FEASIBILITY OF USING CLEAR-SPAN ARCHES FOR SHORT-SPAN BRIDGES

Amin Kamal Akhnoukh[1], Asad Esmaeily[2]

ABSTRACT

The majority of bridges throughout the State of Kansas and other similar states, are short-span structures, serving either as a bridge on a relatively low rate traffic road, railroad underpass or mostly as drainage structures. This large number justifies any effort towards a more economically and technically efficient structure.

Conventional box sections are widely used in the state of Kansas for bridges spanning 3 to 60 feet, mostly as stream-passing structures. Short span arch bridges are an alternative for spans ranging from 10 ft to 80 ft. They can replace a multiple span box-bridge with a single span arch for spans more than 20 feet. Selection of a proper system for a case, involves numerous technical, environmental and economical factors.

In this study, a decision-making process is proposed for selection of the best option for a case. “Reinforced concrete box sections” and “metal-arch sections” as the main two short-span bridge alternatives are compared. First the possible options are technically determined considering major factors such as hydraulic efficiency, site topography, soil bearing capacity and environmental impact. If both systems are technically suitable for a case, a detailed design and cost analysis study, conducted using the proper software for the box section and in turn, the arch section, will finalize the selection process. However, cost analysis and technical factors are not independent. As example, soil bearing capacity affects the price of strap footing construction, hence, affecting the economical feasibility of metal-arch bridges.

Based on this study, in general, for the existing conditions in the State of Kansas, box sections are still the best alternative. However, for certain topographical sites and stream conditions, an arch-section with a single span, may be a better technical and economical option, especially when environmental regulations are a main concern. The process is introduced and summarized in a flowchart, which acts as a decision support tool for proper system selection.

KEY WORDS: Short span bridge, Box section software, Environmental Impact, Cost analysis, Flowchart

[1] Former graduate research assistant of civil engineering at Kansas State University, current PhD student at the Dept. of Construction Systems at University of Nebraska, E-mail: aakhnoukh@mail.unomaha.edu

[2] Assistant Professor of Civil Engineering at Kansas State University, Manhattan, KS 66506, Tel: (785)-532 6063, Fax: (785)-532 7717, E-mail: asad@ksu.edu

INTRODUCTION

The National Bridge Inventory Study Foundation (NBISF) completed a survey about the existing bridges all over the United States of America in the period from year 1992 to year 2000 (NBISF 2000). This 9-years-study checked the conditions of the existing bridges. It was found that 1 in every 4 bridges has a significant deficiency, either structural or geometrical. These deficient bridges are required to be renovated or totally demolished and reconstructed to suit the new design codes.

The number of inspected bridges in the State of Kansas exceeded 2000 bridge per year. Structurally deficient bridges represented 5% of this number. They represent bridges that can not sustain loads from heavier vehicles introduced by car manufacturers. The geometrically deficient bridges, represented by 20% of the number included in the NBISF survey, have inadequate width to serve vehicles with a larger size. Out of 25,000 bridges, inspected in the State of Kansas, the number of deficient bridges exceeded 7,000. Table 1 shows the total number of inspected bridges, including the number of structurally deficient or functionally obsolete cases included in the study.

Table 1 - NBISF Study on Deficient Bridges in the State of Kansas

Year	Total # of Bridges	Structurally Deficient		Functionally Obsolete		Total of Both	
		Number	Percent	Number	Percent	Number	Percent
1992	2983	162	5.43%	702	23.53%	864	28.96%
1993	2942	141	4.79%	586	19.92%	727	24.71%
1994	2848	142	4.99%	560	19.66%	702	24.65%
1995	2929	147	5.02%	571	19.49%	718	24.51%
1996	2709	129	4.76%	532	19.64%	661	24.40%
1997	2712	90	3.32%	427	15.74%	517	19.06%
1998	2724	209	4.00%	416	15.27%	525	19.27%
1999	2787	89	3.19%	420	15.07%	509	18.26%
2000	2429	61	2.51%	362	14.90%	423	17.41%

NBISF classified the bridges included in its study according to the material of construction. Materials included reinforced concrete, steel, pre-stressed concrete, wood and masonry, as shown in Table 2.

