AESTHETIC AND ENGINEERING ANALYSIS
OF ALOUETTE RIVER CROSSING

by

VLADIMIR PASICNYK, P.Eng.

For. Eng., Czech Technical University

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Vladimir Pasicnyk

Faculty of Forestry

The University of British Columbia
Vancouver, B.C.

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ABSTRACT

This thesis deals with bridge design as an important part of road design and layout. Bridges frequently dominate roads and railways, and are, in many cases, a prominent feature of the landscape. Discriminating selection of the type of bridge and material to be used, having regard to technical and aesthetic requirements, is therefore essential. Road construction and bridge design are both applied arts in landscaping, and should be considered as such throughout the planning sequence.

Since the main thrust of this thesis is directed toward the aesthetic and engineering aspects, no attempt has been made to include overall economic analyses or details of construction; however, to indicate the basic nature of the engineering principles and to demonstrate appropriate dimensions of bridge components, calculations and sketches of a few bridges are included.

Various types of bridges are evaluated and discussed in terms of their accordance with modern environmental requirements. The design of the new bridge across the Alouette River at the U.B.C. Research Forest is taken as a particular case study, the analyses of this crossing showing that thoughtful selection of both bridge and location can not only enhance the landscape, but also improve route conditions. Engineers should blend their talents with nature so as to create a harmonious landscape.

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Chapter I

INTRODUCTION

1.1 Method of study of the forest bridge across Alouette River

The chronological sequence of the study is as follows:

(a) The collection of information containing the present situational requirements and the conditions governing future improvement;

(b) Field work - detailed stadia survey of the present location including elevations of the road and bridge, and photographing the site in relation to surrounding landscape;

(c) Office work on the detailed plan of the bridge site and approaches;

(d) The determination and plotting of the selected bridge site and the location of the approaches in plan and profile, with horizontal and vertical alignment;

(e) Evaluation of the landscape type and environment of the bridge site;

(f) Selection of different types of bridges most suitable to the engineering requirements and the environment;

(g) Selection of types of material most suitable to the environment and to the bridge type;

(h) The locating of bank abutments and intermediate supports according to the considered material, environmental requirements, and overall appearance of the bridge;

(i) Engineering calculations of the dimensions of the main parts of the selected types of bridges in accordance with CSA-S6 Design of Highway Bridges[1];

(j) Bill of materials for the main elements of the selected types of bridges;

(d) Evaluation of the analyzed types of bridges from the aesthetic point of view, giving consideration to economics and the final recommendation of the most suitable type.

[1] Canadian Standards Association, Design of Highway Bridges, CSA Standard S6-1966, May 1966 (Ottawa, Canada: Canadian Standards Association, 1966).

1.2 Introduction to Aesthetics

Basic aesthetic feeling is natural to everyone who observes an object or landscape. Knowledge and education, however, elevate this natural aesthetic feeling through comprehension (of the aesthetics) and experience extends this still further. Newby[2] summarized Munro's[3] explanation of aesthetics very clearly by saying:

> "If we express visual perception of a landscape as an aesthetic experience, it could take this general equation form suggested by Thomas Munro (11): AE = PO + CP + EC. The aesthetic experience (AE) thus is the sum of relationships between the perceived object or landscape (PO), the characteristics of the perceiver (CP), and the environmental conditions or circumstances (EC) at the time of exposure. The perceived object or landscape includes existing, suggested and anticipated qualities, cultural and historical meanings, and formal arrangements in spatial, temporal, causal, and other modes of organization. The characteristics of the perceiver involve stable, permanent, or slowly changing traits such as sex, physique, intelligence, personality, stage of maturation, special aptitudes, familial background, and education; also involved are transitory, rapidly changing traits such as mood, interest, exposure to social trends or fads, and the activity of the moment. Finally the environmental conditions or circumstances surrounding the interaction include such things as physical location, presence of other people, other perceptual stimuli, and the physical and cultural environment."

[2] F.L. Newby, Man-Nature-Beauty: A research dilemma. Paper. Vol. VI, Section 26, XIV IUFRO-Kongress, Munchen, Germany, 1967. p. 452.

[3] T. Munro, Toward science in aesthetics. (New York, N.Y.: The Liberal Art Press, 1956). p. 27.

1.3 Elements of Aesthetics

Basic elements of analysis have been set in order to facilitate evaluation of aesthetics and as a result, improve landscape management[4]. They have been grouped into:

1.3.1 Basic Concepts

1.3.2 Dominance Elements

1.3.3 Dominance Principles

1.3.4 Variable Factors

1.3.1 Basic Concepts

Basic concepts deal with characteristic landscape, divided for simplification into subgroups of landscape forms, according to the governing dominant elements.

