sub soil is not stable. Where there is a large river gradient and high water velocity, stone pitching and/ or gabion mattresses between the foundations are required to prevent future erosion. Local gabions mattresses can be made while “sandwiching” stones between galvanised wire mesh and anchoring the mesh with $\frac{3}{4}$ inch galvanised pipes. Because of their high costs and high risk of collapse, many designers prefer deep wing-walls over gabions.

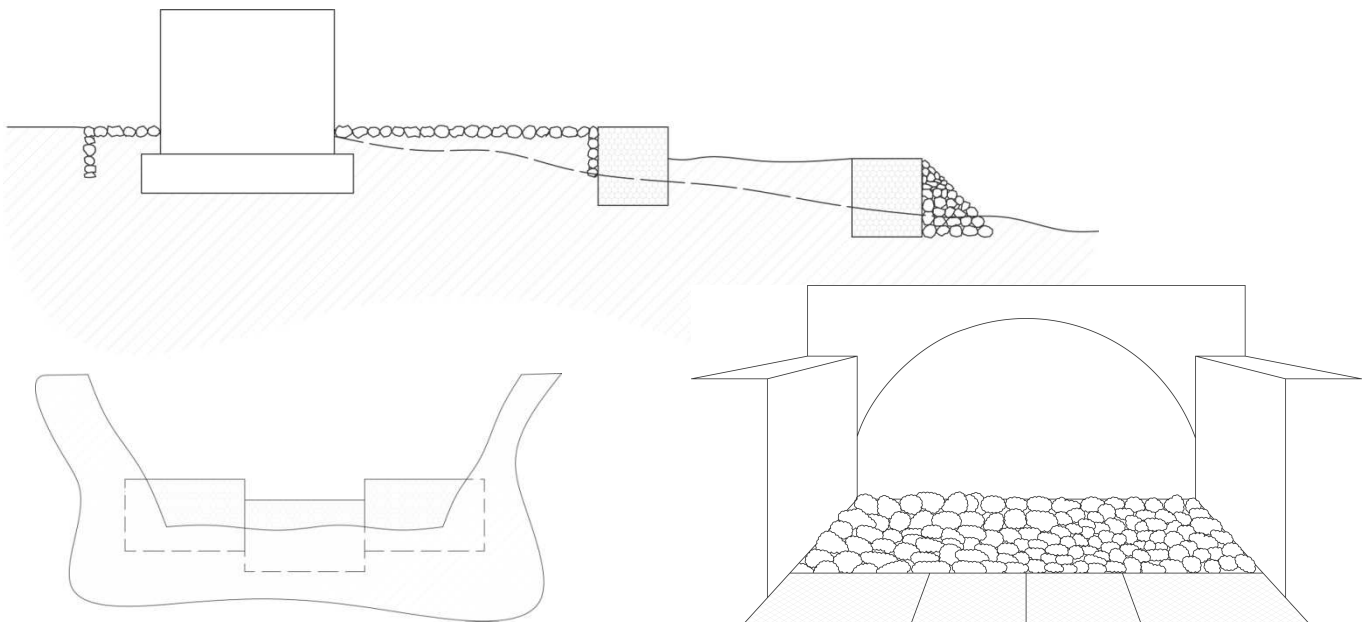


Fig. 42: erosion protection with gabions and stone lining will be required for sites with heaving scouring.

River bank protection

Newly formed slopes can be easily damaged by runoff surface water, cattle, etc. It is therefore necessary to protect the slopes by:

- Cutting the bank gradient to 60%
- Planting of grass at high density (elephant grass cuttings at distance of 20*20 cm, paspalum grass at 7*7 cm, vetiver grass 15*15 cm) and/or grass mats obtained from the excavation.
- Placing a riprap with stones or additional gabions mattresses for risky sites
- Planting of bamboo and ficus trees (strong branches used as cuttings) along the river banks. Contrary to trees, bamboo can be planted in the immediate vicinity of the bridge as its roots will not expand and cause cracks. Trees should not be planted close to the bridge. The erosion protection along the river banks of trees such as eucalyptus or grevillea is limited.



Fig 43: If not properly installed, gabions often collapse fast (a). This example started sagging after the first flood and had to be redone. Before the gabions are placed at the river banks, large stones will be rammed in as support basis to avoid early scoring under the gabion. The stones are carefully placed in the cage to avoid damaging the galvanized coating. The craftsmen will look for a good bond between the stones (b). The stone volume in the cage is 100% self supporting. There is no pressure of the stones on the cage. All cavities are filled with small stones and river sand. The gabions are filled in such way, that if walking on them, the stones should not move (c). Half way the filling, wires are tied to across the cage to reinforce the gabion

3.2.12 Auxiliary road works

A parapet of 30cm is not strictly necessary, but is usually added on top of the head walls to prevent moisture entering. Other items can be considered: guardrails for pedestrians, drainage holes in the wing walls, road signboards etc.

3.2.11 Maintenance

Stone arch bridges usually require little maintenance. Their heavy weight helps them to withstand floods, as long as scouring of the foundations is prevented. Periodic maintenance includes repairing of wing-walls, collapsed gabions and stone lining, and removing silt & debris from the stream channel. The cattle access in the neighbourhood of the bridge is strictly prevented. The erosion of the base of the river and scouring of the wing-walls & foundations will be carefully assessed after floods. The first floods of the rainy season are the riskiest. Tree log and debris will then often jam the bridge and culvert openings. The road committees should be sensitised to clear the structures from trunks, rubbish and excessive silt immediately after the floods.

3.3 Selection of construction materials

Stones

Large and good quality stones shall be used for the construction of the bridge structure. Fortunately, areas where large quantities of culverts are required are usually associated with steep terrain where stone is relatively abundant. However the quality of the stones should be monitored. Stones should be strong, hard and free from cracks. Another important characteristic is that their surface must be rough. River pebbles cannot be used as the mortar will not adhere well on the smooth surface. The stones must also be large. The community is instructed to only collect stones that need to be carried by at least 2 people. For the arch section, large, flat and long stones are required. They are stored for that purpose. The best shaped flat stones are used for the closure of the arch in the middle. Small stones will lead to high construction costs and weak structures. Laterite, volcanic tuff and sedimentary rocks such as sandstone, shale, and other porous or brittle stones can only be used for backfilling and not for the structure. Volcanic rock, basalt slate and crystalline stones (granite, gneiss) are excellent construction materials.



Fig. 44: Large stones make the bridge strong and reduce cost considerably. Prior to collection, the community should be given examples of the adequate stone size and the type of stones required.

All stones should be washed with a strong brush and clean water. Stones need to be moistened just before construction to increase the adherence of the mortar.

Note: Locally produced bricks do not meet the required strength standard and are not recommended for the construction of arch bridges. Only for culverts of 80 cm diameter, good bricks can be used in 2 courses, provided there is a good soil buffer (>40 cm) on top and that the foundation is made in stone.

Sand

Sand should be coarse and fairly granulated with minimum silt. The quality of the sand is important for the strength of the masonry. It is better to haul sand from a distance, rather than to use locally available sand with high silt content. The best sand is collected from fast flowing sections of the river. Sand collected from slow moving parts is likely to contain mud or silt and should be rejected. Dirty sand has a negative effect on the strength of the structure. Different tests can be carried out

to make sure the sand is clean. One of them is to rub some sand between the fingers. If the sand does not stick to the finger, it can usually be used for construction. Sand is sieved to remove organic matter. The dumping site for sand is stripped of vegetation and compacted. Stored sand heaps are protected with thorn branches from goats and playing children. A ditch prevents rain water run-off. Ideally sand is kept dry. During the rainy season, the use of wet sand will require to turn the dry mortar mix at least 6 times to get a homogenous blend. Wet sand has a reduced bulk affecting the usual volume measurements. Tamping the sand in the batch box before mixing will increase its bulk.

Cement

The cement should be stored in a dry place on wooden platforms. A gap of 10 cm from the walls will prevent moisture absorption. Cement which has absorbed moisture is not suitable for construction. It is recommended to arrange the store in such way, that the oldest bags are used first.

Water

Water used for making mortar must be clean. Water that contains salt, silt, organic matter or soap is unsuitable for mixing mortar. If the river water is muddy, it will be necessary to store the water first in drums so that the silt settles. Moringa extracts will enhance the sedimentation process. Usually, too much water is used in the mortar mix leading to weak masonry works. The maximum amount of water is 20 litres per 50 kg cement bag. If the sand is wet, even less will be necessary. Water in large quantities is also required for the curing. Stone masonry and concrete must be kept damp for 2 weeks by watering it every 2 hours and covering it with plastic sheeting or grass.

Mortar

Mortar binds the stones together and increases the construction stability. The usual mixing of materials with local basins or wheelbarrows should be avoided, as it is hard to control the exact amounts. The use of a gauged batch box is required for the preparation of quality mortar, to ensure the right proportions. A 30*30*35 cm box has an equivalent volume of a 50 kg bag of compacted cement. The contents of the batch are struck off with a levelling rod. For building stone arch bridges and culverts, a 1:3 mix ratio is recommended. The sections permanently exposed to moisture and the arch should not have a lower mix. To avoid contamination, the mortar is mixed on a temporary "floor" made of bricks or rammed in stones. The mixed mortar is used within an hour. Spilled mortar is immediately recycled to avoid waste.



Fig. 45: The use of a gauged batch box and ruler is a precondition for producing quality mortar. Basins and wheel barrows should not be used as it is difficult to control the exact amounts.

Fig. 46: Prior to construction, all stones need washing to ensure that the mortar adheres to the surface.

3.4 Implementation modalities and site management

Implementation modalities for local governments

For local governments in Uganda, there are a number of possibilities to construct arch bridges as outlined in the table below. Whatever the approach - strong quality and cost monitoring is required for every construction step. The integrity and quality of the personnel determine success or failure.

Implementation Modality	Strengths	Weaknesses
Public procurement works done by contractor	<ul style="list-style-type: none">• Strong legal and contractual framework.• Less monitoring requirements• In theory better checks and balances	<ul style="list-style-type: none">• Long procurement period• High cost but no quality guarantee• No mobilisation of local resources
Force on accounts done by works department	<ul style="list-style-type: none">• Lower cost• Faster implementation• More flexible approach	<ul style="list-style-type: none">• High monitoring requirements• Little checks and balances• No mobilisation of local resources
Force on accounts combined with community involvement	<ul style="list-style-type: none">• Strong involvement community provides for check and balances• Cost reduction through mobilisation of local resources.• Strong local ownership and cost efficiency restores credibility of the local government.	<ul style="list-style-type: none">• Community contribution will take time• High monitoring requirements

Organisation of the building site

A well-organised worksite makes working easier for everyone.

The **mason** (on a small construction site) or **site foreman** (on a bigger construction site) is responsible for the organisation of the overall construction works.

- S/he ensures the coordination of the activities and selects the teams of masons and helpers (casual labourers and village labourers).
- S/he ensures that the construction is carried out according to the drawings, the Bill of Quantities and the technical specifications, and gives precise technical instructions.
- S/he supervises the excavations, the setting out of the work, stone dressing, the mixing of the mortar, the execution of the masonry and the backfilling and compaction.
- S/he makes a daily entry in the site register, noting what work was carried out, the names of the workers employed, the number of cement bags used and any other events.
- S/he supervises the ordering of cement and tools and checks the quality of local materials.
- S/he takes advice from the site manager and the technicians who examine the works.

The **storekeeper** stores the tools and supervises their maintenance.

- S/he keeps the key of the store.
- S/he records each delivery and use made of the tools and equipment in a register.
- S/he warns the mason/site foreman of imminent shortages.

The **site manager** regularly checks, by examining the work and the site register; the progress of the work, whether the work plans are being respected and the amount of money spent.

Construction season and time

Construction is best done during the dry season. Water levels are then low and accessibility of the sites is better. For the community, it is usually also easier to provide labour during the dry season. Construction during the rainy season will invariably increase costs of flood protection and transport.

The construction time varies a lot due to the span and the ability of the community to mobilise the materials. As a reference, a bridge of 5 meters span and 3.6 m width will be constructed by 2 masons & 4 helpers in about 30 days provided that the materials are on site. Consider that carpenters will need time to accustom themselves with the arch form work. Some mistakes are usually made and it is good to order the scaffold in advance to avoid construction delays.

Multiple construction sites

Some districts work with one experienced construction team to ensure the quality. In order to increase the number of bridges built per year, it is a good idea to build the foundations, wing-walls and abutments of several bridges during the dry season. The arches, headwalls etc are then finalised during the wetter parts of the year. Tackling several construction sites simultaneously will also reduce the problem of stalling construction because of the delay of stone supply by the community. Masons move to the sites where sufficient stones were delivered. In the meantime, the other villages will have more time to collect stones and will be encouraged by the tangible progress.

Construction supervision

Good supervision is critical for the quality of the construction, not only for the stability and durability of the bridge, but also to overcome scepticism of the community being used to reinforced concrete structures. Particular attention is paid to the control of site work: execution, planning, building materials, and maintenance of equipment. The following is required:

- **By the beneficiary community**, carrying out the day-to-day monitoring of the construction works. As they are on site daily, the local road committee informs the district works department if there are problems with the quality and quantity of the construction. They should also keep a log book of the attendance of mason and casual labour and the use of materials.

- **By the Lower Local Government**, making sure beneficiaries implement their responsibilities and reporting progress or any problems to the Works Department.

- **By the District Local Government**, supervising and certifying the construction of the bridge.

Continuous supervision is required in during the construction of the first stone arch bridges to build capacity and ensure the adherence to minimum technical requirements. The need for construction supervision is reduced if skilled and integer masons are employed. The selection of experienced masons is critical.

Next to their technical role, engineers and technicians involved in labour-based projects play an important managing role. One of the challenges is often the mobilization of the community. Late community contribution is often the main reason for the delay of the works.



Fig 47: Multi stone arch bridges can be used to cover large spans. The span of this bridge was 50 metres and consisted of 5 arches. The picture is a courtesy of Rashid Mtamila/Tanzania.



Fig 48: The success of the construction depends on the integrity and expertise of the craftsmen and supervising technical staff. There is no shortcut for proper management of human resources and construction contracts. Adherence to quality and minimum technical standards requires training and continuous supervision.