Table 2 - Classification of Bridges Based on the Construction Material

Bridge Construction Material	Number of Bridges
Reinforced Concrete Bridges	14,435
Steel Bridges	8299
Pre-stressed Concrete Bridges	1040
Wooden Bridges	1623
Masonry Bridges	198

CLASSIFICATION OF BRIDGES ACCORDING TO THEIR SPANS

Bridge classification can be based upon various factors. Span is a major factor that dictates the type of construction system and material to be used for the bridge construction. Some studies have been conducted on steel bridges, exploring different types of bridge construction systems (JASBC 1981). Other studies considered specifying the best concrete bridge construction system for different spans. Kansas Department of Transportation (KDOT) has specified various reinforced and pre-stressed concrete bridge systems, for different spans, ranging from 50 ft to 90 ft as shown in Table 3

Table 3 - Feasible Spans for Different Bridge Types

Type of Bridge System	Span (ft)
(K-3) Pre-stressed Concrete Girder (Composite)	50 – 70
(K-4) Pre-stressed Concrete Girder (Composite)	60 – 100
Post-Tension Concrete Haunch Slab	50 – 90

Based on previous researches, existing short span bridges within the State of Kansas are mostly stream crossing bridges and the main system adopted by Kansas Department of Transportation (KDOT) is the short span box section bridges. There is not a specific standard for classification of bridges based on their spans. Most of the time, type of a bridge for a certain span is identified based on a case-study. Considering various bridge standards, research results and recommendations obtained from consulting firms at different locations within the State of Kansas, bridges can be classified based on their spans as follows:

1-Long Span Bridges include spans greater than or equal to 200 ft. Suspension and cable stayed bridges are two common types of bridge systems in this range.

2-Medium Span Bridges include spans ranging from 60 ft to 200 ft. Most of the existing bridge systems are in this range. Hunched slab bridges, pre-stressed concrete girder bridges, and the majority of steel bridges as steel deck girders are medium span bridges.

3-Short Span Bridges include spans ranging from 20 ft to 60 ft. Systems of bridge construction within this range are limited. KDOT box bridges are the dominant system used for this range of spans. Other systems include reinforced concrete arch and the newly invented metal-plate arch bridge, constructed by Contech and Conspan (Contech and Conspan 2000).

DEFINITION OF A SHORT SPAN BRIDGE

The minimum value of the span range considered in this paper, 20 ft., is based on KDOT Bridge Design Manual Spans with values less than 20 ft are defined as culvert and not bridge. The bridge span (S) is measured in a direction perpendicular to the bridge walls (side supports), and not parallel to the roadway (L), as shown in Figure 1.

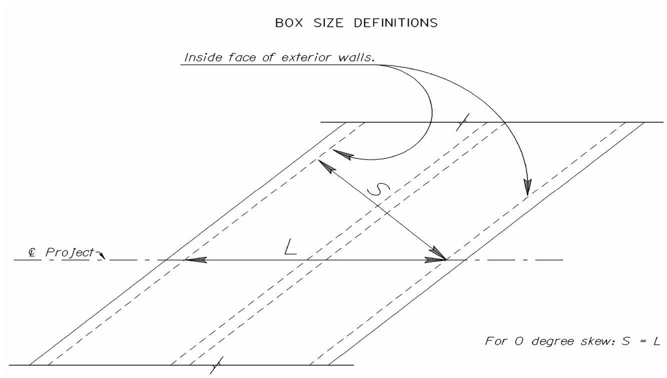


Figure 1 - Definition of Minimum Bridge Span (S)

Based on KDOT manual, skewed bridges can be classified as follows:

Road Culvert:	S < 10' 0"
"500" Culvert:	S > 10' 0" and L < 20' 0"
Bridge	L > 20' 0"

The maximum value of the span range considered in this study, 60 ft, is determined considering the maximum achievable span constructed by the KDOT box sections. The 60 ft span box-bridge can be constructed using triple cell boxes each of the maximum standard cell span of 20 ft.

MAIN FACTORS IN SELECTION OF THE TYPE OF SHORT-SPAN BRIDGES

Several factors are considered when selecting the appropriate system of construction for short span bridges. Technical factors may help the designer to select a specific system. However, the technical factors may not lead to a specific bridge system for a case. For cases where several options are technically applicable, the final cost of construction for a bridge system finalizes the selection process and specifies the proper system suitable for the case. The main technical and economical factors considered in the selection process in this study are hydraulic efficiency, site topography, environmental conditions and regulations, and cost of construction.

