Preliminary analysis and hanger adjustment of tied arch bridges
by William Edward Beyer

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Engineering Mechanics
Montana State University

Abstract:
Preliminary design of a tied arch bridge is complex due to the many possible parameters of the problem. After obtaining a design the minimization of dead load moment is an important consideration. Similarly, obtaining proper tensions in the hangers of a tied arch bridge is very important, to prevent overstressing of the arch.

By using matrix structural analysis, the effects of certain parameters upon tied arch behavior are investigated. The parameters include rise to span ratio, hanger spacing, ratio of areas of rib and tie, and ratio of moments of inertia of rib and tie. The geometry of an existing span was used for analysis.

The results of the parametric study are portrayed graphically for a range of the parameters. Methods for analysis of dead load moment and hanger tension adjustment are developed. Finally a preliminary design example is considered.

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APPROVAL

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William Edward Beyer

This thesis has been read by each member of the thesis committee and has been found to be satisfactory regarding content, English usage, format, citations, bibliographic style, and consistency, and is ready for submission to the College of Graduate Studies.

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ABSTRACT

Preliminary design of a tied arch bridge is complex due to the many possible parameters of the problem. After obtaining a design the minimization of dead load moment is an important consideration. Similarly, obtaining proper tensions in the hangers of a tied arch bridge is very important, to prevent overstressing of the arch.

By using matrix structural analysis, the effects of certain parameters upon tied arch behavior are investigated. The parameters include rise to span ratio, hanger spacing, ratio of areas of rib and tie, and ratio of moments of inertia of rib and tie. The geometry of an existing span was used for analysis.

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CHAPTER I

INTRODUCTION

Description

Tied arch bridges are distinguished from other forms of arch bridges by the presence of a tie chord. Figure 1 shows a typical profile of a tied arch bridge and gives the nomenclature of the parts of the structure. Tied arch behavior is similar to that of a self-anchored suspension bridge. In both cases the effects of live load structural distortion are practically eliminated. The tie girder carries the thrust of the arch rib. Hence, tied arches are ideally suited for sites where foundation conditions will not permit an economical substructure, which could carry the thrust of a conventional arch. Tied arches are also used where moderate span lengths are required with a maximum clearance.

History

The history of the tied or bowstring arch in America can be traced back to Trees' and King's truss, [3]. Trees' and King's truss consisted of tubular iron arches, with a tie beam attached to each end of the arch which supported the roadway. The patent on Trees' and King's truss expired Oct. 1, 1878. Some of the trusses designed by Squire Whipple in the mid-nineteenth century also possessed some