3.5 Common construction mistakes.

Issue	Mitigation required
1. Wrong stone laying for the arch Stones of the arch are laid in a horizontal position, rather than in a radial position, leading to a weak structure.	<ul style="list-style-type: none"> Put the mason square on the mould and align the axis of the stone with the square. Alternatively, follow a rope fixed in the middle of the mould, to ensure a right slope (radius $\frac{1}{2}$ circle). Make sure stones come as a wedge: the small base at the bottom and the larger head at the top. Once the stones are in position, tap with a hammer so that they slide in the right position and mortar is better spread in the gaps under the stones.
2. Weak masonry foundation & abutment. The aim of untrained masons is usually to align stones with the other rope to get a clean appearance but not to look in the first instance for a good bond. Gaps are left between the stones and some stones are not embedded in mortar.	<ul style="list-style-type: none"> For foundations and abutments, stones are laid horizontally and a good bond is looked for by mixing large and small stones. All gaps are systematically filled with small stones and mortar. Wobbly stones are lifted and more mortar and aggregates are put under them so that all cavities are filled.
3. No fitting of the stones in existing gap The immediately available stone is often used by masons whether or not it fits in the existing gap. This leads to poor bonds and high construction costs.	<ul style="list-style-type: none"> 1-2 labourers should be charged with stone "scouting": identify the type of gap and look for corresponding stone. Put flat and long stones on one pile and have them ready for closing the arch at the final stage of construction.
4. The arch is built with small stones and poor bond leading to a weak structure.	<ul style="list-style-type: none"> Select the best stones for the arch and keep them apart to avoid that they are used in the early construction stages. Train the community on the required stone shape and size.
5. Poor mortar mix The quality of the mortar is often poor, to save on cement costs. The quantity of water used is usually too high, to improve the workability of the mortar.	<ul style="list-style-type: none"> A gauged batch box (30x30x35 cm) should be used and the mix ratio respected. The measured quantities are struck off with a ruler. Quantity of water used should be reduced to a maximum of 20 lt per cement bag of 50kg. Improvement of the sand quality and use of a sieve to remove undesirable particles. Cement and sand should be mixed 4 times (even 6 times if the sand is wet during the rainy season).
6. Excessive use of mortar Gaps between the stones are often filled with mortar only, leading to an excessive use of mortar and weak structures.	<ul style="list-style-type: none"> Smaller gaps are filled with small stones of the right shape/size and mortar. Labourers should pound stones. The crushed aggregates should be available next to each mason for gap filling.
7. Waste of mortar Mortar is wasted while be scooped out of the metal basins. Other mortar is dropped below the mould. The mortar is too wet and the local containers are small.	<ul style="list-style-type: none"> Use maximum 20lt of water per cement bag. Use large cut jerry cans instead of small metal basins. Once possible, put the mortar basins on the mould and not on the earth floor. This allows for immediate recycling without contamination. At regular intervals collect the mortar from the base of abutments and from under the mould. Put banana leaves or plastic sheeting at the base of the abutments to avoid fallen mortar being soiled.
8. Inadequate interpretation of drawings. Abutments and shoulders are smaller than the required width. Serious risk of structure instability. Abutments are constructed as foundations.	<ul style="list-style-type: none"> Train masons and technicians on reading of drawings. Enforce required dimension by measuring with a tape measure. The rope alone is not sufficient. Use squared stones and not irregularly shaped stones.

Issue	Mitigation required
9. Poor quality stones are delivered by the community.	<ul style="list-style-type: none"> • Samples of proper stones provided to the community. A village leader of a successful construction site is invited to share his/her experience with a new community. Small stones and smooth river pebbles are discouraged from the beginning.
10. Slow progress of the works Masons are not making enough use of the casual labourers.	<ul style="list-style-type: none"> • The person in charge for the construction site should immediately identify idle workers and assign tasks to them in relation to the actual bottlenecks at the moment. • Moving heavy stones should be done by the labourers and not by the masons. • The gaps are filled by the labourers and not by the masons. • Special stone spotters are trained to identify the right shaped stones.
11. No stone washing. Stones are washed with dirty water or not at all. As a consequence the mortar does not adhere to the stones leaving a weak structure.	<ul style="list-style-type: none"> • Stone washing with plastic brushes is compulsory and a labourer should be employed for that purpose. • Replace the water when it starts being brown. • Wash the stones at a distance from the immediate construction site to avoid sullyng other stones again.
12. Insufficient space for 2nd arch for multiple structures. On abutments with 2 arch springs, there is insufficient space for the second one.	<ul style="list-style-type: none"> • Wherever possible put the moulds parallel so that both arches are constructed simultaneously.
13. Late removal of the mould Mould removal takes too long as craftsmen are waiting for the mortar to cure.	<ul style="list-style-type: none"> • The mould can be immediately removed provided that the arch is closed. It is not the mortar that holds the arch but the wedge shaped stones positioned along the radius.
14. Small soil buffer on top of the arch In valleys, bridges stand out above the surrounding landscape. This high “hump” results in a small soil buffer on the top of the arch.	<ul style="list-style-type: none"> • Provide for at least 50 cm soil buffer on the top of the arch for better stability. • Where approaches are becoming too high because of the soil buffer, apply a concrete cap on the middle of the arch instead.
15. Cracking wing-walls No bond between abutment and wing wall The corners of the outer abutments are often finished as straight walls. Wing-walls are too high with only a base of 1 stone.	<ul style="list-style-type: none"> • Construct the wing-walls and abutments at the same time. Leave gaps in the outer abutments, so that there is a strong bond with the wing walls. • Backfilling & compaction behind wings walls should be done systematically small layers and mixed with stones.
16. Poor quality arch formwork. Carpenter does not produce a progressively curved arch mould but a set of assembled straight timber pieces. Bending moments will occur in the stone masonry leading to structural cracks in the arch.	<ul style="list-style-type: none"> • Train carpenters and supervise the construction of the first moulds. • Provide quality moulds as an example that can be copied. • Curved line should be drawn with a rope on the timber and cut with a circular saw or machete/ panga.
17. Difficult removal of formwork after construction. Most of the timber is damaged and cannot be re-used.	<ul style="list-style-type: none"> • Use 2 wedges under the formwork. This will ease the removal of the trusses and the purlins without destroying the planks.
18. Dumping of soil behind the wing-walls and abutments leads to cracks of wing-walls and does not strengthen the structural stability of the arch bridge.	<ul style="list-style-type: none"> • Soil is compacted in layers of 10 cm with a heavy metal axle. • Stones are added between layers and compacted. • Soil is moistened to obtain the right moisture content so that compaction is easy.

3.6 Training of masons

Before training masons, craftsmen with good basic skills and professional ethics should be selected. The selection test is simple: building a small stone masonry wall with mud mortar. The mastering of basic theoretical aspects are verified, with regards to the mortar (preparation, mix ratio, etc), required tools, materials quality and interpretation of simple drawings. It is good practice to inspect previous works of the masons before signing an agreement. The training is based on a gradual hands-on approach, starting from culvert construction to small bridges. Although the standard masonry principles apply, specific building techniques (notably the positioning of the stones for the arch and assembling the formwork) are explained and their application monitored in early stages. Even though these call for some tricks of the trade, the techniques are quite simple and can be mastered quickly. Structural principles should also be well understood, so that adaptation to new situations can occur. The different steps of stone arch bridge construction are taught including site preparation, site levelling, setting out of the foundations, stones selection, stones laying, mortar mix, backfilling and compaction. During the training, it is important to stress the crucial points for stone arch construction (stones selection, laying of the stones making up the arch, plumbing, rational use of mortar, respect of the dimensions, construction of the arch formwork etc).



Setting out of foundations



Abutment construction



Arch construction

Fig. 49: The training of masons starts usually with culvert construction.

While prior formal practical training of the masons is essential, on-the-job training at sites supervised by qualified craftsmen is core to acquiring specific arch building skills at an affordable cost. It is important to keep in mind that newly trained masons will require regular supervision. Twinning craftsmen with experienced masons at construction sites is an efficient training method.

3.7 Promoting the technology.

In addition to the training for the masons, professional training should be provided at other levels in order to create teams capable of undertaking projects from design to construction stage, as well as the maintenance of bridges. Involving local entrepreneurs, engineers and craftsmen will ensure that the skills of stone arch bridge technology are locally anchored. It is good practice to expose councillors, members of parliament, sub county chiefs and other local government decision makers to the advantages of arch bridges by visiting constructed bridges and by outlining the impact on their development budgets and service delivery of the respective constituencies. The public needs to be made aware of the possibilities of arch bridges. Awareness-raising activities (site visits, official commissioning, radio talk shows, adverts) showing their full potential, can be considered for the first bridges in the district.

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5. Table of Annexes

Annex 1: Quantities and cost estimates

- i. General templates roman arches (see spreadsheets <http://practicalaction.org>)
- ii. Bill of quantities roman arch 5.5 metre span
- iii. Bill of quantities roman arch 9 metre span
- iv. Bill of quantities segmental arch 8 metre span
- v. Bill of quantities segmental arch 8 metre span
- vi. Bill of quantities triple stone arch culvert

Annex 2: Drawings examples

1. Roman arch bridge - 3.8m span
2. Roman arch bridge - 5.5m span
3. Roman arch bridge - 9m span
4. Segmental arch bridge – 8 metres span
5. Segmental arch bridge – 11metres span
6. Single arch culvert
7. Triple arch culvert

Annex 3: References of people involved stone arch construction

Annex 4: Memorandum of Understanding - example

Annex 5: Technical Specifications - example

Annex 6: Checklist: Assessment of the request and site

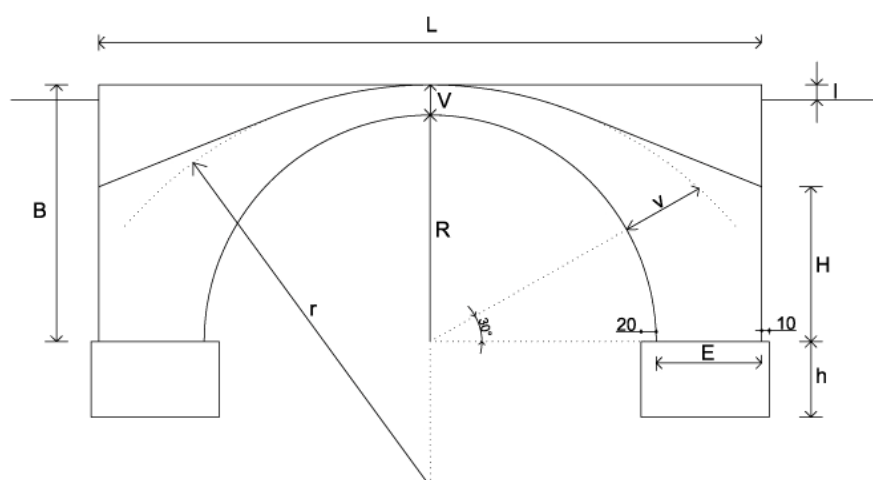
Annex 1: Quantities and cost estimates

Design parameters

Parish:
 Sub County:
 River:

Geographic data	Distance from SC headquarters (km)	
	Distance from town (km)	
	Distance from District HQ (km)	
	Distance borrow pit stones (km)	
	Distance borrow pit sand (km)	
	Current span (m)	
	Level of the banks from the river bed	
Design parameters (m) - to be specified	New span - 2R	
	Width of the bridge (head walls included)	
	Thickness of the foundation (must be > h)	
	Thickness sub foundation	
	Stone pitching thickness	
	Rip rap thickness	
	Length of the rip rap + mesh wire	
	Thickness backfilling above keystone	
	Thickness concrete cap above keystone	
	Length concrete cap above keystone	
	Height headwalls	
	Width headwalls	
	Length wing walls	
	Width wing walls	
	Number of moulds	

Design parameters (m) - calculated		
2R	Span (m)	
V	Thickness of the keystone	
v	Thickness at 30°	
r	Radius of the extrados	
E	Thickness of the abutments	
H	Height of the abutments	
h	Min. height of the foundations	
B	Height of the bridge	
L	Length of the bridge	
I	Level difference with the existing banks	



Unit costs

Costs are in

	Unit	Unit cost
Industrial materials		
Cement 50kg	bag	
Timber 2*4*12	Piece	
Timber 1*12*12	Piece	
Wire mesh	m ²	
Gunny bags	Piece	
Local materials		
Stones	Trip (3tons)	
Backfilling	Trip (3tons)	
Sand	Trip (3tons)	
Tree pole 7m	Piece	
Labour		
Mason	man.day	
Casual labour	man.day	
Village labour	man.day	
Carpenter	Lumpsum	
Tools		
Iron compactor	Piece	
Shovels	Piece	
Pick axes	Piece	
Wheelbarrow	Piece	
Water drum	Piece	
Karai	Piece	
Plate compactor (hiring, including fuel)	day	
Transport		
Trip of materials	km	
Fuel for monitoring	litre	

TOTAL QUANTITIES					
		Unit	Quantity	Unit	Quantity
Stones	With mortar	m ³	0.0	ton	0.0
	Dry	m ³	0.0	ton	0.0
	Total	m ³	0.0	ton	0.0
Backfilling		m ³	0.0	ton	0.0
Cement	Mortar	bags	0.0	ton	0.0
	Concrete	bags	0.0	ton	0.0
	Total	bags	0.0	ton	0.0
Sand	Mortar	m ³	0.0	ton	0.0
	Concrete	m ³	0.0	ton	0.0
	Total	m ³	0.0	ton	0.0
Aggregates		kg	0.0	ton	0.0
Water		Drum 200L	0.0	m ³	0.0
Timber	2*4*12	Pieces	2.0		
	Poles 7m	Pieces	28.0		
	1*12*1	Pieces	0.0		

Kasese District LG/ Kasese District Poverty Reduction Programme

Costs of a stone arch bridge: 5.5 metres span roman type

Ultimate cost will depend on foundation depth and need backfilling approaches

Prices in Ush

2650 Ush/ US\$

	Unit	Quantity	Cost/unit	Total	Village	External
Industrial materials						
Cement	bags	132	33,000	4,356,000		4,356,000
Form work to rough finish, including labour	m²	31	60,000	1,866,106		1,866,106
Gabion boxes (1m x 1m x 3m)	Piece	12	300,000	3,600,000		3,600,000
10mm stell bars for gabions	kg	67	3,500	232,848		232,848
Local materials						
Stones for masonry	Trip (5tons)	27	90,000	2,430,000	2,430,000	
Stones for gabions	Trip (5tons)	13	90,000	1,166,400	1,166,400	
Murram backfilling and wearing surface road	Trip (5tons)	13	90,000	1,170,000	1,170,000	
Sand	Trip (5tons)	9	40,000	360,000	360,000	
Poles to support formwork	Piece	18	3,000	54,000	54,000	
Labour						
Mason	man.day	67.0	30,000	2,010,000		2,010,000
Casual labour - assistance construction mason	man.day	201.0	8,500	1,708,500		1,708,500
Village labour material collection and arrangement on site	man.day	143.0	5,000	715,000	715,000	
Village labour (digging trenches)	man.day	30.0	5,000	150,000	150,000	
Village labour (Compaction area foundation)	man.day	10.0	5,000	50,000	50,000	
Village labour (leveling road, backfilling and stabilizing)	man.day	31.0	5,000	155,000	155,000	
Village labour (removing excess soil from river bed)	man.day	9.0	5,000	45,000	45,000	
Village labour (guarding cement and tools)	man.day	34.0	5,000	170,000	170,000	
Tools						
Iron compactor	Piece	1	50,000	50,000		50,000
Shovels	Piece	6	7,000	42,000		42,000
Pick axes	Piece	2	12,000	24,000		24,000
Wheelbarrow	Piece	1	75,000	75,000		75,000
Water drum	Piece	1	45,000	45,000		45,000
Karai	Piece	6	3,000	18,000		18,000
Plate compactor (hiring, including fuel)	day	1	80,000	80,000		80,000
Transport @ 2500 Ush/km						
Cement	trip	2	46.00	3,000		276,000
Stones (masonry + gabions)		40	2.00	3,000	239,760	
Murram		13	2.00	3,000	78,000	
Sand		9	2.00	3,000	54,000	
Formwork		1	46.00	3,000		138,000
Gabion boxes		1	46.00	3,000		138,000
Plate compactor		1	46.00	3,000		138,000
Monitoring @ 3600 Ush/l						
Monitoring sub county	trip	8	9.00	3,600	38,880	
Allowance works staff		12		12,000		144,000
Monitoring BTC/Works Department		12	36.00	3,600		233,280
Total				22,050,774	6,876,040	15,174,734
Contingencies (10%)				2,205,077	687,604	1,517,473
GRAND TOTAL				24,255,851	7,563,644	16,692,207