Hydraulic Efficiency

The majority of short span bridges constructed in the State of Kansas are stream-passing bridges. The size of the bridge opening, its shape and length play an important role in defining the hydraulic efficiency of the bridge section, and specifies if the constructed bridge can handle the passing stream. Two possible approaches are introduced in this paper to check the bridge section hydraulic efficiency. First, when the section length parallel to the stream flow direction is less than 250 ft, where the bridge section does not fully control the discharge calculations, yet it forms disturbance as it changes the stream hydraulic section properties. Adopted discharge can be specified according to the tolerated change in the stream flow. In this case, hydraulic charts are introduced by bridge manufacturers for calculating amount of flow versus cross section area. Second, where the bridge section length controls the flow properties and discharge calculation for cases of length sections (length of bridge opening parallel to flow direction is greater than or equal 250 ft), Manning's equation for measuring flow velocity is used, and the discharge is calculated using the continuity equation. Larger box section area compared to the arch bridge area (for similar topographical conditions), in addition to the lower Manning roughness co-efficient for concrete boxes (0.15) compared to corrugated metal sheets co-efficient (0.32) makes the box sections a better candidate for lengthy stream-passing cases. Also, for cases where the bridge section does not control the flow calculations, box bridges require a smaller area to pass a certain discharge making it better for sites with a tight topography

Site Topography

The construction site topography controls the geometrical properties of the selected bridge. This includes bridge span, height, and depth of backfill. Standard box sections introduced by KDOT, and short span metal arches by Contech, have a similar span range. However, they have different abilities to match the total depth of construction site. This is attributed to the mandatory existence of a minimum depth of earth-fill above the arched sections compared to no earth-fill for boxes. Figure 2 introduces the minimum and maximum limits of bridge height versus span for both types of sections. The arch sections can not be used for short span bridge construction in shallow construction sites. A minimum of 10 ft height should be available to construct an arch bridge with a span less than 32 ft. Greater spans ranging from 32 to 48 ft require a 20 ft minimum depth for construction of arch bridges. These heights versus span values are compared to 3 and 6 ft heights respectively for standard box sections

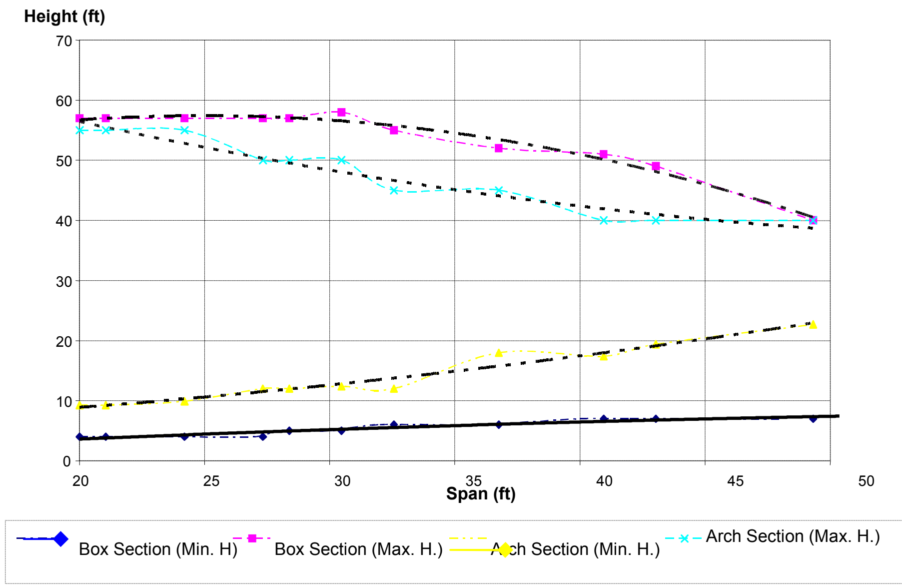


Figure 2 - Comparison of Minimum and Maximum Heights Required for Both Bridge Systems

Cost of Construction

The cost of construction for both bridge types includes both direct and indirect costs. However, for comparison, the cost of constructing the box barrel will be compared to the metal arch and strap footing cost. It should be noted that the strap footing is a requirement for metal arches, as box sections rest on the ground through the bottom slab of the barrel. As a rule of thumb, the cost of construction for concrete box unit area (measured perpendicular to the stream flow direction) varies directly with the depth of backfill, and indirectly with the bridge height. The cost comparison study of both bridge systems were accomplished by calculating the area for passing a certain amount of stream discharge. Both systems are selected, and the price is calculated for the concrete barrel versus the metal arch and its strap footing (RSMEANS 2004). Strap footing price is highly related to the soil bearing capacity as it is the sole factor defining the size of the footing, hence its cost of construction. Box sections are the main system for sites with a factored bearing capacity of 1000 psf or less due to the drastic increase in the footings construction costs for Arch systems. Pricing of both systems for a soil bearing capacity of 1500 psf is shown in Figure 3.

