An overview on "Arch Bridges in Nepal"

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ABSTRACT**:** Nepal, being a Himalayan Kingdom, there are more than 6000 rivers all flowing from very high Himalaya on the northern side to low plane in the south. These rivers are characterized by the very high discharge and rapid current, especially in rainy seasons. Very high potential of excessive erosion and aberration, and the very high discharge within the small gorges are the daunting problems with the RCC deck bridge. To address these problems in a satisfactory manner, use of materials with superior quality and the location of the piers in higher elevation are essential. Such a strategy is not economical for the country with poor economy. In addition, with reference to the great potential of tourism in the country, aesthetic point of view for the structures is also important. In view of these points, arch bridge is the obvious choice for Nepal. The geology of Nepal in mountainous region is favorable for abutments of arch bridges. Aesthetic beauty of well designed arch bridges is a plus point for the country seeking to increase the tourism potential, which can be a promising income source of landlocked developing country like Nepal. Despite all these feasible situations, very few arch bridges are in existence in Nepal. This paper aims to describe structural and socio-economical aspects of Arch bridges in Nepal, and delineates the reasons why there are only very few arch bridges despite great feasibility.

1 INTRODUCTION

Nepal is a hilly country with the high Himalaya in it's northern part, the hills consisting of Mahabharata range and the Churia Hills [Figure 1], and the Terai to the south. Elevations vary in the kingdom. The highest point is Mt. Everest (8848m) in the north and the lowest point (70 meters above seal level). Altitude increases as you travel south to north. There are hardly any planes as all the topography is composed of hills. Out of 14 peaks of elevation more than 8000 m of the world, eight are to be found in Nepal. Many beautiful lakes, rare wild animals and waterfalls have made Nepal, a destination for people who love nature [Figure 2]. Being a landlocked country, it needs to depend fully on India for almost all goods. Despite having a considerable tourism potential on tourism [9], Nepal has not been able to benefit from it. Among many reasons for this the major one is a lack of good road network. As the most of the area of Nepal is hilly, it is expensive to build roads. In addition, there are more than 6000 rivers all flowing from the higher Himalayas to lower Terai. So, the cost of bridges for roads would be expensive. It is yet another challenge to choose the best type bridge to harmonize with the natural beauty of the landscape. So, we need to choose a bridge type which would be economical while taking into account of its socio economic aspects, construction costs, the costs of foundation etc.

Figure 1: Himalaya Range and hills

Figure 2: The Shikar Himal, Nepal

2 GEOGRAPHY AND GEOLOGY

The Himalayan Range is a young mountain system. It is a broad continuous arc along the northern fringes of the Indian subcontinent, from the bend of the Indus River in the northwest to the Bramhaputra River in the east [6]. The Himalayan mountain chain extends in an east-west direction between the wide plains of the Indus and Bramhaputra in the south and the vast expanse of the high Tibetan Plateau in the north. The limit of the Himalayas in the east and west is marked by the eastern and western arc of Himalayan bends. Between these bends the Himalayan range is approximately 2400 km long and 200 km to 300 km wide. The Himalayas cover an area of approximately 600,000 sq. km in south Asia [10].

The Himalayas were formed by the collision of the Indian Plate with the Tibetan (Eurasian) Plate around 55 millions years ago [7]. Many scientists believe that at that time the northward moving Indian plate first touched the southern edge of Tibetan (Eurasian) plate.

Table 1: The major type of rocks found in Himalayas

Geomorphic Unit	Width (km)	Altitudes (m)	Main Rock Types	Main processes for landform development
Mahabharat Range	10-35	1000-3000	Schist, phyllite, gneiss, quartzite, granite and limestone belonging to the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
Midlands	40-60	300-2000	Schist, phyllite, gneiss, quartzite, granite, limestone geologically belonging to the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
Fore Himalaya	20-70	2000-5000	Gneisses, schists, phyllites and marbles mostly belonging to the northern edge of the Lesser Himalayan Zone	Tectonic upliftment, Weathering, erosion, and slope failure
Higher Himalaya	10-60	>5000	Gneisses, schists, migmatites and marbles belonging to the Higher Himalayan Zone	Tectonic upliftment, Weathering, erosion (rivers and glaciers), and slope failure
Inner and Trans Himalaya	5-50	2500-4500	Gneisses, schists and marbles of the Higher Himalayan Zone and Tethyan sediments (limestones, shale, sandstone etc.) belonging to the Tibetan-Tethys Zone	Tectonic upliftment, wind and glacial erosion, and slope degradation by rock disintegrations