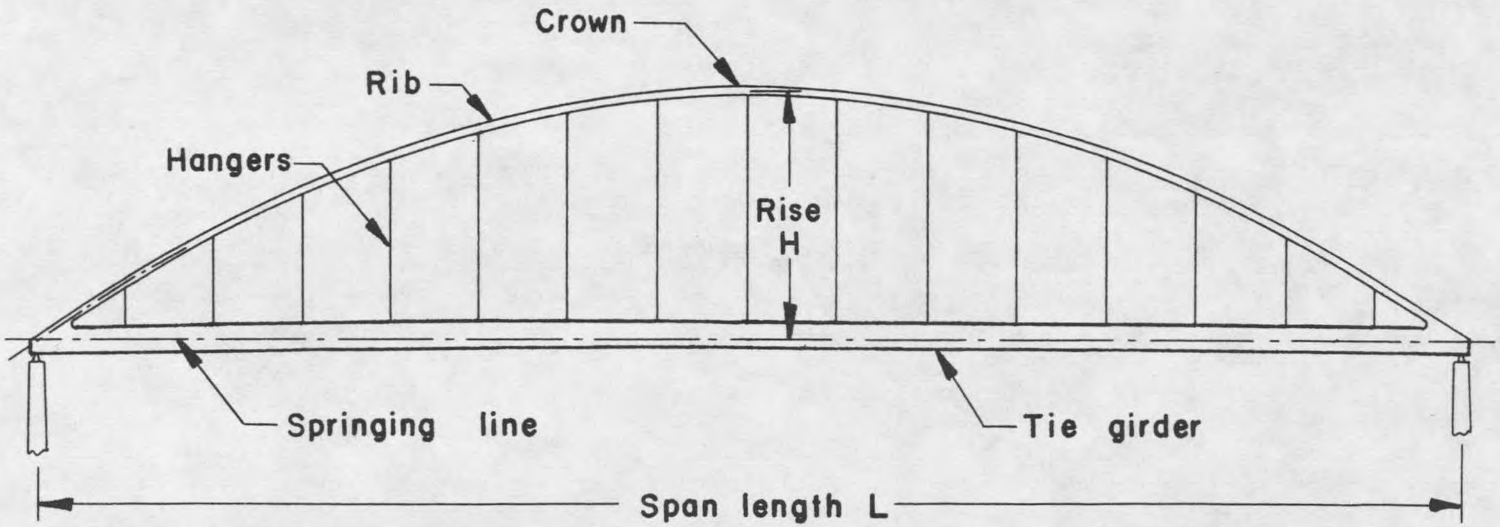

Figure 1. Tied arch bridge nomenclature.

of the features of tied arch construction. The tied arch was also being widely used in the mid-nineteenth century in Europe. The first bowstring arch was at Lugao in Hungary, designed by Hoffman and Medersbach in 1833, [48]. Austrian engineer Joseph Langer designed a truss-tied arch in 1859, [61].

Originally tied arch bridges such as the Tacony-Palmyra [55] or the West End [57] were designed with deep ribs, to carry the majority of the live load moment. In 1941, J. M. Garrelts revolutionized the design of tied arch bridges in America, with the design of the St. Georges Bridge. In the St. Georges Bridge the tie was made about 13 times as stiff as the rib, and therefore carried the majority of the live load moment, [7, 36].

Virtually all tied arch spans constructed today utilize the stiff tie and slender rib concept. In addition to superior aesthetics Garrelts gave the following advantages for this type of tied arch, [7]:

1. The erection will generally require less falsework because the tie girders will support erection equipment over longer spans.

2. The demands on erection equipment are reduced by reason of the fact that the heaviest members are lifted only to the level of the deck rather than to the top of the span. This may in some designs eliminate the necessity of special creeper travelers moving along the rib and permit the use of more common equipment operating from the deck.

3. Although no direct comparison in weight has been made as yet, it can be pointed out that some economy may result from the shorter length of the heavy tie as compared to the longer length of a heavy rib. This saving is partly offset by heavier splices.

4. Since the tie girder will always have little, if any, compression, the ends of the members at splice points need

not be milled. All milling of the splices in the curved rib is therefore confined to lighter, smaller members.

5. The connections at the ends of the span appear to be simplified when the deep girders are horizontal or nearly so, and the transfer of the vertical shear into the shoes is readily accomplished by detail parts that are easier to fabricate. The erection in this panel is much less difficult because a milled splice for the first rib member can generally be located above the tie girder so that the first section of the rib can be erected after the girder has been placed on the shoe and the first hanger erected. No temporary support for a heavy, inclined section of rib is required.

Figure 2 shows a sketch of a typical modern steel tied arch bridge, utilizing a stiff tie and slender rib.

In the 1950's design of tied arches underwent further refinements and improvements. The advent of high strength steels made tied arches competitive economically for much longer spans and heavier loads. Additionally the development of the digital computer led to a much better understanding of tied arch behavior. The Fort Pitt Bridge and Fort Duquesne Bridge in Pittsburgh are two notable double deck tied arch structures constructed in 1957, and 1960 respectively, [63, 65].

By using an orthotropic deck, the dead load of a bridge can be greatly reduced. Two notable tied arch bridges utilizing orthotropic decks are the Port Mann Bridge in 1963, [11, 15, 41], and the award winning Fremont Bridge in 1973, [14]. The Fremont Bridge is the longest tied arch bridge in history with a 1200 foot main span.