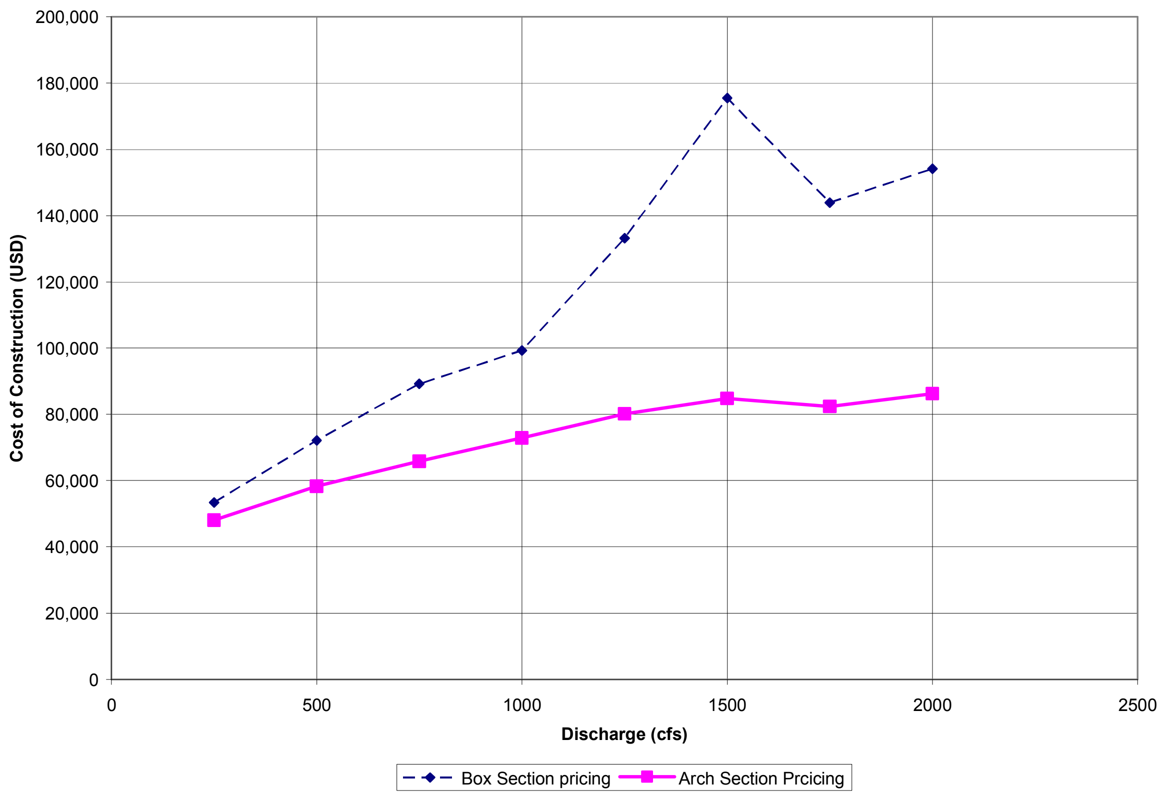
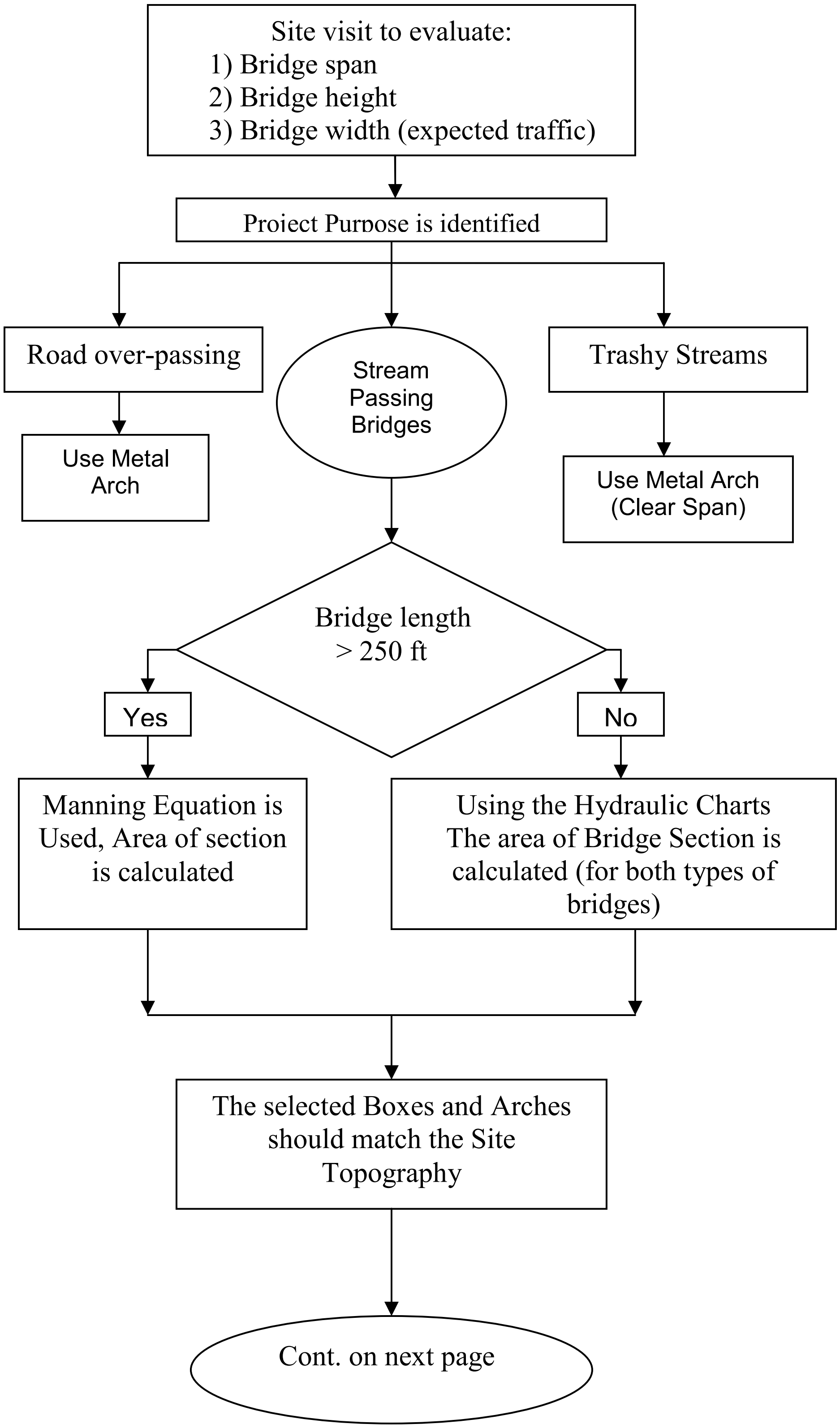