Costs of a stone arch bridge roman type - 9 metres span

Ultimate cost will vary in function of depth foundation - subs soil requirements

Prices in Ush

2650 Ush/ US\$

	Unit	Quantity	Cost/unit	Total	Village	External
Industrial materials						
Cement	bags	273	33,000	9,009,000		9,009,000
Form work to rough finish, including labour	m²	29	60,000	1,715,310		1,715,310
Gabion boxes (1m x 1m x 3m)	Pieces	8	300,000	2,400,000		2,400,000
10mm steel bars for gabions	kg	44	3,500	155,232		155,232
Local materials						
Stones for masonry	Trip (5tons)	55	80,000	4,400,000	4,400,000	
Stones for gabions	Trip (5tons)	9	80,000	691,200	691,200	
Murram backfilling and wearing surface road	Trip (5tons)	32	80,000	2,560,000	2,560,000	
Sand	Trip (3tons)	29	70,000	2,030,000	2,030,000	
Poles to support formwork	Piece	27	3,000	81,000	81,000	
Labour						
Mason	man.day	120.0	30,000	3,600,000		3,600,000
Casual labour - assistance construction mason	man.day	200.0	8,500	1,700,000		1,700,000
Village labour material collection and arrangement on site	man.day	312.0	6,000	1,872,000	1,872,000	
Village labour (digging trenches)	man.day	48.0	6,000	288,000	288,000	
Village labour (Compaction area foundation)	man.day	16.0	6,000	96,000	96,000	
Village labour (leveling road, backfilling and stabilizing)	man.day	39.0	6,000	234,000	234,000	
Village labour (removing excess soil from river bed)	man.day	15.0	6,000	90,000	90,000	
Village labour (guarding cement and tools)	man.day	60.0	6,000	360,000	360,000	
Tools						
Iron compactor	Piece	1	50,000	50,000		50,000
Shovels	Piece	6	7,000	42,000		42,000
Pick axes	Piece	2	12,000	24,000		24,000
Wheelbarrow	Piece	1	75,000	75,000		75,000
Water drum	Piece	1	45,000	45,000		45,000
Karai	Piece	6	3,000	18,000		18,000
Plate compactor (hiring, including fuel)	day	1	80,000	80,000		80,000
Transport @ 3000 Ush/km						
	trip	km				
Cement	3	27.00	3,000	243,000		243,000
Stones	55	2.00	3,000	330,000	330,000	
Murram	32	2.00	3,000	192,000	192,000	
Sand	29	17.00	3,000	1,479,000		1,479,000
Formwork	1	27.00	3,000	81,000		81,000
Gabion boxes	1	27.00	3,000	81,000		81,000
Plate compactor	1	27.00	3,000	81,000		81,000
Monitoring @ 3600 Ush/l						
	trip	km				
Monitoring sub county	8	5.00	3,600	21,600	21,600	
Allowance works staff	16		12,000	192,000		192,000
Monitoring BTC/Works Department	16	17.00	3,600	146,880		146,880
Total				34,463,222	13,245,800	21,217,422
Contingencies (10%)				3,446,322	1,324,580	2,121,742
GRAND TOTAL				37,909,544	14,570,380	23,339,164
					38%	62%

Costs of a stone arch bridge segmental type - 8 metres span

Ultimate cost will vary in function of depth foundation - subs soil requirements

Prices in Ush

US\$

2650 Ush

	Unit	Quantity	Cost/unit	Total	Village	External
Industrial materials						
Cement	bags	227	31,000	7,037,000		7,037,000
Form work to rough finish, including labour	m ²	26	50,000	1,319,469		1,319,469
Gabion boxes (1m x 1m x 3m)	Pieces	8	300,000	2,400,000		2,400,000
10mm steel bars for gabions	kg	44	3,500	155,232		155,232
Local materials						
Stones for masonry	Trip (5tons)	46	60,000	2,760,000	2,760,000	
Stones for gabions	Trip (5tons)	9	60,000	518,400	518,400	
Murram backfilling and wearing surface road	Trip (5tons)	25	90,000	2,250,000	2,250,000	
Sand	Trip (3tons)	24	70,000	1,680,000	1,680,000	
Poles to support formwork	Piece	24	3,000	72,000	72,000	
Labour						
Mason	man.day	108	30,000	3,240,000		3,240,000
Casual labour - assistance masons	man.day	160	8,500	1,360,000		1,360,000
Village labour material collection	man.day	254	8,000	2,032,000	2,032,000	
Village labour (digging trenches)	man.day	48	8,000	384,000	384,000	
Village labour (Compaction area foundation)	man.day	16	8,000	128,000	128,000	
Village labour (leveling road, backfilling)	man.day	40	8,000	320,000	320,000	
Village labour (removing excess soil river bed)	man.day	15	8,000	120,000	120,000	
Village labour (guarding cement and tools)	man.day	54	8,000	432,000	432,000	
Tools						
Iron compactor	Piece	1	50,000	50,000		50,000
Shovels	Piece	6	9,000	54,000		54,000
Pick axes	Piece	2	12,000	24,000		24,000
Wheelbarrow	Piece	1	100,000	100,000		100,000
Water drum	Piece	1	45,000	45,000		45,000
Karai	Piece	6	3,000	18,000		18,000
Plate compactor (hiring, including fuel)	day	1	80,000	80,000		80,000
Transport @ 3000 Ush/km						
	trip	km				
Cement	3	27.00	3,000	243,000		243,000
Stones	46	2.00	3,000	276,000	276,000	
Murram	25	4.00	3,000	300,000		300,000
Sand	24	17.00	3,000	1,224,000		1,224,000
Formwork	1	27.00	3,000	81,000		81,000
Gabion boxes	1	27.00	3,000	81,000		81,000
Plate compactor	1	27.00	3,000	81,000		81,000
Monitoring @ 3600 Ush/l						
	trip	km				
Monitoring sub county	8	5.00	3,600	21,600	21,600	
Allowance staff works department	16		12,000	192,000		192,000
Monitoring BTC/Works Department	16	17.00	3,600	146,880		146,880
Total				29,225,581	10,994,000	18,231,581
Contingencies (10%)				2,922,558	1,099,400	1,823,158
GRAND TOTAL				32,148,139	12,093,400	20,054,739
					38%	62%

Costs of a stone arch bridge Kalong Kyarumba Sub County

Span 11 metres - segmental arch

Prices in

Ush

2650 Ush/US\$

Cost will vary according to the foundation depth, depending on the site natural conditions.

	Unit	Quantity	Cost/unit	Total	Village	External
Industrial materials						
Cement	bags	257	31,000	7,956,667		7,956,667
Scaffold, excluding labour				1,118,000		1,118,000
Wire mesh	m²	6	18,000	100,800		100,800
Gunny bags	Piece	100	1,100	110,000		110,000
Local materials						
Stones for masonry and stone pitching	Trip (3tons)	75	70,000	5,250,000	5,250,000	
Stones for rip rap	Trip (3tons)	0	70,000	0	0	
Stones for aggregates	Trip (3tons)	1	70,000	70,000	70,000	
Backfilling	Trip (3tons)	46	70,000	3,220,000	3,220,000	
Sand	Trip (3tons)	24	70,000	1,680,000	1,680,000	
Poles to support formwork	Piece	11	4,000	44,000	44,000	
Labour						
Mason	man.day	114.0	30,000	3,420,000		3,420,000
Casual labour - assistance construction mason	man.day	342.0	8,500	2,907,000		2,907,000
Village labour material collection	man.day	262.0	6,000	1,572,000	1,572,000	
Village labour (diversion)	man.day	20.0	6,000	120,000	120,000	
Village labour (digging trenches)	man.day	48.0	6,000	288,000	288,000	
Village labour (Compaction area foundation)	man.day	16.0	6,000	96,000	96,000	
Village labour (crushing aggregates)	man/day	11.0	6,000	66,000	66,000	
Village labour (leveling road, backfilling)	man.day	39.0	6,000	234,000	234,000	
Village labour (removing excess soil from river bed)	man.day	15.0	6,000	90,000	90,000	
Village labour (guarding cement and tools)	man.day	57.0	6,000	342,000	342,000	
Carpenter	Lumpsum			140,000		140,000
Tools						
Iron compactor	Piece	1	200,000	200,000		200,000
Shovels	Piece	6	9,000	54,000		54,000
Pick axes	Piece	2	18,000	36,000		36,000
Wheelbarrow	Piece	1	100,000	100,000		100,000
Water drum	Piece	1	50,000	50,000		50,000
Karai	Piece	6	4,000	24,000		24,000
Plate compactor (hiring, including fuel)	day	1	350,000	350,000		350,000
Transport						
	trip		Ush/km			
Cement	4	96.00	3,000	1,152,000		1,152,000
Stones	76	2.00	3,000	456,000	456,000	
Sand	24	2.00	3,000	144,000	144,000	
Scaffold	2	96.00	3,000	576,000		576,000
Miscellaneous (wire mesh, equipment, gunny bags, etc)	2	96.00	3,000	576,000		576,000
Plate compactor	1	96.00	3,000	288,000		288,000
Monitoring @ 3600 Ush/l						
	trip	km				
Monitoring sub county	8	2.00	3,600	8,640	8,640	
Allowance staff works department	14		12,000	168,000		168,000
Monitoring BTC/Works Department	14	106.00	3,600	801,360		801,360
Total				33,808,467	13,680,640	20,127,827
Contingencies (10%)				3,380,847	1,368,064	2,012,783
GRAND TOTAL				37,189,313	15,048,704	22,140,609

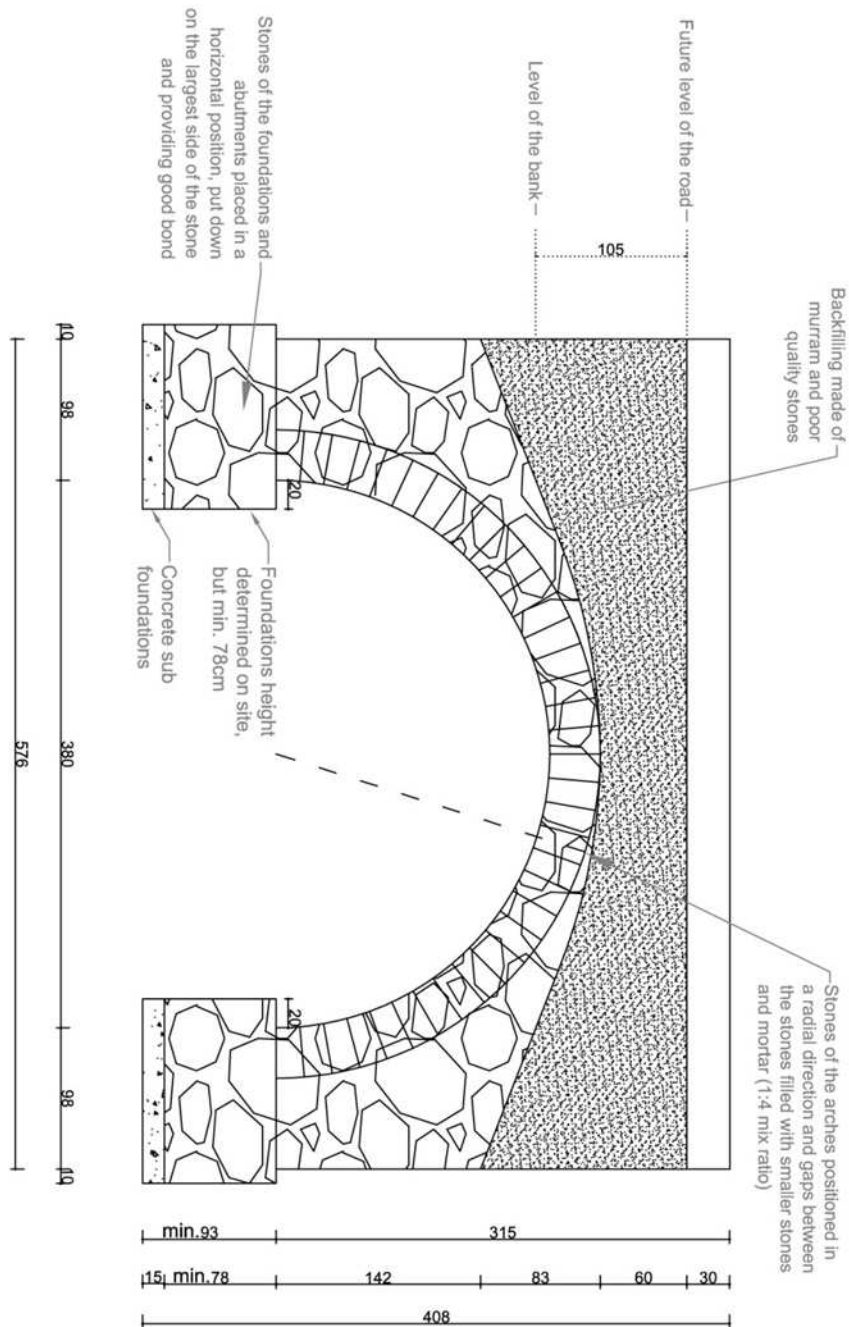
Kasese District LG/ Kasese District Poverty Reduction Programme
Costs of a multiple stone arch culvert (3 arches) in Kanyambara, Munkunyu Sub-County

Prices in Ush

1 US\$= 2650 Ush

	Unit	Quantity	Cost/unit	Total	Village	External
Industrial materials						
Cement	bags	46	31,000	1,426,000	93,000	1,333,000
Timber	Moulds	3	77,350	232,050		
Local materials						
Stones	Trip (5tons)	15	60,000	900,000	900,000	
Murram backfilling and wearing surface road	Trip (5tons)	2	60,000	120,000	120,000	
Sand	Trip (3tons)	5	60,000	300,000	300,000	
Water	Drum 200L	126	5,000	630,000		
Labour						
Mason	man.day	30	30,000	900,000		900,000
Casual labour - assistance construction mason	man.day	90	8,000	720,000		720,000
Village labour stone/sand collection and arrangement on site	man.day	45	5,000	225,000	225,000	
Village labour (digging trenches)	man.day	6	5,000	30,000	30,000	
Village labour (Compaction area foundation)	man.day	6	5,000	30,000	30,000	
Village labour (leveling road, backfilling and stabilizing)	man.day	10	5,000	50,000	50,000	
Village labour (removing excess soil from river bed)	man.day	3	5,000	15,000	15,000	
Village labour (guarding cement and tools)	man.day	15	5,000	75,000	75,000	
Tools						
Iron compactor	Piece	1	50,000	50,000		
Shovels	Piece	6	7,000	42,000		
Pick axes	Piece	2	12,000	24,000		
Wheelbarrow	Piece	1	75,000	75,000		
Water drum	Piece	1	45,000	45,000		
Karai	Piece	6	3,000	18,000		
Plate compactor (hiring, including fuel)	day	1	80,000	80,000		
Transport @ 3000 Ush/km						
	trip	km				
Cement	4	92.00	3,000	1,104,000		1,104,000
Sand	45	4.00	3,000	540,000		
Stones	30	4.00	3,000	360,000		
Murram	2	4.00	3,000	24,000		
Plate compactor	1	92.00	3,000	276,000		
Monitoring						
	trip	km				
Monitoring sub county	6	4.00	3,600	8,640	8,640	
Monitoring BTC/Works Department allowance	7		12,000	84,000		84,000
Monitoring BTC/Works Department motorcycle	5	102.00	3,600	183,600		183,600
Total					1,846,640	4,324,600
Contingencies (10%)						
GRAND TOTAL				6,171,240	1,846,640	4,324,600