Today the science of tied arch bridges is still expanding. In other countries inclined hangers (Nielsen System) are being used [10, 24, 34, 35]. In some cases the entire deck is being used to act as

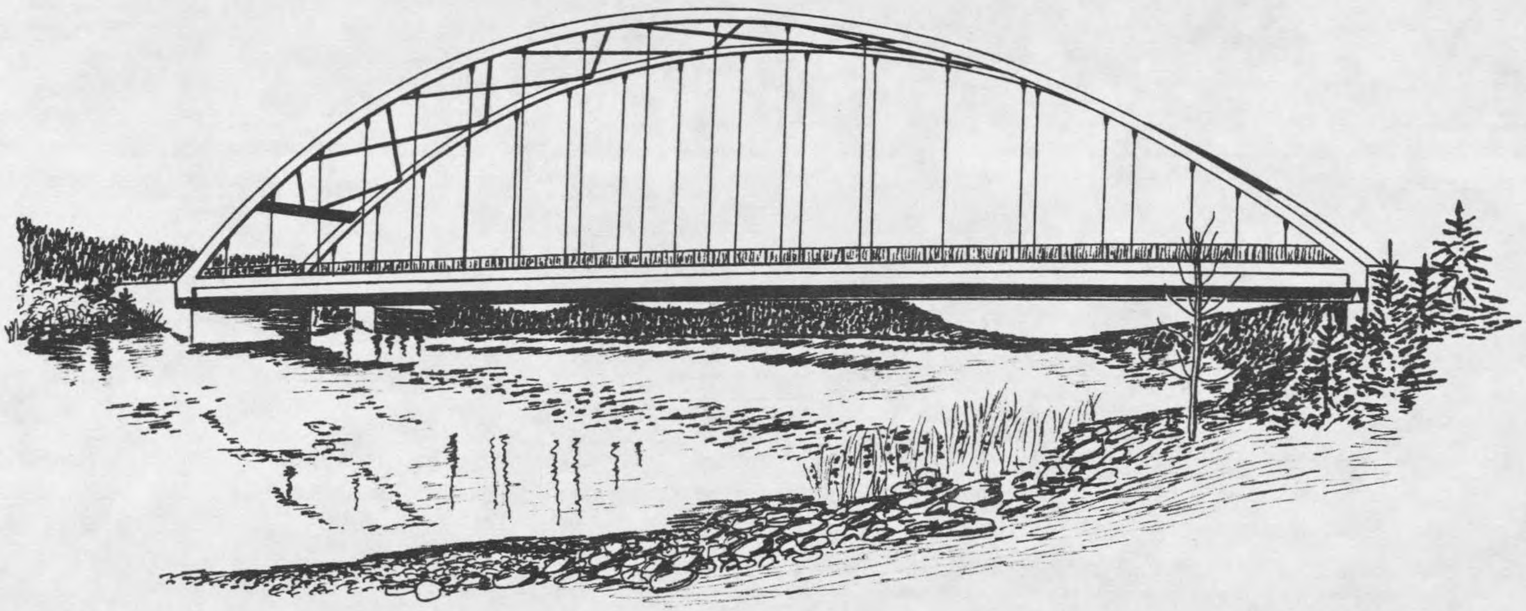

Figure 2. Typical modern steel tied arch bridge.

the tie [48]. For increased stability inclined tied arches are being tried [20, 22, 29]. The use of prestressed concrete for the ribs and for the deck is being investigated [29, 54]. These are all topics which would be of interest for further research and are beyond the scope of this thesis.

CHAPTER II

MINIMIZATION OF DEAD LOAD MOMENTS IN A TIED ARCH

The principle of moment minimization

One of the advantages in the use of an arch is having the ability to eliminate practically all of the dead load moments. To accomplish this the arch axis should be shaped to match the dead load funicular polygon or moment diagram. The moment diagram should be that of an equivalent simply supported beam carrying the dead load of the rib, tie, and the loads of the floor system and upper lateral bracing. If the arch axis is made up of straight members rather than curved members, it is only possible to minimize dead load moments but not totally eliminate them. This is due to the local bending effects between hangers caused by the self weight of the members. Additionally the lengths of the arch members must be fabricated to eliminate dead load deformations.

