BTC UGANDA

Kasese District Local Government

Stone arch bridges

A strong & cost effective technology for rural roads

A practical manual for Local Governments

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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

Many people and institutions contributed to this manual: the KDPRP steering committee, Local Authorities at District and Sub County levels, the District Executive Committee and the Chief Administrative Officer, William Kanyesigye. Special thanks goes to Paul Dequeker, Belgian architect, for having shared his broad experience in Congo with us. The manual was written by Eng. Sophie Grigoletto and Steven Hollevoet. The draft was reviewed by the Kasese District Works department, Alphonse Katswamba , Dave Renno, Ruediger Behrens (GIZ) and Neil Noble of Practical Action. Neil also produced some of the technical drawings.
Jonas Geeroms edited some diagrams.
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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.

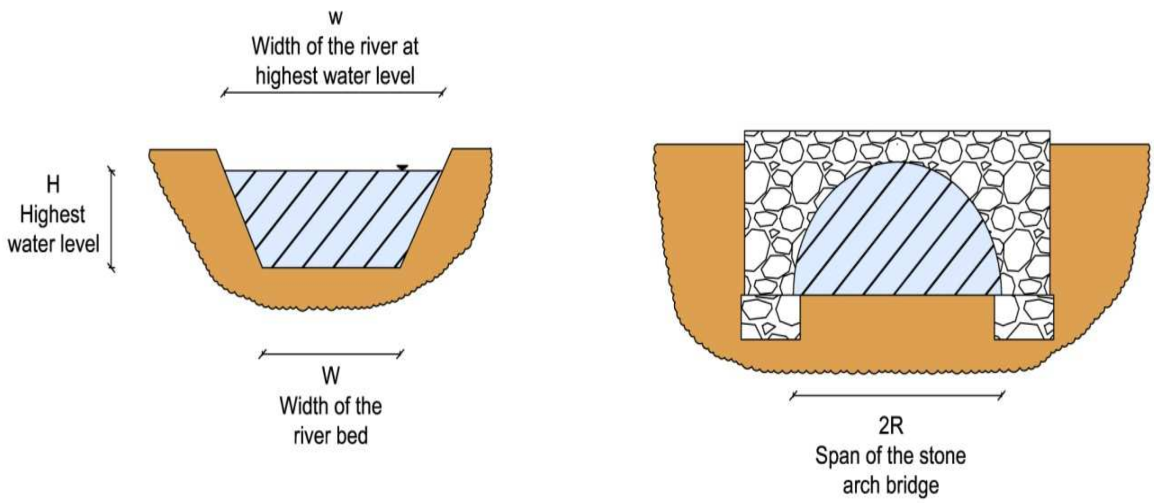


Fig. 14: Left side: river profile at highest water level. Right side: Roman stone arch bridge with an equivalent opening. Hatched surfaces have the same area, i.e. the area of the river section at highest water level. The radius of the required roman bridge can easily be calculated: $R = \sqrt{\frac{(w+W)\times H}{\pi}}$

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.

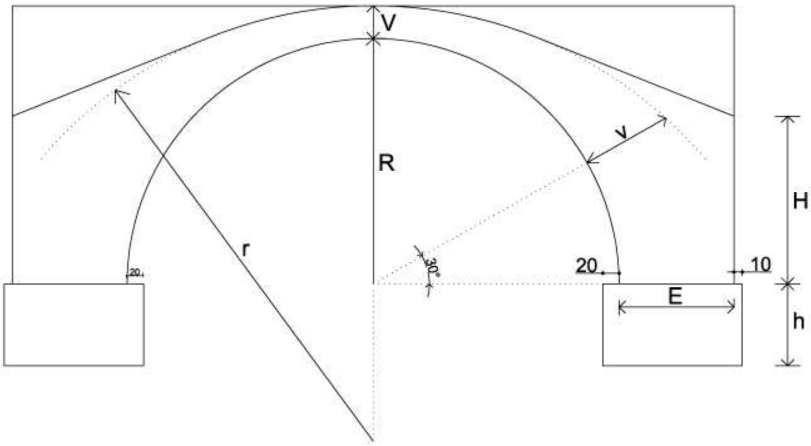
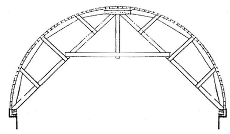


Fig. 15: diagram, formwork and example of a roman arch bridge



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**	**m³**	**m³**
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