Annex 2: Drawings example



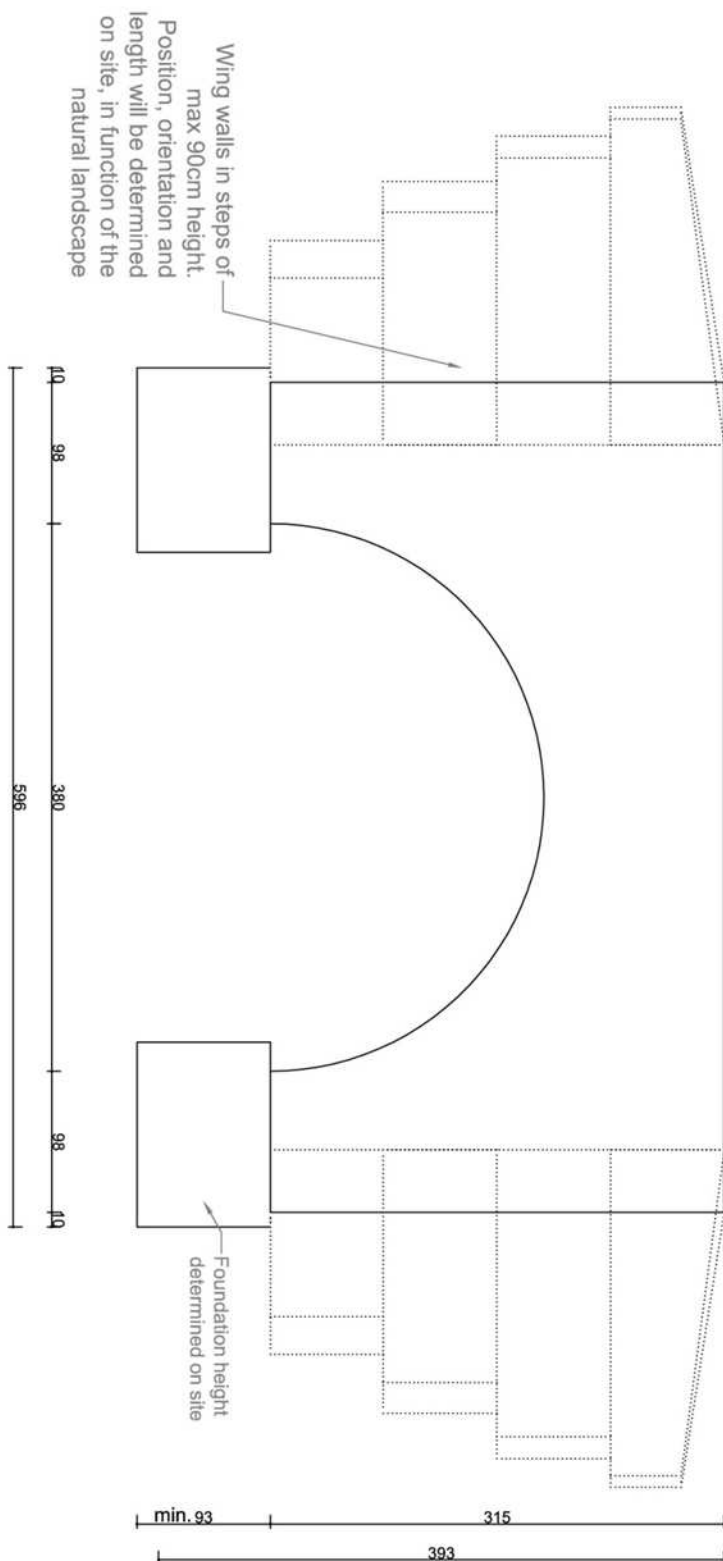
Kasese District Poverty
Reduction Programme



Arch bridge

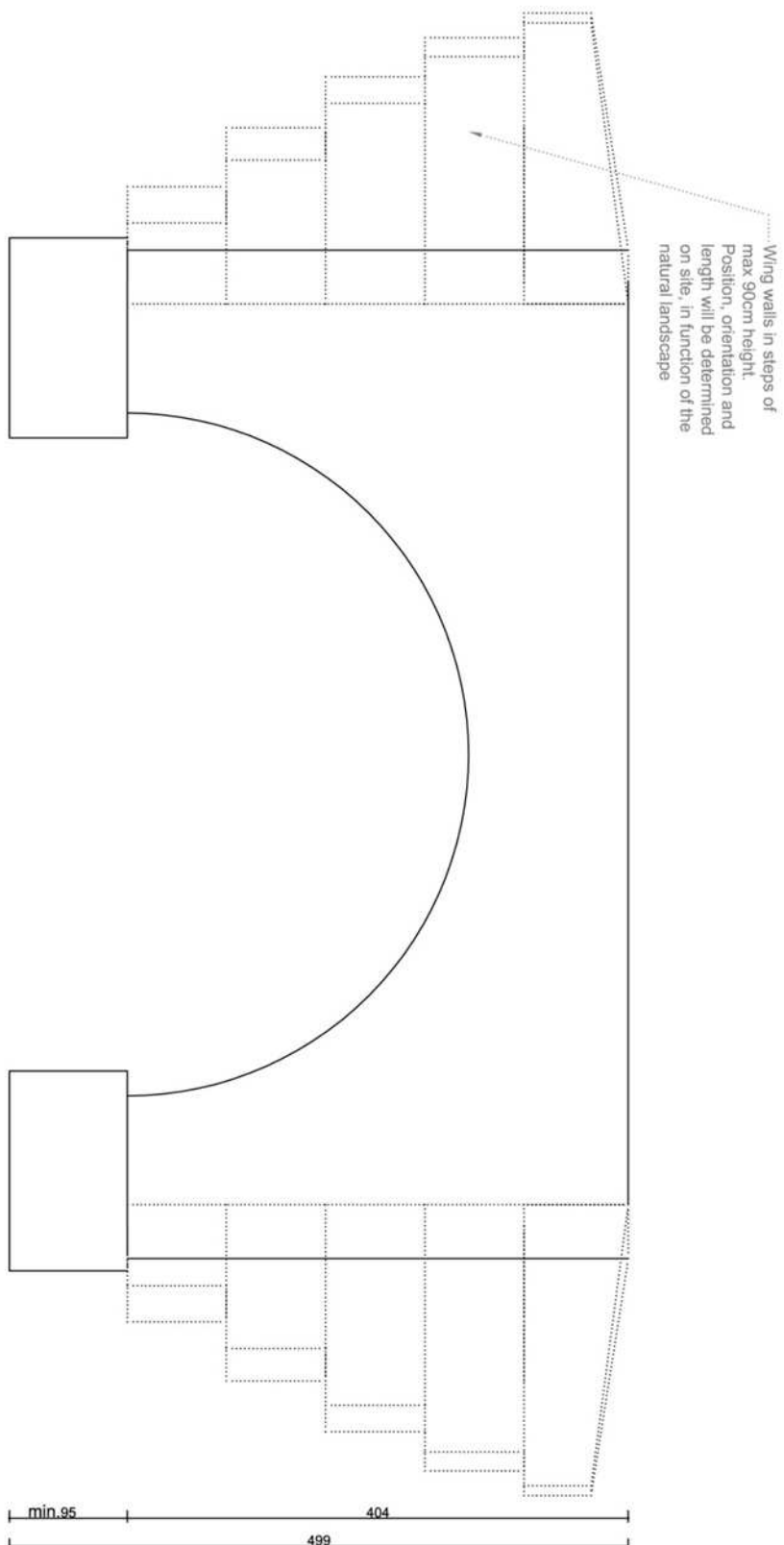
Cross section

Date: May 2012
Measurements in cm



 Kasese District Poverty Reduction Programme 	Arch bridge		Front view	Date: May 2012
				Measurements in cm





 Kasere District Poverty Reduction Programme	 BTC UGANDA	Arch bridge	Front view	Date: May 2012
				Measurements in cm