As the majority of the rocks are a strong type and the fragility of the mountain is not so severe we can say that the geology of most of the hill and mountain area of Nepal is sound. Hills with steep slopes and rivers with large catchments among many such hills are the characteristics

of the mountains and hills in Nepal. So, if we plan to construct RC deck bridge (beam bridge),it may be uneconomical for many reasons [17]. In some of the projects, they may be feasible if we consider the cost of construction but arch bridges may be feasible if we consider the long term aspect and the aesthetic benefits.

Rock cliff, Mustang

Majority of rock type

Deepest George of world

A hill station, Nepal

Suitable topography for arch bridge

Major topography, Nepal

Figure 3: The topography and Geology of Nepal

3 FEASIBILITY OF ARCH BRIDGE

The major type of bridges constructed or under construction to date are i) RCC T beam ii) RCC slab bridge iii) Steel Plate Girder iv) Steel Truss bridge v)PSC(pre stressed concrete) bridge [14]. There are only few arch bridges in Nepal and most of them were constructed by the Chinese government. As already explained, the geology of Nepal is good enough to resist the thrust of even long span arch bridges [4] [15]. These arch bridges have a pleasing appearance which readily leads an increase in the tourism potential, one of the major factors if we consider the long term economy [9].

As the river passes deep between steep slopes on both sides and the discharge in the river is usually very high in the monsoon season with tremendous current, it is compulsory for us to construct the bridge quite above the HFL corresponding to at least 50 years return period [13]. As the river bed is steep slope, the current in the river is usually very high and carries large sized boulder and hits the piers with greater momentum. So, as we need to raise the bridge high above the water level, it is necessary for us to build long piers. This leads to increase the cost for piers. On top of that, as the pier has to resist high turbulence and the momentum from the boulders, we need to shield the pier with protective measures, which also results in raised costs for the bridge. Furthermore, we need to invest more money for repairs to the piers.

As the member of the beam bridges are subjected to bending, the axial capacity of the structural elements will never be used. Instead, to resist high bending moment, we need to invest more money in the materials used. The enormous axial capacity of the element will never be used. Arch type construction is the only structural type in which strength of material will be used fully [17].

In most cases we need to spend more money on river training works as we need to construct many piers. On the one hand considering above mentioned factors, the cost of the bridge will be

high. On the other hand these beam bridges hardly ever fulfill another major requirement i.e. aesthetics. Bridges are a major structure in improving the aesthetic value of the locality. These beam bridges, steel plate Girder Bridge, and steel truss bridge can hardly be said to enhance the aesthetics of the surroundings[3][5].

There is another type of bridge which we have rarely practiced to date, the arch bridges. The architectural beauty that arches bridges offers is obvious [17]. All the beautiful hills of Nepal with well designed arch bridge will be very pleasing to the eye. Beside aesthetics, we get rid of the problem of pier construction and we never need to think about the safety of the piers with regard to boulders. As arch members are mostly in compression, we optimize the use of the strength of the materials. As, concrete is readily available in Nepal and its high compressive strength can be used effectively in arch bridges. As the abutments are very form and rocky, it is cheaper to resist thrust from arch rib with lower foundation cost. Moreover, the cost of the material will be effectively reduced, which means a good deal for our situation as we have to depend fully on India for reinforcement. In very rural areas also, we can build stone arch bridges as we have an abundance of good type of rock in most of the areas [7]. So, in some places we can construct arch bridge without the use of reinforcement which may be good alternatives for short span bridges. These types of bridges are possible only with an arch type construction [17].

As the concrete use to be mostly in compression in arch type bridges, so there is far less chance of cracks in RC arch structures [16]. This leads to superior durability of the structure, in turn leading to a reduction in maintenance costs of the structure. Considering all these aspects, arch bridges seems to be an urgent option for the future bridge construction in Nepal [15].