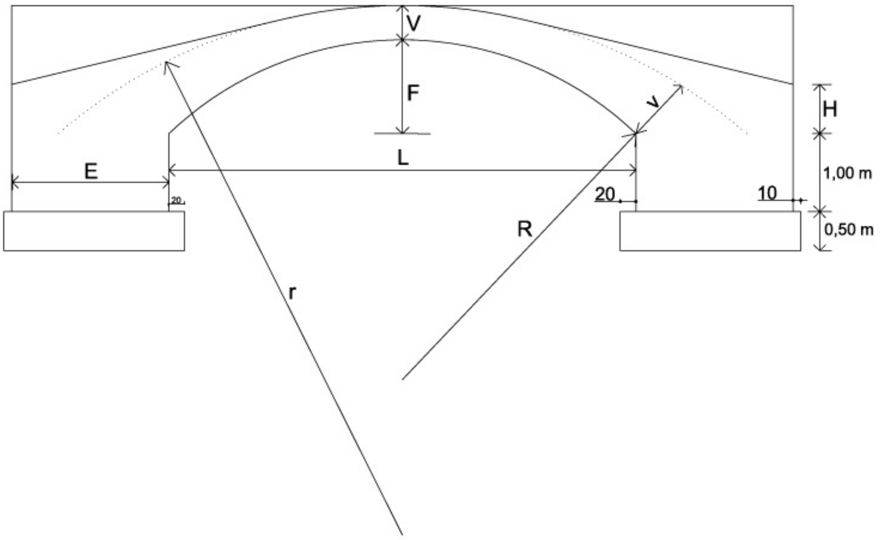
For rural feeder roads, the standard width of a bridge is 3.6 meters, which allows for single lane crossing of lorries.

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.



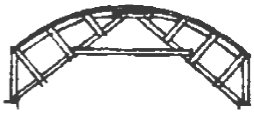


Fig. 16: Diagram, formwork and example of a segmental arch bridge.

L (m)	F	R	V	r	v	E	H	Vol. m³/m	Vol. m³ 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.

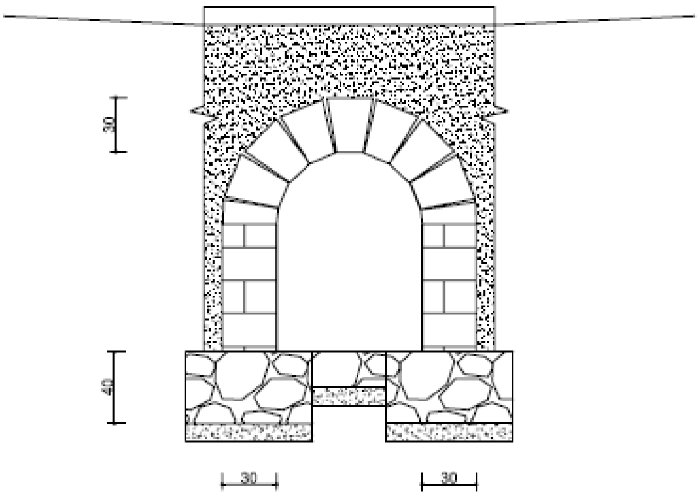


Fig. 17: Single stone arch culvert - dimensions in cm.

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.

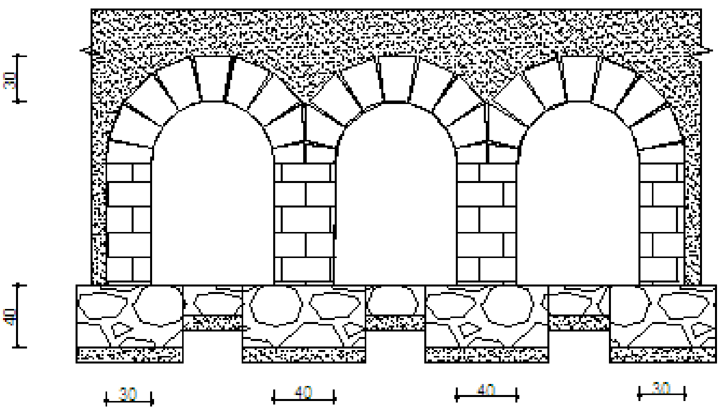


Fig. 18: Multiple stone arch culvert- - dimensions in cm.