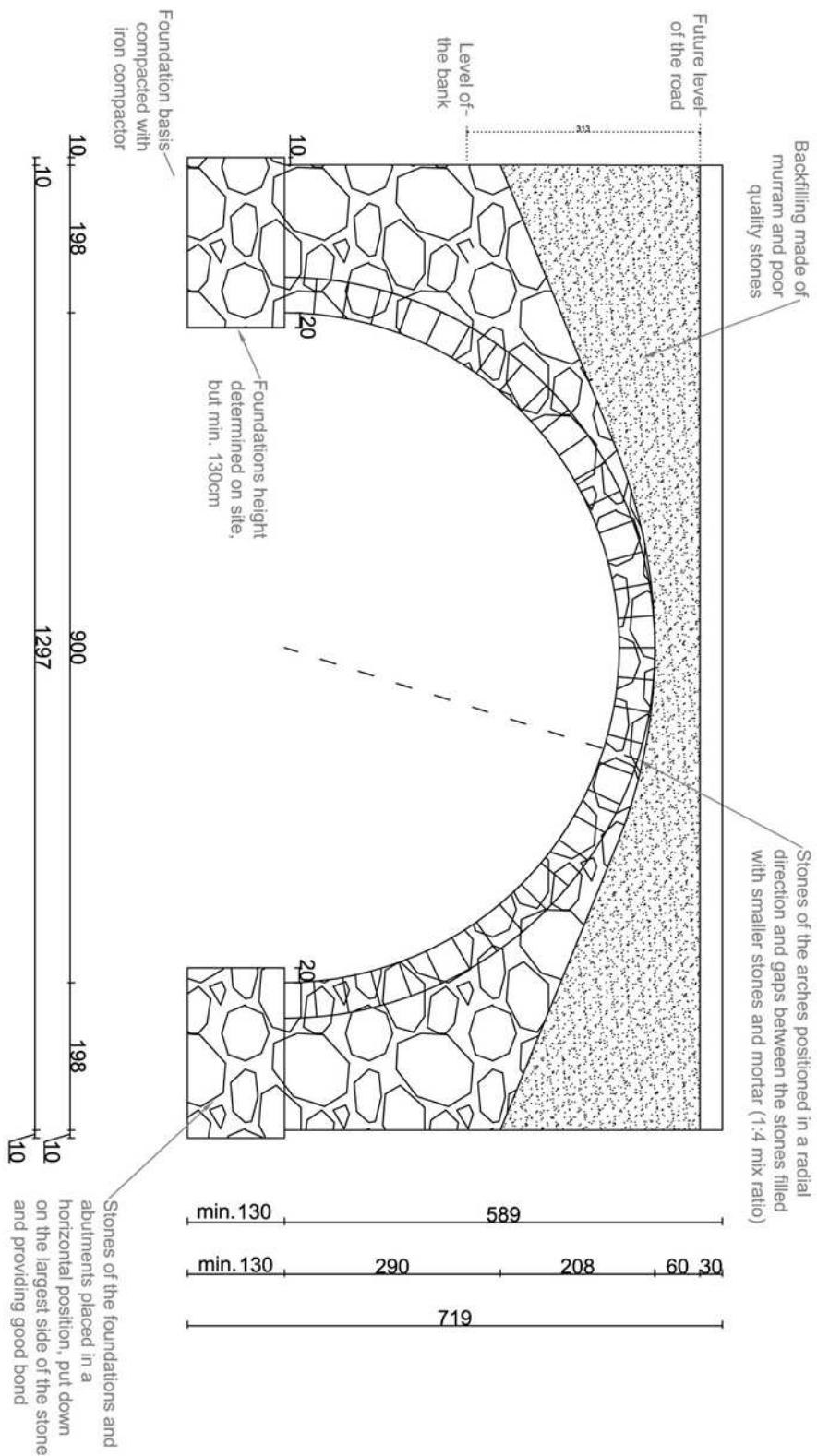


Arch bridge

Top view

Date: May 2012

Measurements in cm



Kasese District Poverty
Reduction Programme



BTC UGANDA

Arch bridge

Cross section

Date: May 2012

Measurements in cm



Kasese District Poverty
Reduction Programme

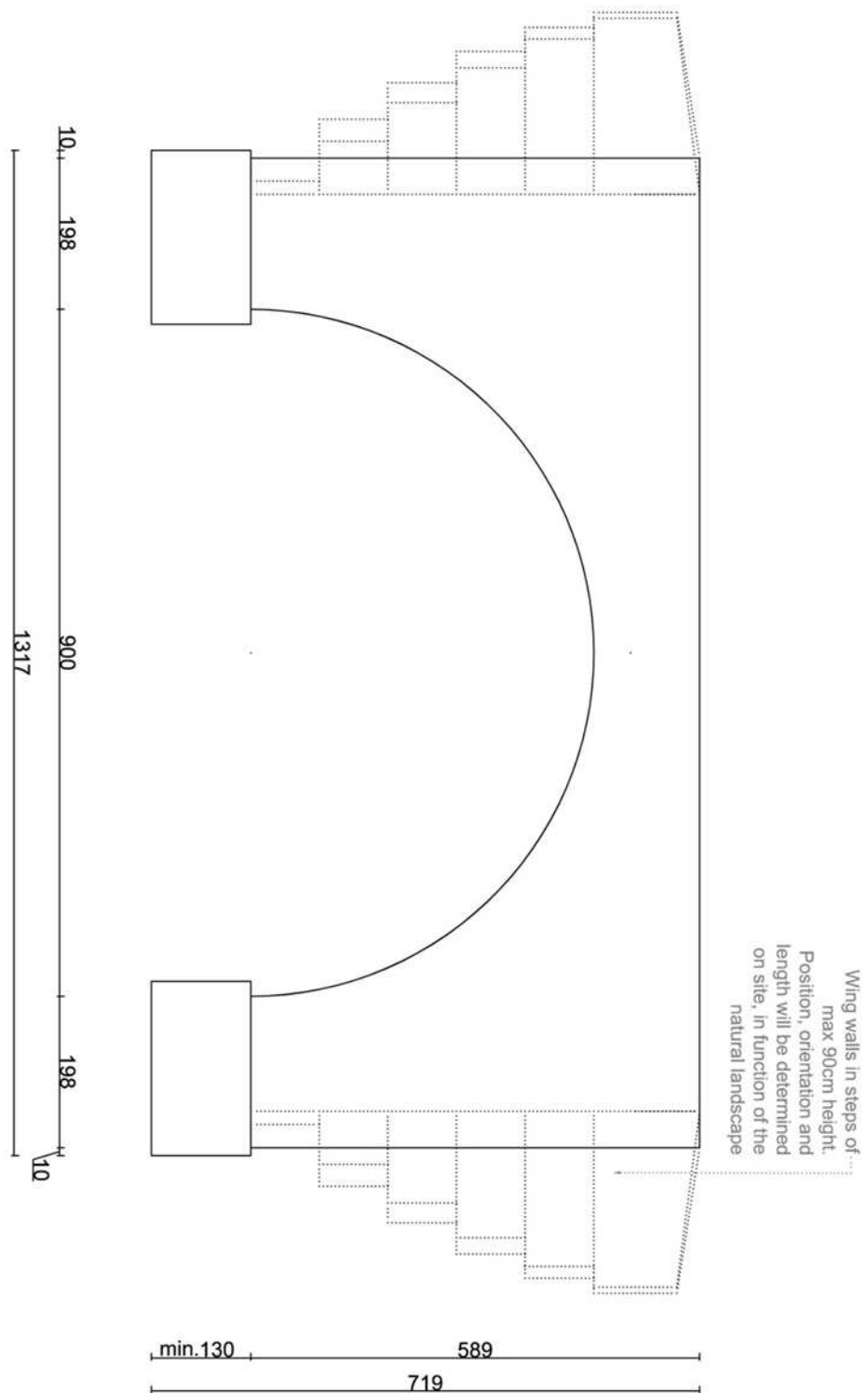


Arch bridge

Front view

Date: May 2012

Measurements in cm





Kasese District Poverty
Reduction Programme

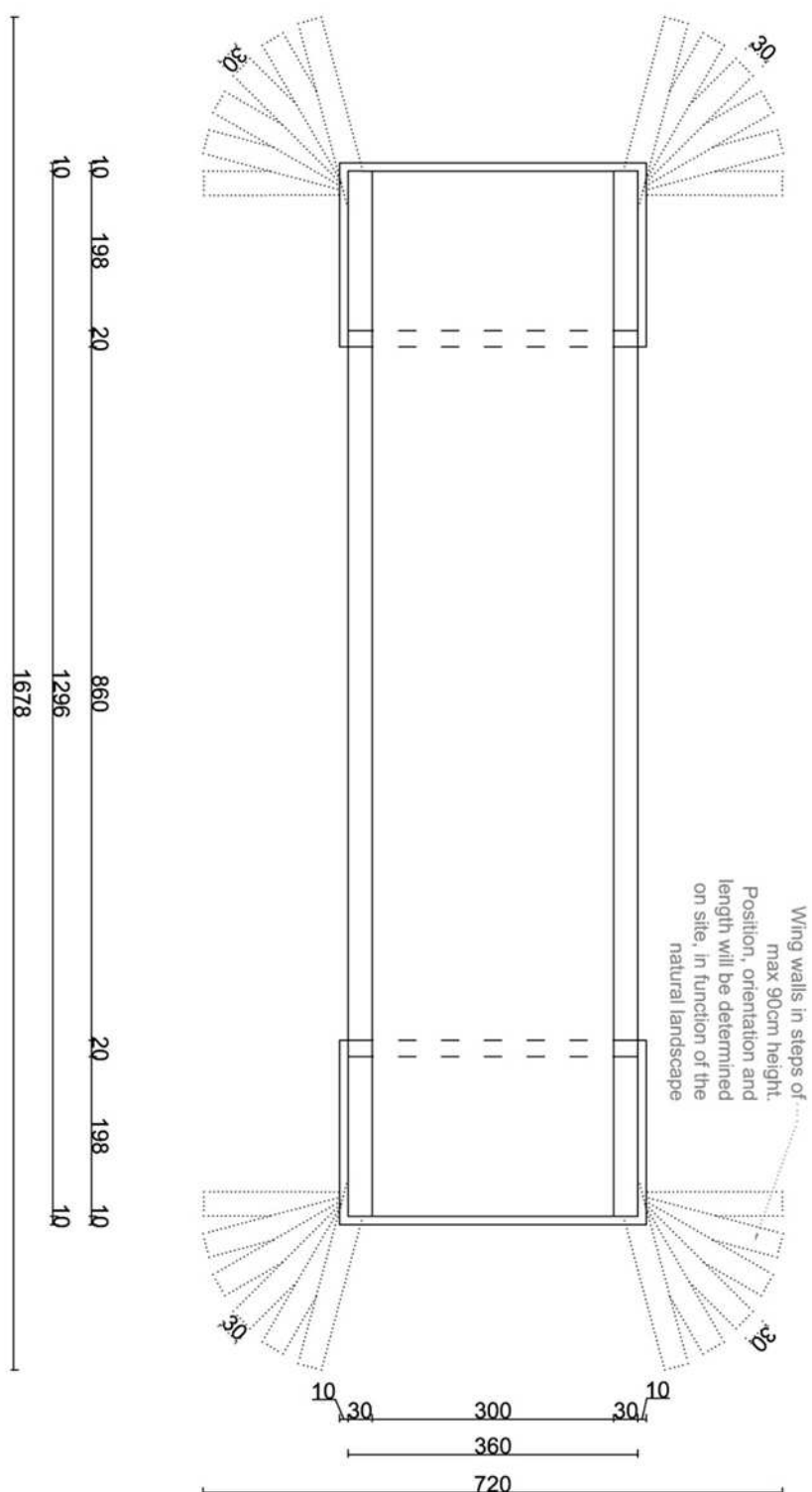


BTC UGANDA

Arch bridge

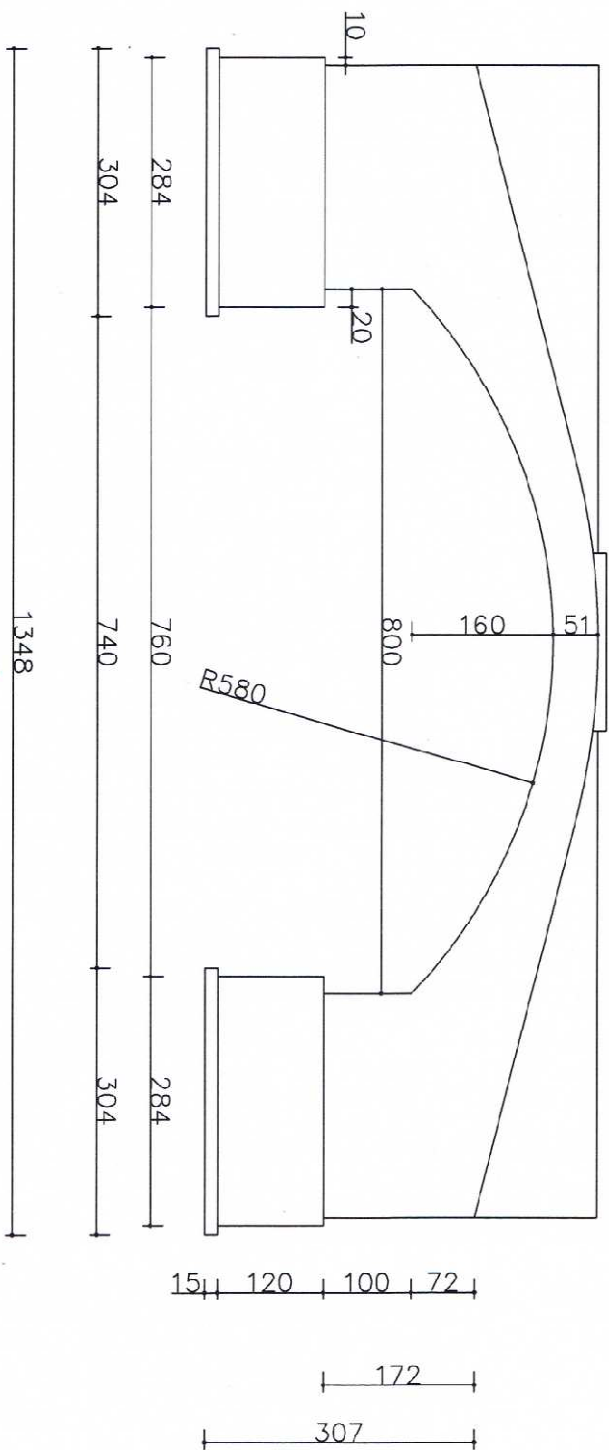
Top view

Date: May 2012
Measurements in cm



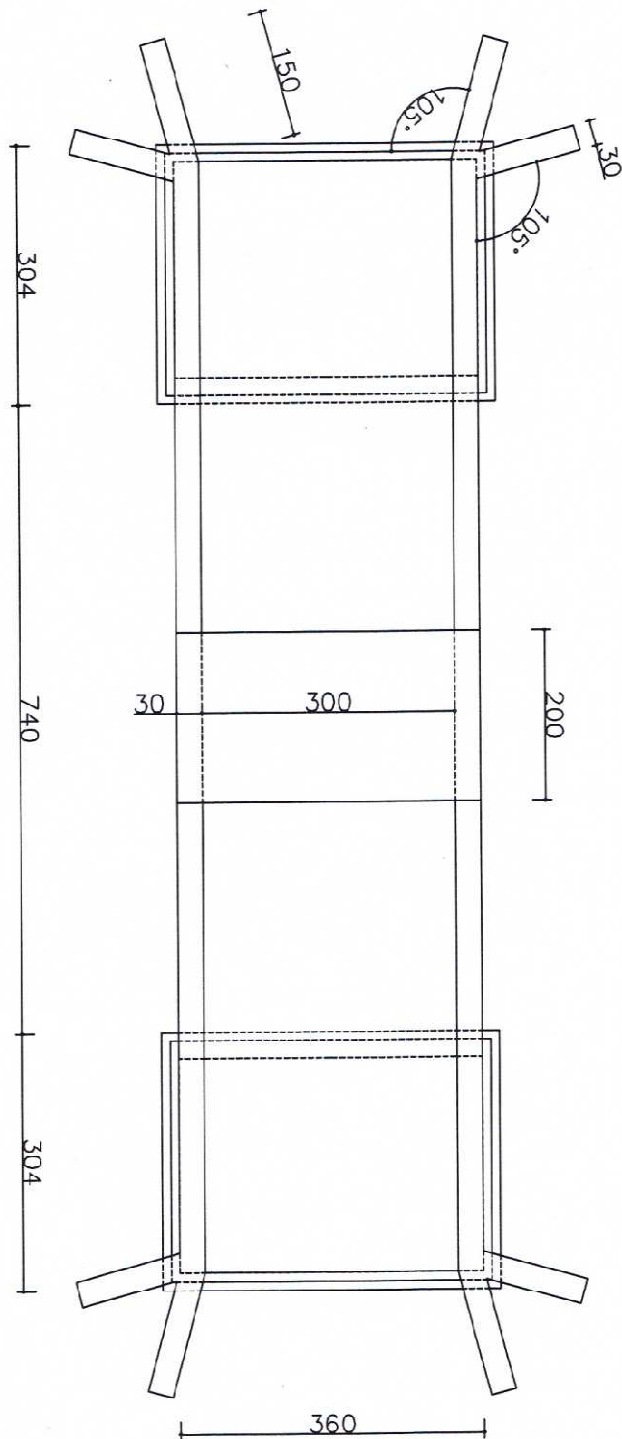


Arch bridge Sebwe river : Front view

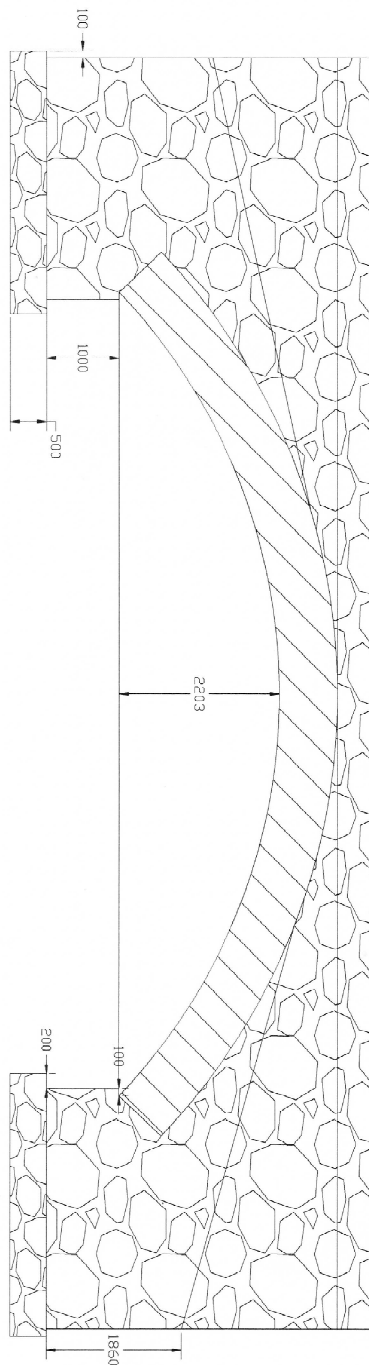


		Kasere District Poverty Reduction programme	Ndagutu Bugoye SC Sebwe river	Units in cm Date : February 2013
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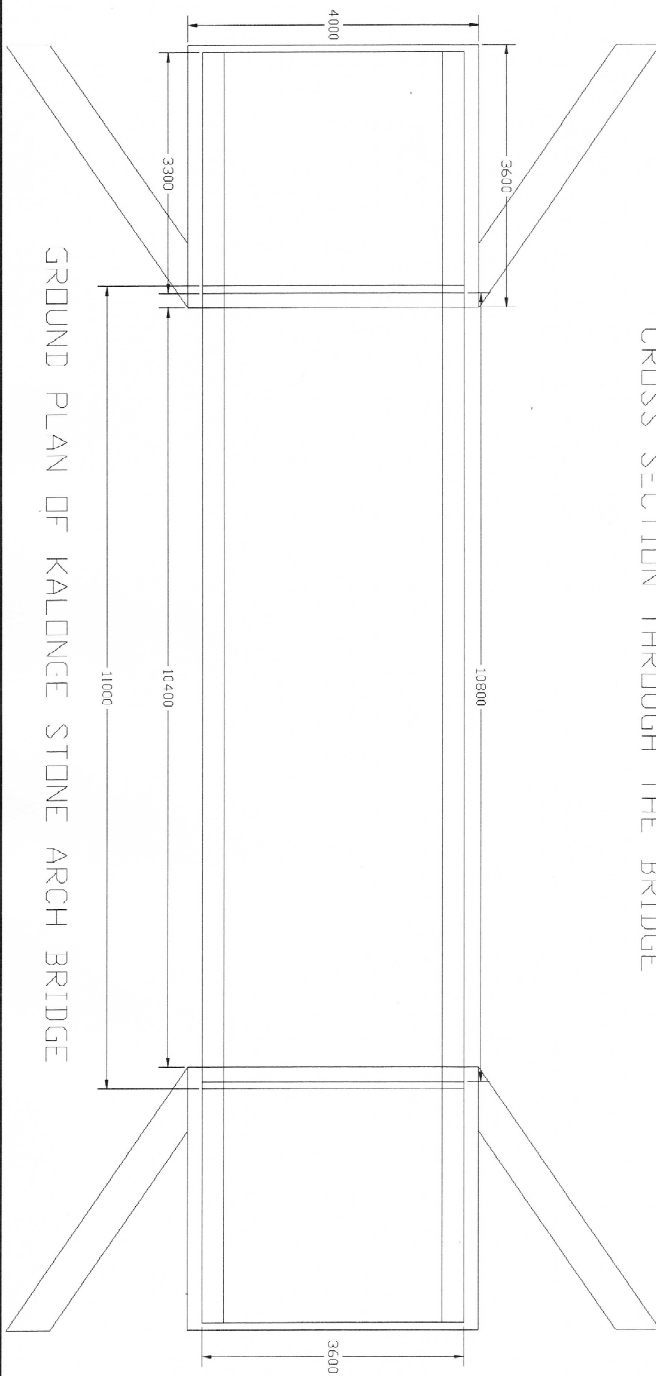
Arch Bridge Sebwe river : Top view