Application of the principle to a frame example

Figure 3 shows an example of a simple beam loaded with a third point loading and the corresponding moment diagram.

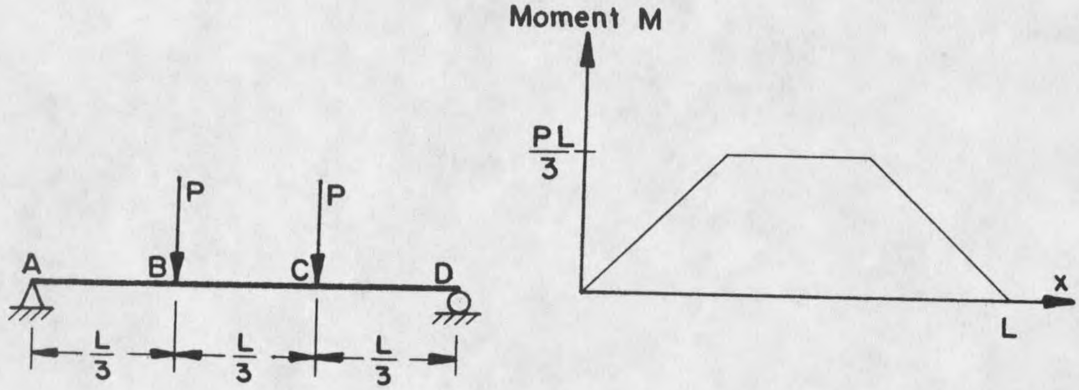

Figure 3. Simply supported beam and corresponding moment diagram.

By reshaping the beam of Figure 3 into a frame corresponding to the moment diagram it can be seen from Figure 4 that the loads P are now being carried primarily axially. There will be secondary moments induced into the frame due to the deformation of the frame.

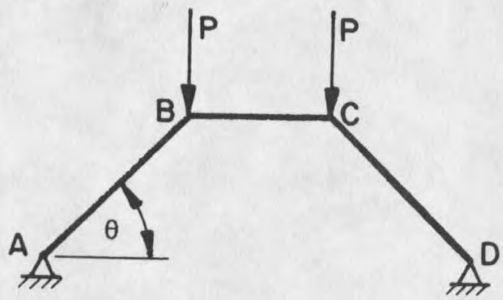

Figure 4. Shaping beam to match funicular polygon.

Also from Figure 4 it can be seen that as the angle θ decreases the axial load in each member increases. Therefore, for an arch, as the rise to span ratio decreases the axial forces in the rib and tie will increase. Basic tied arch action is accomplished by replacing the rocker at point D of Figure 4 with a roller and adding a tie member AD as shown in Figure 5.

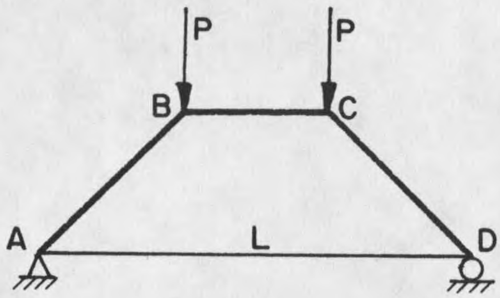

Figure 5. Basic tied arch action.

Under dead load action the arch axis will shorten due to the axial thrust. This effect is called rib shortening. Similarly tie lengthening and hanger stretching will occur due to axial tension. These effects cause secondary moments in the rib and tie which can become quite large. The moments due to rib shortening and tie lengthening can be minimized by fabricating the arch rib longer by a certain amount, and by fabricating the tie shorter by a certain amount. Hangers which are not adjustable also would need to be fabricated shorter by certain amounts. In effect what this does is camber the arch equal and opposite to the deflections induced by the dead load [14], as shown in Figure 6.