Arch bridges have become economically competitive because of the development of new construction methods and material technology [8]. In some cases, even if an arch structure can't be justified from structural point of view, its aesthetic advantage could nevertheless be decisive. They provide a natural and appropriate structural solution that is both aesthetically pleasing and clearly shows its function. It is easily integrated into the environment and always meets with wide public approval as a structural form. Durability and longevity are indisputable advantages of arch type construction [2].

Why, then, are there so few arch bridges in Nepal?

Though there is a great potential for arch bridges in Nepal we have very few of them. Except for some arch bridges constructed by the British government, almost all arch bridges are designed and constructed by the Chinese government. The reason for that is the following. [15]

1. Lack of manpower in Nepal. There are very few arch experts in Nepal.
2. As the economy is very weak, rather than going for long term benefit, it is necessary for the country to choose other alternatives which are cheap at the time. Because of the need for the cheap solution we can hardly think of long term benefits.
3. For construction of arch bridges, the construction methods and equipments are very important for arch bridge will be unstable until its closure [8]. We don't have enough construction experiences on this type of bridges.
4. The main challenge with arch construction is the need to transmit significant horizontal force to the foundation. Furthermore, arch bridges rely on the lateral rigidity of the deck for resisting horizontal actions such as wind and earthquakes. Before placing the deck, an arch may therefore require expensive temporary works during construction. Lack of construction technology is one major reason.

Some Pictures of arch bridges in Nepal:

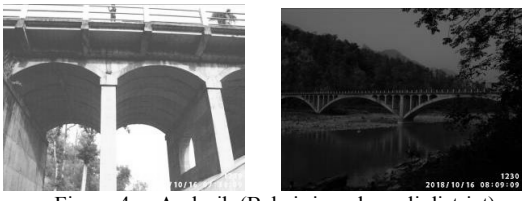
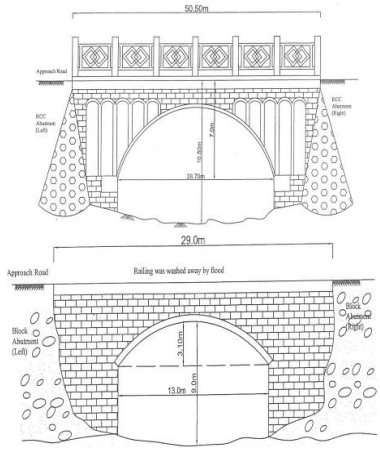
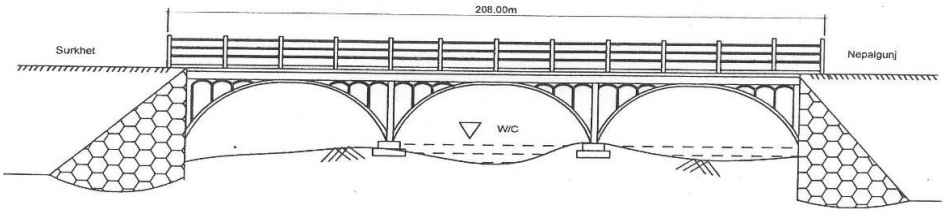


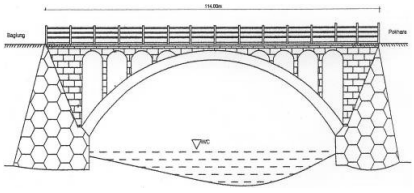
Figure 4: Arch rib.(Babai river, karnali district)



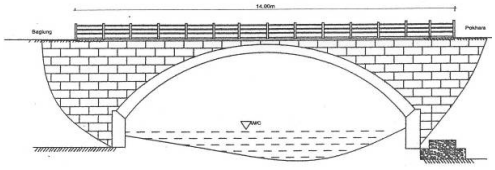
Cross Sectional Sketch of typical arch bridges in the central region of Nepal



Cross sectional sketch of typical arch bridge in the mid-eastern region of Nepal



Sketch of bridge over kali Gandaki river



Typical arch bridge in western Nepal

Figure 5: Some typical sketches of arch bridge in Nepal

Friendship Bridge, the Nepal China border

Arch bridge near the Nepal China border

Figure 6: Arch Bridge connecting China and Nepal

Different Type of Bridges and their frequency in Nepal:

Table 2: Bridges in Nepal

type of bridges	No
Blank	2
Bailey Truss	8
Cable Stayed	1
RCC Arch	43
Floating Drum	1
Hume Pipe	2
Portal Frame	2
PSC	46
RCC Slab	328
RCC Slab & Plate Girder	2
RCC Slab & Steel Truss Girder	1
RCC Slab & T-Beam	1
RCC T-Beam	466
Steel & Timber Girder	1
Steel Plate Girder	53
Steel Truss	46
Steel Truss(composite)	4
Stone Masonry Arch	3
Suspension Steel Truss	3
Timber	5
Vented Pipe	9
total	1027

There is no good road network yet in Nepal. Some districts even are yet to be touched by national highways. Traveling by air is only option remaining for these areas. Despite having very limited road network, the above data base shows that we need to construct many more bridges as there are many rivers we need to cross. Out of 1027 bridges in Nepal, only 43 are arch bridges. Among these, three arch bridges are stone masonry arch bridges. Almost all the other arch bridges are concrete arch bridges and there are none of the other kinds of arch bridges like, CFST, steel arch bridges etc. All the arch bridges are deck type arch bridges.

Until now only 4.4 % of the bridges of Nepal are arch bridge. Table 2 shows the types of bridges in Nepal. Though the stone arch bridge seems to be a very feasible and economic option in countries like Nepal with cheap labor costs there are only three stone arch bridges. Only one bridge, the bridge over Kali Gandaki has a span greater than 100 m (114 m).Table 3 presents the detailed database for arch bridges in Nepal. Most of the bridges have a span 20-60 m. To be more exact, 23 out of 42 bridges are of span ranging between 20-40 m. 12 bridges are ranging 40-60 m and only 6 bridges are spanning more than 60 m. From this data, it is obvious that we have a lot of work to do in arch bridges.

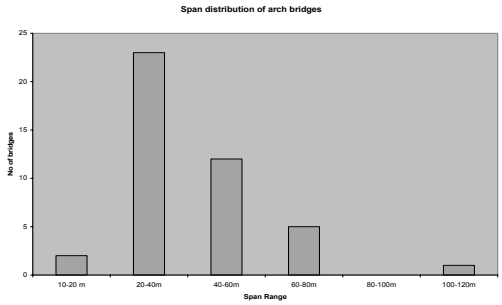


Figure 7: Chart depicting most of the arch bridge in Nepal is spanning less than 40 m.

Table 3: Table depicting arch bridges, their location, their load capacities, span type etc.