 BTC UGANDA		Kasere district Poverty Reduction programme	Ndugutu Bugoye SC Sebwe river	Units in cm Date : february 2013
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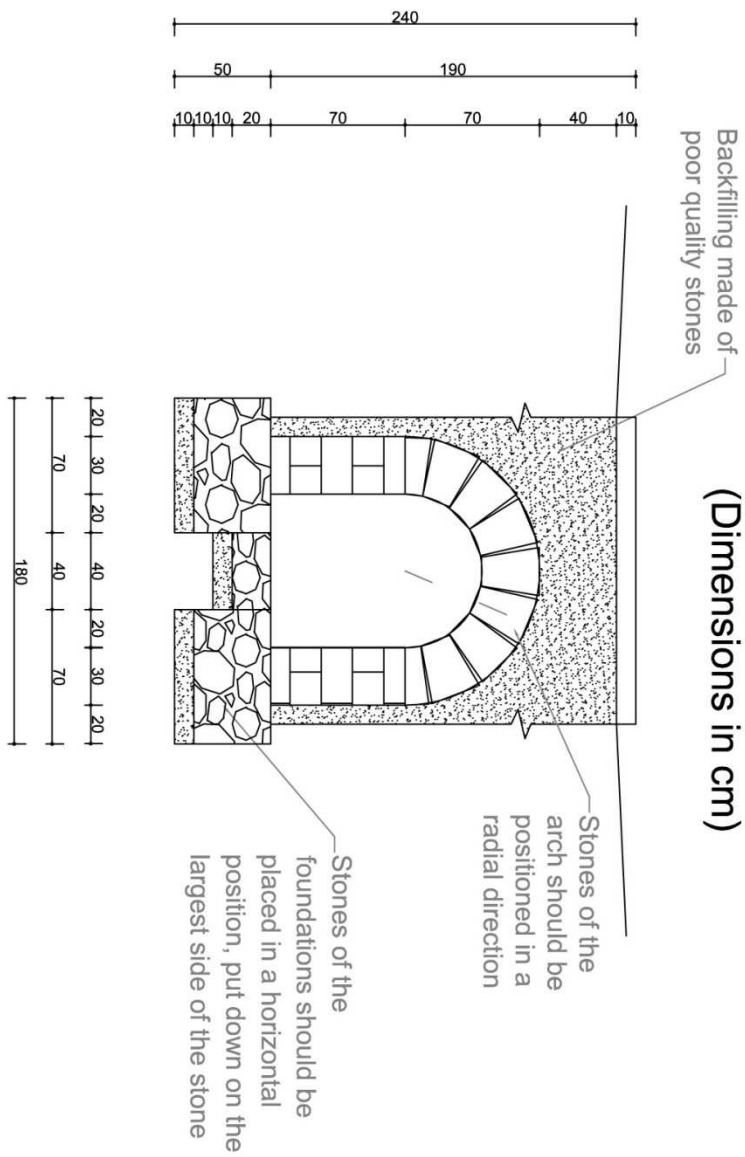
CROSS SECTION THROUGH THE BRIDGE



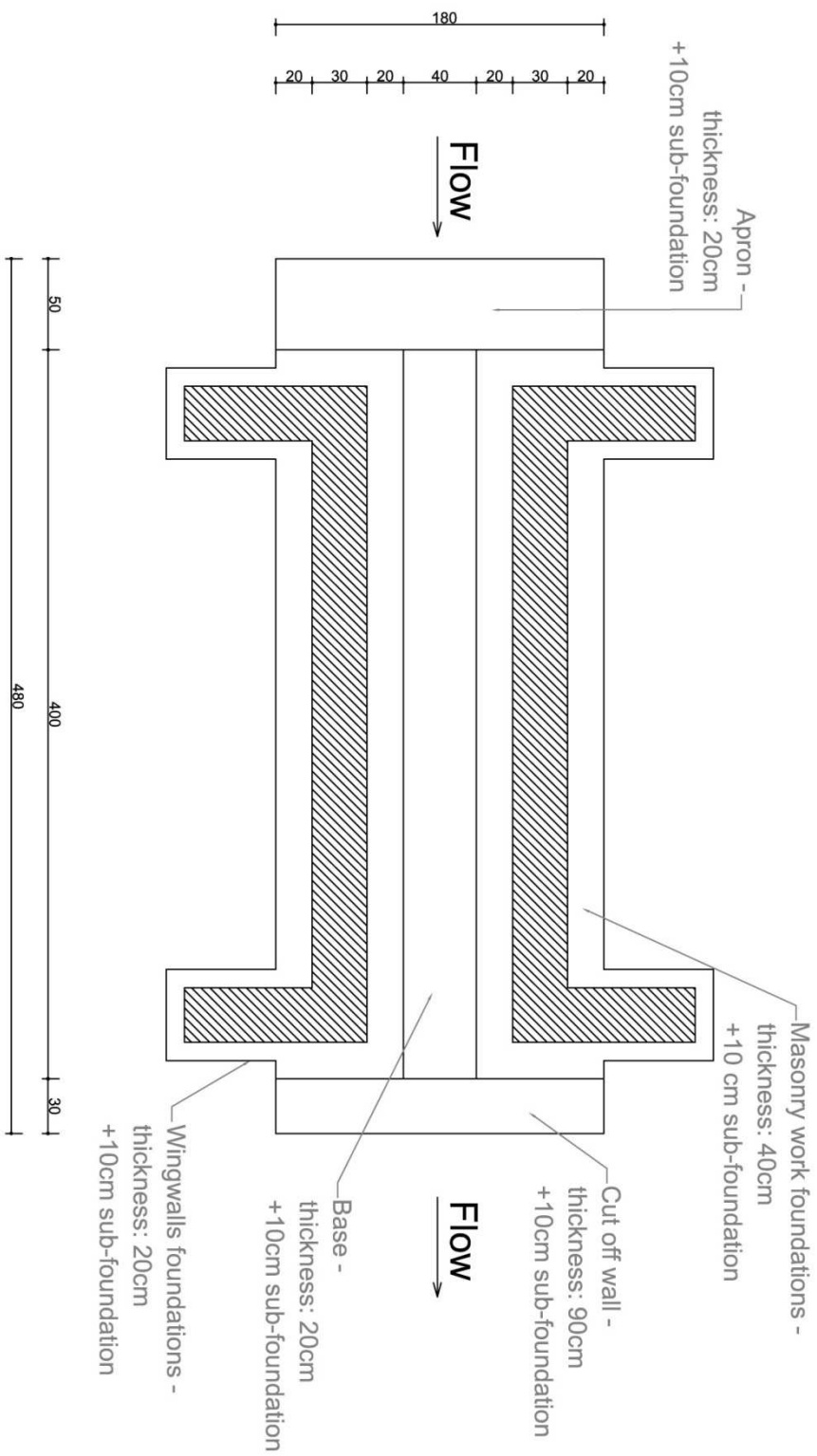
GROUND PLAN OF KALANDE STONE ARCH BRIDGE

General Notes							
<table border="1"> <tr> <td>No.</td> <td>Revision/Date</td> <td>Date</td> </tr> <tr> <td> </td> <td> </td> <td> </td> </tr> </table>		No.	Revision/Date	Date			
No.	Revision/Date	Date					
<p>KALANDE STONE ARCH BRIDGE IN KYARLEBA SUB-COU NITY</p> <p>KASESE DISTRICT POVERTY REDUCTION PROGRAMME</p> <p>18/06/2013</p>							

Culvert - Cross section (Dimensions in cm)

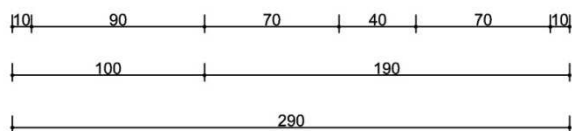
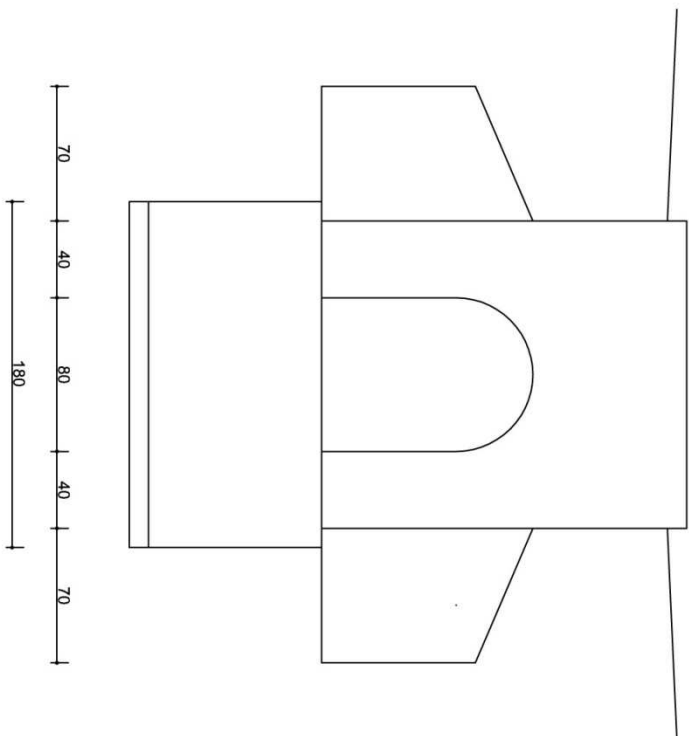


Culvert - Foundations layout (Dimensions in cm)



Culvert - Front view

Downstream (Dimensions in cm)

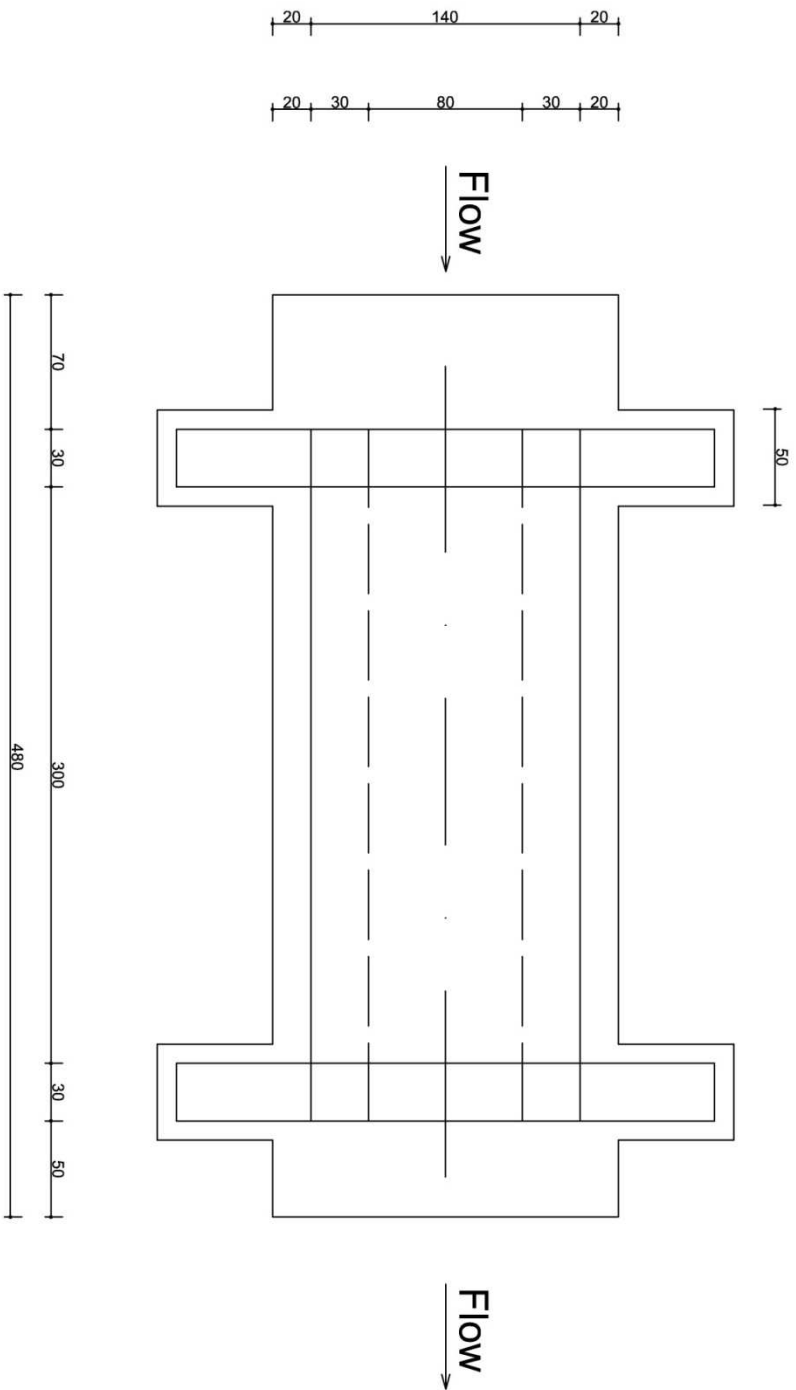


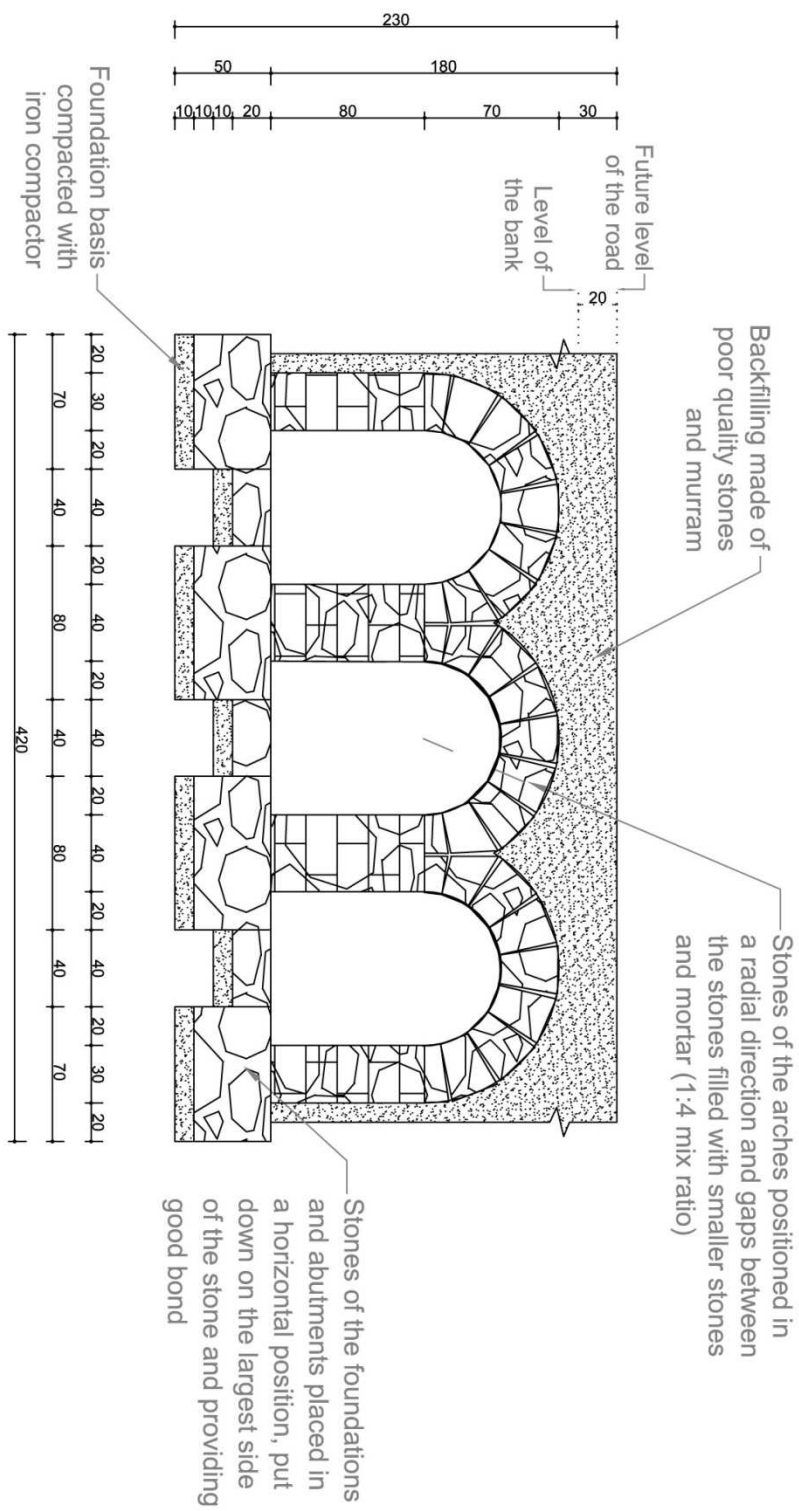
Culvert - Longitudinal section
(Dimensions in cm)