Figure 3: Cost of Construction for Both Bridge Alternatives (Adopting Similar Discharge)

Environmental Conditions

California Transportation Department (CALTRANS) conducted a long term research project for measuring the accumulation of debris and trash within a bridge opening (CALTRANS). A short span bridge with 2 openings, each of 10 ft span and 8 ft height were considered. The amount of accumulated debris was 5 ft high and extended for 100 ft at the upstream side and 300 ft at the downstream side of the considered bridge. This reduced the bridge opening hydraulic efficiency by two third of its original value. Minimum bid for clearing the debris was 123,423 USD which is slightly less than the cost of removing the bridge and constructing a new one-opening short span bridge. The result favors the construction of a one opening bridge when it is required to cross a trashy stream. The impact of the environmental condition is depicted on the following decision-making flow-chart.


Site visit to evaluate:
1) Bridge span
2) Bridge height
3) Bridge width (expected traffic)
Project Purpose is identified
Road over-passing
Stream Passing Bridges
Trashy Streams
Use Metal Arch
Use Metal Arch (Clear Span)
Bridge length > 250 ft
Yes
No
Manning Equation is Used, Area of section is calculated
Using the Hydraulic Charts The area of Bridge Section is calculated (for both types of bridges)
The selected Boxes and Arches should match the Site Topography
Cont. on next page