Name of Road	River/ Stream	Chainage Km	Length m	Width, m		Span No	Foundation	Loading Capacity
				Road way	Carriage way			
ARM "	Phulphing	106+750	65.00	8.00	6.00	1	Spread	CH-15/CH-80
ARM "	Friendship Bridge	112+830	67.30	8.00	6.00	1	Spread	CH-15/CH-80
PRM "	Nagdi	81+040	37.15	6.94	6.00	1	Spread	CH-15/CH-80
PRM "	Muse Khola	121+430	18.50	6.90	6.00	1	Open	CH-15/CH-80
PRM "	Rudi Khola	151+590	20.30	7.90	7.10	1	Open	CH-15/CH-80
PRM "	Hadeli Khola	153+530	19.80	7.90	7.00	1	Open	CH-15/CH-80
NMRM	Jugedi	10+370	50.50	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Kharre	11+300	36.50	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Phohor Khola	12+850	38.50	7.00	6.00	1	-	CH-15/CH-80
NMRM "	Lamobaluwa	16+380	28.40	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Khani	16+850	28.00	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Bhorle	19+500	56.80	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Mauri	21+700	26.30	7.00	6.50	1	Spread	CH-15/CH-80
NMRM "	Dumre	22+030	32.40	8.00	7.00	1	Spread	CH-15/CH-80
NMRM "	Simaltal	24+250	37.20	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Rigdi	25+570	50.25	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Jalbire	29+210	25.66	10.00	9.00	1	Spread	CH-15/CH-80
NMRM "	Nyanse	32+670	31.00	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Tope	32+860	23.00	8.50	7.50	1	Spread	CH-15/CH-80
NMRM "	Kali	33+350	60.00	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Gairi	34+660	60.00	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Khahare	35+490	65.60	7.00	6.00	1	Spread	CH-15/CH-96
KRM "	Leoti	79+700	32.00	9.90	7.10	1	Open	BS/HA Loading
KRM "	Ruduwa	91+490	32.00	9.90	7.10	1	Open	BS/HA Loading
RRM "	Babai River	53+880	222.40	11.00	8.00	3	Open	CH-15/CH-80
F35 "	Daraundi	6+450	91.40	7.00	6.00	2	Open	CH-15/CH-80
Pokhara-Baglung-Beni Road, F42 - 90.0 Km	Firke Khola	1+942	52.60	7.00	6.10	1	Open	CH-15/CH-80
F42 "	Yangdi - 1 Khola	5+784	50.85	8.00	6.00	1	Open	CH-15/CH-80
F42 "	Yangdi - 2 Khola	18+263	44.30	12.00	11.10	1	Open	CH-15/CH-80
F42 "	Liwade Khola	19+081	38.50	6.20	5.30	1	Open	CH-15/CH-80
F42 "	Odare - 1 Khola	31+237	34.30	8.70	7.80	1	Open	CH-15/CH-80
F42 "	Odare - 2 Khola	31+375	26.40	9.90	9.00	1	Open	CH-15/CH-80
F42 "	Dhoti Khola	38+782	56.60	8.30	7.40	1	Open	CH-15/CH-80
F42 "	Khumaye Khola	39+022	29.20	7.50	6.60	1	Open	CH-15/CH-80
F42 "	Sheetal Gupha Khola	39+900	24.15	7.60	6.60	1	Open	CH-15/CH-80
F42 "	Khahare Khola	40+810	31.45	9.00	8.00	1	Open	CH-15/CH-80
F42 "	Modi	46+472	61.10	7.00	6.00	1	Open	CH-15/CH-80
F42 "	Pati Khola	47+042	52.70	7.00	6.00	1	Open	CH-15/CH-80
F42 "	Ambote Khola	47+097	29.60	7.70	6.70	1	Open	CH-15/CH-80
F42 "	Armadi Khola	50+911	36.50	8.60	7.60	1	Open	CH-15/CH-80

F42 "	Kali Gandaki	67+464	114.00	8.00	6.00	1	Open	CH-15/CH-80
ARM "	Khokhundol	105+600	30.50	7.00	6.00	1	Spread	CH-15/CH-80
NMRM "	Chinsenji	35+120	41.15	7.00	6.00	1	Spread	CH-15/CH-80

4 RECOMMENDATION

Labor cost being very cheap and the cost of reinforcement being very expensive (No steel raw material throughout the country), the stone arch bridge is recommended for short span ranging (20-50 m). Research on the ultimate load capacity of stone arch bridges is recommended. This will be an economic option in most of the hilly area where short span bridges requires.
High tech construction methods should be introduced to generate the possibility of constructing long span arch bridges in deep gorges. Swing methods and cantilever methods will be better option for Nepalese topography.
Super long span arch arch bridges connecting cliffs enhance the beauty of the landscape. Before selecting a bridge type, its aesthetic qualities should be judged properly.

5 CONCLUSION

Based upon the above information, it can be concluded that,

i. Arch bridges are an urgent option for the context of Nepal if we want plan for long term economy.
ii. All the arch bridges that have been constructed to date are all in good condition without any repair work needed [15], [16]. That shows that arch bridges are a good investment with regard to durability and maintenance cost.
iii. The fact that there are very few arch bridges are in Nepal does not imply that arch bridges are not feasible in Nepal. Instead it implies the compromise the government needs to make because it is easier to construct other type of bridges. As the economy of the country is not good the government is compelled to think of the cheapest option for the present moment, regardless what the long term effect is.
iv. If we consider the total effect, the arch bridges will be very often the economic option.
v. The basic premises for tourism in Nepal are: delicately built upon the magnificent Himalayas, brave and chivalrous Gurkhas, skilled and distinguished Sherpas, a rich intriguing culture and a mysterious and magnificent heritage. Adding natural beauty to the scenic topography with well chosen bridge is one urgent issue.

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