The diagram illustrates the longitudinal section of a culvert. The flow direction is indicated by an arrow labeled "Flow" pointing to the right. The culvert is shown with a concrete structure and a gravel bed. The dimensions are as follows:

- Total length: 270 cm
- Length of the culvert barrel: 190 cm
- Length of the approach section: 80 cm (90 cm total minus 10 cm for the culvert barrel)
- Length of the exit section: 80 cm (90 cm total minus 10 cm for the culvert barrel)
- Length of the culvert barrel: 190 cm
- Length of the approach section: 80 cm (90 cm total minus 10 cm for the culvert barrel)
- Length of the exit section: 80 cm (90 cm total minus 10 cm for the culvert barrel)
- Length of the culvert barrel: 190 cm
- Length of the approach section: 80 cm (90 cm total minus 10 cm for the culvert barrel)
- Length of the exit section: 80 cm (90 cm total minus 10 cm for the culvert barrel)

Culvert - Top view (Dimensions in cm)





Kasese District Poverty
Reduction Programme

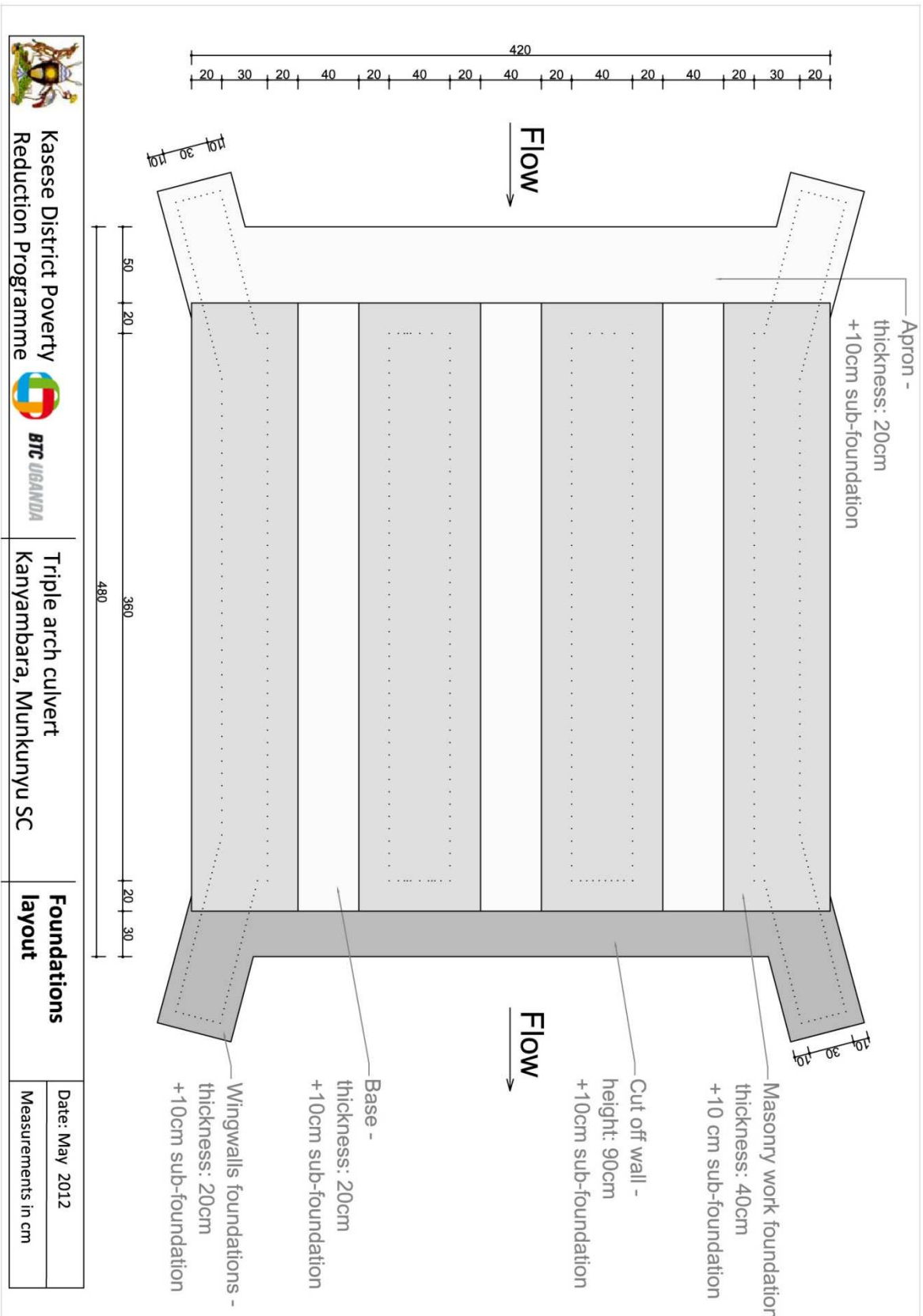


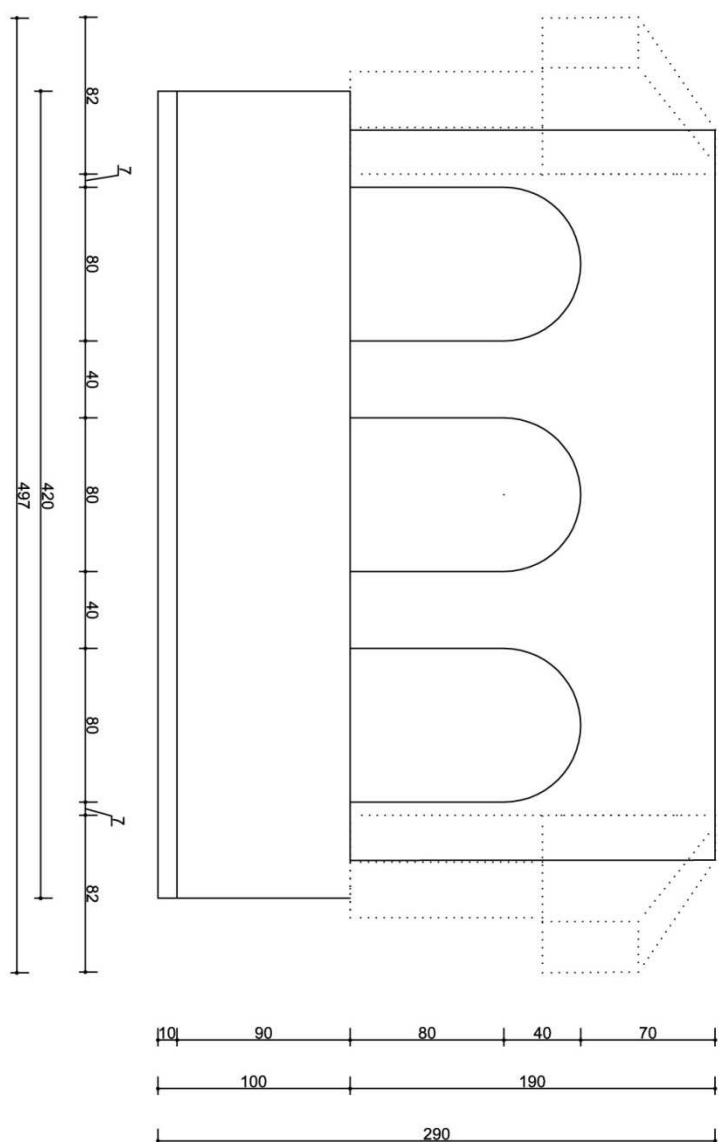
Triple arch culvert
Kanyambara, Munkunyu SC

Cross section

Date: May 2012

Measurements in cm





 Kasere District Poverty Reduction Programme	 BTC UGANDA	Triple arch culvert Kanyambara, Munkunyu SC	Front view Downstream	Date: May 2012
				Measurements in cm



Kasese District Poverty
Reduction Programme

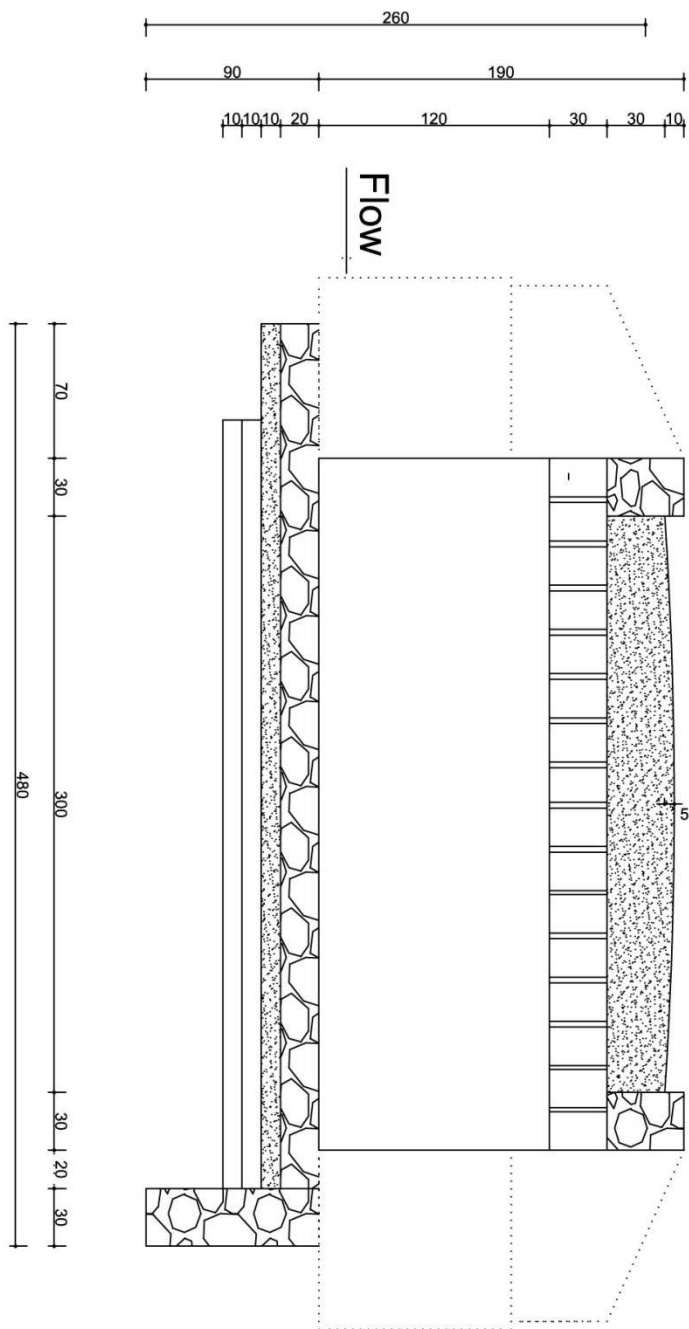


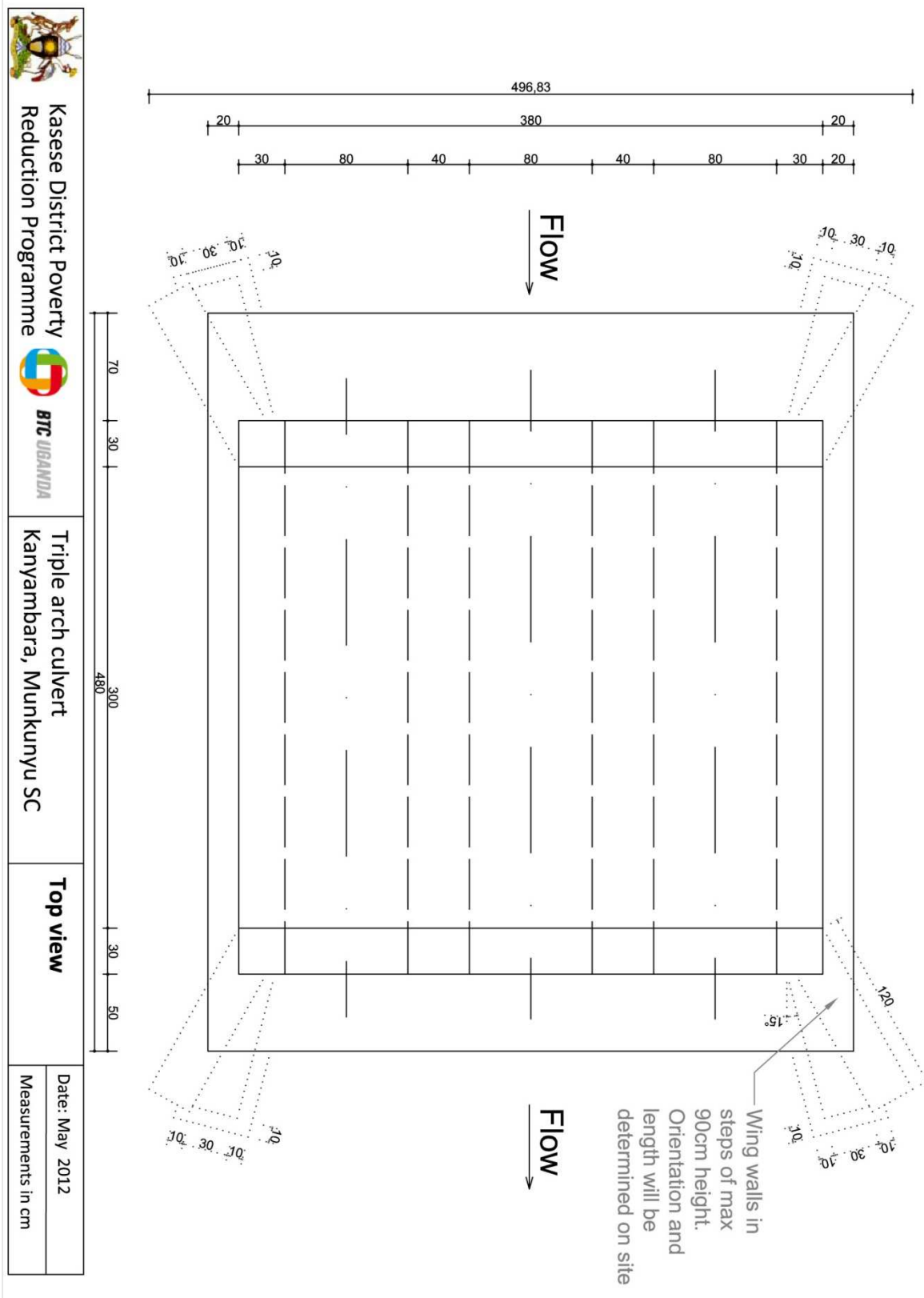
BRT
UGANDA

Triple arch culvert
Kanyambara, Munkunyu SC

**Longitudinal
section**

Date: May 2012
Measurements in cm





Annex 3: Reference masons & technical staff.