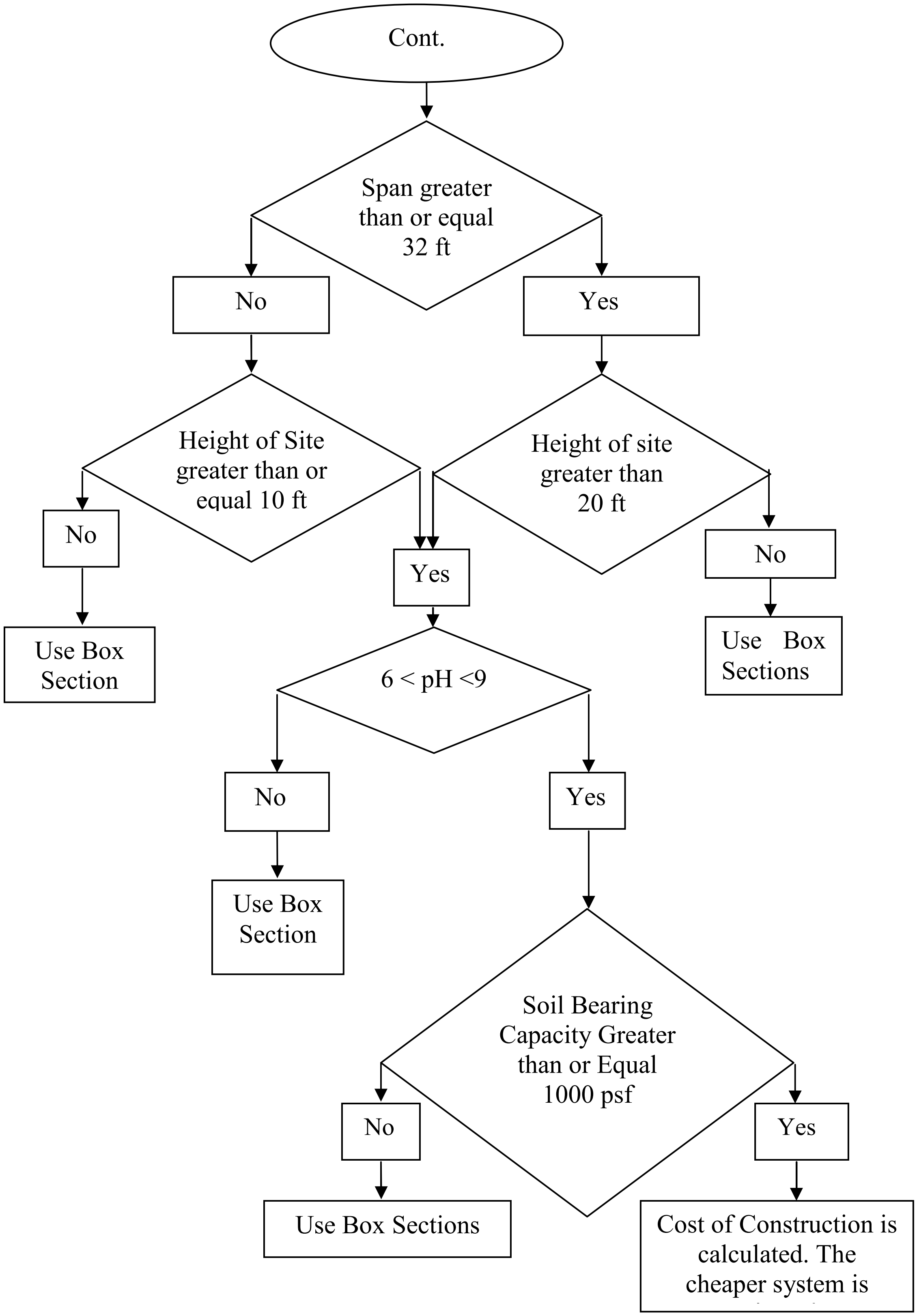


Figure 4: Sequential process of Bridge System Selection

CONCLUSION

The majority of bridges within the State of Kansas, and across the United States of America are short-span bridges, with a great percentage as stream-crossing bridges. Two major system of construction used for these cases are, short span concrete boxes, and clear span metal arches. The study conducted on the feasibility of using these sections within the State of Kansas showed that metal arches represent a cheaper alternative for sites with a high soil bearing capacity, if other factors such as topology and stream quality do not eliminate this option. They are also the better option for construction of bridges crossing trashy stream, where the clear-span arch has a better ability to adopt the discharge without detention of debris and trashy material. Metal-arch single-span bridges are also a better option from the hydraulic and marine life point of view on the long run. However, a demanded higher hydraulic efficiency, a tight topographical condition, and a low soil bearing capacity, limits the usage of metal-arch bridges and favors the usage of the KDOT concrete boxes as a common practice for construction of short span bridges in the State of Kansas. Due to the absence of strict guidelines and standards for selection of the better alternative from the available options, the flowchart introduced in Figure 4 can serve as a guide for selection process.

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