Country	Name	Task	Telephone number email address
Tanzania	Mwiwa Daniel	Mason & foreman	+255 75 2334317
	Rashid Mtamila	road technician	mtamilaone@yahoo.com
Uganda	Jeff Ssekempi	engineer	+256 75 4410753 jefsosso@yahoo.com
	Alphonse Katswamba	building technician	+256 75 7707768 katswambaa@yahoo.com
	Enock Kule	mason	+256 78 3429103
	Lawrence Muhindo	mason	+256 77 3596162
	Gideon Baluku	mason	+256 778620173
	Bwambale Sylvain	mason	+256 783369773
Rwanda	Chrisostome Mugiraneza,	mason	+250 788587004.
International	Eng. Grigoletto Sophie	engineer	sophie_grigoletto@hotmail.com
	Steven Hollevoet	adviser	mambo_steven@yahoo.co.uk

Annex 4: Technical specifications example

Kasese District Poverty Reduction Programme

Technical Specifications for: Construction of a double arch culvert in Kalibu, Kilembe Sub-County

As stone masonry is a locally little-known technology and differs from the bricks masonry technology, the following technical specifications shall be followed carefully:

- Dirty stones shall be washed with a steel brush to remove soil before use.
- After digging, soil shall be compacted in the proper way with an iron compactor.
- Stones of the foundations and of the abutments shall be placed in a horizontal position, put down on the largest side of the stones and providing good bond.
- No more than 1.8 bags of cement shall be used per m³ of stones.
- The mix ratio of mortar shall be 1:4.
- Selection of the stones shall be wise and sound in order to minimize the quantity of mortar.
- Gaps between the stones shall be filled with smaller stones and mortar.
- Good quality stones shall be used for the construction of the foundations, the abutments and the arches. Poor quality stones shall be used for backfilling only.
- A space of one centimetre on each side between the moulds and the abutments shall be made to make the removal of the moulds easier.
- Stones of the arch shall be placed in a radial position.
- The construction of the arches shall start from the both sides of the arch to the top at the same time.

Annex 5: MOU -example

**Memorandum of Understanding for:
Construction of 1 arch bridge 8m
To improve access
To markets and social services**



BTC UGANDA

Bugoye Sub County – Ndugutu – Sebwe river.

4. 1. The Parties

This agreement is entered between the following parties:

Road committee

Represented by the chairperson - name.....

C/o PO Box

Tel:

(Hereinafter called the “road committee”)

Sub County Bugoye

Represented by the sub county chief, Mr. Esau Murongo

With its registered offices at Mahango sub county / Kasese District

C/O PO Box 250 Kasese

Tel: 0702 55 20 48

(Hereinafter called the “sub county”)

Kasese District Local Government

Represented by the Chief Administrative Officer,

P. O Box 250 Kasese

Tel:

E Mail:

(Hereinafter called “district”)

5. 2. Contact Persons

The contact persons for this agreement are:

Stakeholder	Name	Telephone
Road committee		
Kasese District Local Government		
Belgian Technical Cooperation		

This MoU is not commercial contract. The MoU aims at co-funding and pooling resources for the construction of one arch bridge/drift in order to improve access to remote area.

6. 3. Background

The roads are usually designed with an insufficient number of arch bridges due to the high cost of concrete arch bridges the number of constructed structures is usually insufficient. It causes inadequate drainage and premature erosion, leading to high maintenance costs. Moreover the traditional pole bridges do not allow for the crossing of heavy vehicles and need continuous replacement.

Stone arch culverts and bridges provide a solution to the problems related to the use of conventional concrete bridges. When compared to concrete bridges, stone arch bridges have the following benefits and advantages:

- The cost of labour required in the construction of stone arch bridges is lower than the cost of concrete used in concrete arch bridges.
- Stones are often available in the vicinity (10-15 km) of the construction site.
- There is no need for expensive iron bars, gravel, concrete or galvanized pipes.
- The weight of the stone arch bridges reduces the risk of floods washing them away.
- Unlike with galvanized arch bridges, stone arch bridges cannot be stolen and resold.
- A larger proportion of local resources are mobilized and used.
- Construction is simple and low skilled village craftsmen and labour from the local villages can be used to implement the work.
- Employment is created due to the higher labour input required.

This technology enables greater involvement of the rural communities and district councils during the planning and execution of road works and results in a greater sense of ownership. It is hoped that constructing of stones bridges and arch bridges will alleviate the problem of poor access to marginalized communities.

7. 4. Objective.

The objective of this memorandum of understanding is to construct a stone arch bridge at Ndugutu (span 8 meters – segmental arch) in order to improve access to markets and social services of rural communities. The drawings and bills of quantities of the structure can be found in annex. They are part and partial of this MoU. KDPRP is unfortunately not in the position to fund the road works. KDRP assistance will focus on the structure only.

8. 5. Time Schedule.

This agreement comes into force after signing. The local contribution has to be mobilized ahead of the construction and the construction shall be finished by end of June 2013. KDPRP funding and support cannot go beyond the closure of the programme.

9. 6. Responsibilities of the parties.

Responsibilities of the sub county

1. Mobilize the community and make sure that the beneficiaries implement their responsibilities.
2. In line with government guidelines, constitute the road committee that will be in charge of the implementation of this MoU. Members of the road committee will be selected from the beneficiaries.
3. If required, co-fund from sub county local revenue the community contribution
4. Monitor the construction works and report progress/ any problems to the works department.
5. Include the construction of the stone arch bridge/drift in the sub county development plan and progress reporting.
6. Display the summary information of the contract (cost, funding source, type construction, period, masons) on the public sub county and the relevant parish display board.
7. Ensure the appropriate maintenance of the arch bridge that is to say report scouring, prevent erosion of the river banks and the wing walls, and remove silt.
8. Participate in the selection of reliable road committee.
9. Ensure proper use of the resources notably the cement and transport.

Responsibilities of the road committee

1. Provide local building materials and arrange on site: stones/ sand / gravel/ eucalyptus poles for the scaffold/ water as outlined in the Bill of Quantities and needed for the construction. Local building materials will be made available at both sides of the river.
2. Provide 200 burnt bricks for slab on which the mortar will be mixed. Bricks can be recovered after works.
3. Provide labour for the site clearance, excavation, trenching, cleaning stones, compacting of hard core, backfilling, transport of building materials of nearest arrival point of the lorry, unloading construction materials, remove excess soil from the river bed, fill gabions, excavate murrum, construct coffer dam to prevent floods and guard cement and tools. The road committee will draw a time schedule for the effective contribution of community labour.
4. Provide security for the building site and the building materials. A store ledger will be used for the issuing of building materials.
5. Provide lodging in the vicinity of the construction site to the masons for the time of the construction.
6. At own costs, participate in the preparatory meetings and the capacity building workshops for the road

committee at the locality.

7. On a voluntary base, the road committee will coordinate at community level the construction i.e. mobilize the community, organize the local contribution, and monitor the construction.
8. Carry out the day to day monitoring of the construction works and inform the works department if there are problems with the quality and quantity of the works provided by the masons and casual labour.
9. Keep a log book of the attendance of mason and casual labour.
10. Ensure that potential environmental hazards of the area around the arch bridge are contained.
11. Construct the road and the approaches to the bridges.

Responsibilities of Kasese District

1. Fund the donor part of the construction of the bridge structure (cost skilled labour, external building materials, transport) of the arch bridge/drift through KDPRP. It should be noted that the road and the bridge approaches are not part of the KDPRP funding.
2. Fund the supervision and certification by the district and project engineer of the construction of the arch bridge/drift through KDPRP.
3. Monitor the proper maintenance of the arch bridge.

10. 7. Funding.

This is an agreement for joint funding and pooling of resources. Funding for the construction of the arch bridge/drift will be made available by the Kasese District Poverty Reduction Programme – regie component. KDPRP will make available about 23.725.000 Ush (twenty three million seven hundred twenty five thousand Ush) for hard ware materials and skilled labour. These are estimates.

The sub county and road committee will contribute about 14.771.000 Ush (fourteen million seven hundred seventy one thousand Ush) through local building materials and unskilled labour in kind. These are estimates. The total cost is estimated at about 39.500.000 Ush (thirty nine million five hundred thousand Ush).

11. 8. Maintenance.

In order to ensure that the arch bridge lasts for a good period of time, the road committee will report through the sub county on scouring, prevent erosion of the river banks and the wing walls, and remove silt.

12. 9. Termination of the MoU.

If during any time of the contract, the road management performance will fall below the expected anticipations (mobilizing community contribution, attendance meetings etc) the District may terminate the contract and funds will be allocated to any community ready for assistance. In such event, the road committee shall not be entitled to claim any damages or loss of subsidies.

The MoU will automatically be terminated with the closure of KDPRP in June 2013 even if by then the arch bridge/drift has not been finalized. The liabilities of the ongoing contracts are then the responsibility of the district and not KDPRP.

If the issues which led to the suspension of the financing agreement have not been resolved within a maximum period 3 months, either party may terminate the financing agreement at two months' notice.

13. 10. Settlement of disputes.

This Agreement is entered according to the laws of Uganda, without prejudice to any rights or privileges enjoyed by the District as a development programme pursuant to a bilateral agreement between the Government of Uganda and the Government of Belgium. Any dispute arising will if possible be settled by mutual agreement between the parties. Any dispute concerning the MoU which cannot be settled within one month period by the consultations between the parties may be settled by arbitration at one of the parties' request. In this case the parties shall each designate an arbitrator within 30 days of the request for arbitration. Failing that, either party may ask the RDC to designate a second arbitrator. The two arbitrators shall in their turn designate a third arbitrator within 30 days.

Each party shall be bound to take the measures necessary for the application of the arbitrators' decision.

14. 11. Anti-corruption.

No offer, payment, consideration, or benefit of any kind, which constitute illegal or corrupt practice, shall be made, either directly or indirectly, as an inducement or reward in relation to the MoU negotiations / awarding and/or the execution of the MoU. In order to safeguard the integrity of this MoU, both parties to the agreement

will report any corrupt and fraudulent practices to the other who will then take immediate action, civil and/or criminal, as may be appropriate. The emphasis is put on the theft of materials and misuse of allocated transport.

The district local government, road committee and sub county will put into place proper measures to prevent any double funding. The origin of funding will be clearly outlined in the sub county planning. In line with government procedures, the structure, the asset number and register will identify the source of funding.

15. 12. Solemn Declaration

The parties to this agreement solemnly declare that the information in this agreement with relating annexes is correct. This agreement shall be signed in three identical copies.

For Road Committee: Chairperson

Date: _____

Name: _____

Signature: _____

Witness:

Date: _____

Name: _____

Signature: _____

For the Sub County: SC Chief

Date: _____

Name: _____

Signature: _____

Witness LC3 Chairperson

Date: _____

Name: _____

Signature: _____

5.1

Chief Administrative Officer Kasese District

Date: _____

Name: _____

Signature: _____

Witness District Engineer

Date: _____

Name: _____

Signature: _____

BTC – technical adviser KDPRP

Date: _____

Name: _____

Signature: _____

16. Annexes to the agreement.

1. Bill of quantities of the arch bridge/drift and funding origin including local contribution.
2. Drawing of the arch bridge.

Annex 6: Assessment of request & site

Checklist-data bridge construction

Road : *Bugoye - Ndugutu*
 Span : *current 14 metre timber*
 Works requested: *stone arch segmental bridge 8 metres span*

Sub county : *Bugoye* Parish:

Hydrology

River : *Sebwe*
 Discharge normal year : *11.7 m2*
 Discharge el-ninjo : *19.3 m2*

Site characteristics

Sub-soil for foundation: type & depth
First layer 80 cm loamy sand. Deeper layers strata of small pebble and large stones mixed with loamy sand.

Road previously existing:
Only for motorcycles. New road to be excavated from the escarpment for about 300 metres.

Maintenance road / approaches: *good – reinforced with stones by community.*

Type/condition previous bridge: *timber bridge for pedestrians – good condition.*

Risk erosion future bridge:
limited as sub soil compacted and with many large pebbles, no river bend

Distance borrow pit stones: *500- 1500 metres*
 Distance borrow pit sand: *Tronder power (2 km) and Rukoki (8 km)*
 Distance borrow pit murram: *500 metres*
 Distance project head quarters/supervision unit: *8 km*

Economics

Village(s) involved: *3 villages, 2 trading centres,*
 Others: *1 health facility, 2 primary schools.*
 Expected traffic density: *5 cars per day, 30 motorcycle taxi per day*
 Population density of villages involved:
 Crop production: type and tons. *coffee 75 tons, maize 50 tons, cassava 100 tons, timber.*
 Markets: *2 trading centres*

Village commitment

Payment local contribution : *villagers contributed already for lorries carrying the stones, other contribution labour digging foundations, murrum and poles.*

Priority sub county plan? *Yes included in the sub county 5 year development plan.*

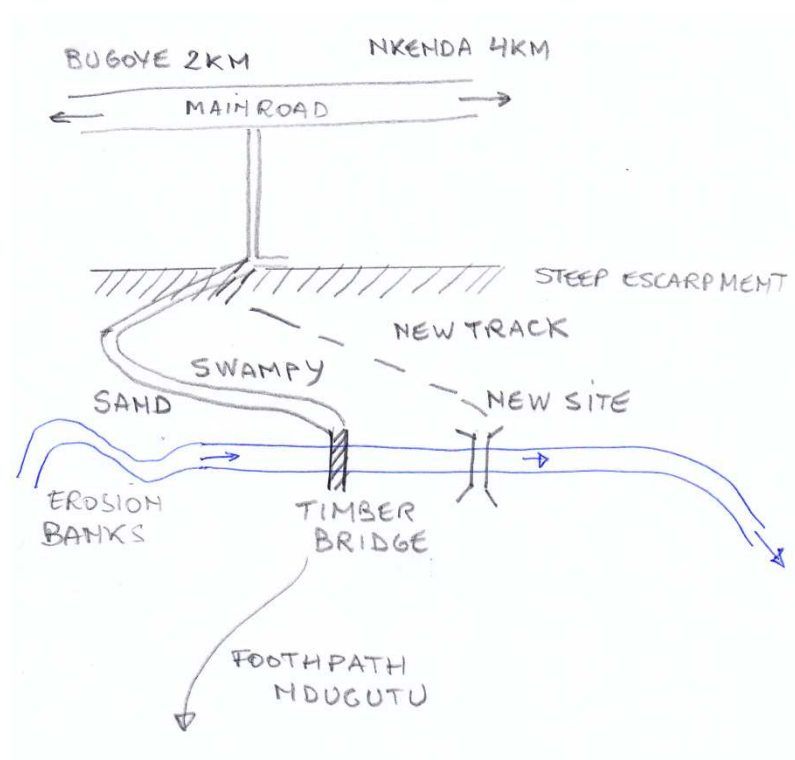
What local contribution is in place? *Yes 15 trips of large stones*

Previous (successful ?) community development activities executed by the village.

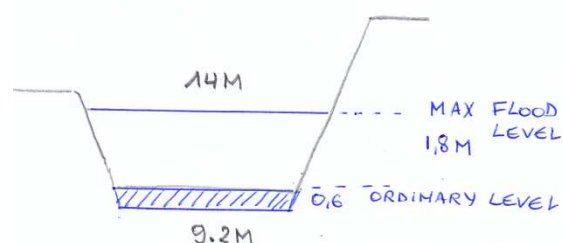
Current timber bridge. Classroom construction primary school

Overall assessment

Highly committed and pro-active community that has mobilised already a large part of the stones. The site has limited risk as the sub soil is firm with pebbles and the river does not meander. However large floods occur which cannot be catered for by any bridge. The economic justification for the bridge is medium – it will avoid a detour of 6 km for 3 villages. Because of the community commitment and mobilised contribution it is recommended to build this bridge.



Map site



Profile