Basic concepts also include variety, which deals with object-rich landscapes and serves as a significant guideline in determining how much variety is desirable in landscape. Deviations from characteristics landscape, which are also included in basic concepts, are caused by the provision of necessary resources for a nation's economy.

1.3.2 Dominance Elements

Dominance elements include form, line, colour and texture. Although all of them are usually present, each one exerts a differing degree of visual power or dominancy.

[4] U.S. Department of Agriculture, National Forest Landscape Management, Feb. 1973, Vol. I (Washington, D.C.: Government Printing Office, 1973). p. 2 - 13.

1.3.2.1 Form

The mass of an object, or of a combination of objects, that appears unified is defined as "form". In two dimensional pictures it is called "shape" but since most landscape objects are three dimensional, the term "form" is more often used.

1.3.2.2 Line

Since a line is a point that has been extended, it can be anything that is arranged in a row or a sequence. A line can be considered separately or it can make up the silhouette of a form. It can also be the intersection of two planes. All these may be found in shorelines, timberlines, avalanche paths, vegetative boundaries, etc.

1.3.2.3 Colour

Even when the objects have identical form, line and texture, colour enables us to differentiate between them. This colour dominance often depends on the position of the observer. Dust and moisture cause distant colours to become muted by a bluish haze, while foreground colours remain strong and dominant.

1.3.2.4 Texture

Distance varies the dominancy of texture. (For example, leaf patterns are dominant when viewing a tree from a distance of a few feet, however, major branches become dominant at a few hundred feet, while entire groups of trees are the dominant texture at a distance of a few miles.)

1.3.3 Dominance Principles

The visual dominancy of form, line, colour and texture are affected by six basic principles, which are: contrast, sequence, axis, convergence, co-dominance and enframement.

Great contrasts are immediately apparent to all observers, while contrasts with little or no visual effect, simply cannot be seen. At times, creating sharp contrasts in the natural environment can be beneficial, but then the object in question must be so well introduced that it can stand up to the close scrutiny which its prominence will demand. The question of contrast is probably the most significant in bridge design, and blending should take precedence over contrast in cases where only a mediocre contrast can be achieved or where contrast is undesirable.

1.3.4 Variable Factors

Dominance elements are also affected by variable factors which can be considered as more or less subjective. They include: motion, light, atmospheric conditions, season, distance, observer's position, scale and time. They help to identify the most critical location or time at which to judge the potential visual impact, under the most severe and sensitive conditions possible.

1.4 Structural Aesthetics

Bridge design is closely allied to architecture and should, therefore, be considered an applied art. An adequate type of design should be selected for each bridge, no matter what purpose it is to serve. Temporary bridges, explicitly designed to serve for a short time, should be considered exceptions. However, even this might be questionable; temporary bridges may serve for long periods of time even after their primary function is over, usually for recreational purposes like hiking, hunting, etc.

Le Corbusier, architect and painter, in his book "Towards a New Architecture"[5], defines engineering aesthetics and beauty by saying that an engineer applies economic laws, and calculations to achieve and create harmony, when he works in accordance with these laws. Calculations, which come from natural laws, provide the tools with which the engineer creates the resulting architecture and in turn, communicates with the observer through harmony. He separates construction from artistic work by saying: "We use stone, wood, concrete, we build houses and palaces, that all is a question of construction. We emphasize the work. This all has a big influence on me, I feel happy and (I) say: It is beautiful. Here we have a construction art."

To summarize Le Corbusier's expressions, we can say that the beauty of an engineering structure lies in its harmony, its balance.

[5] Le Corbusier, Vers Une Architecture ("Towards a New Architecture"), (Paris: Vincent, Freal & Cie., 1958). p. 80.

The balance then has to be considered within the structure itself, and with the surrounding landscape.

It should be pointed out that criticism of each art, even applied art, is very subjective. It is difficult to satisfy everybody. There are, however, generally accepted basic principles, which if followed, can provide visual appreciation.

It seems that selecting an acceptable architectural type of bridge in cities is simpler than in the country (Figures 1 and 2), the main reason being that the type of bridge in cities is actually dictated by the surrounding architecture - or intended architecture - while the solution for rural locations is usually more complex. A sketch study, or plotting the designed bridge onto photographs, immediately shows any discord with the environment. Selection of a proper bridge type outside the cities requires more consideration, depending more on the type of road or highway and the general landscape.

(a) In most cases, since bridges are the most expensive part of the road, the bridge site is naturally prevalent over the road location.

(b) The function of the bridge and the type of transportation it has to serve, dictate its technical requirements - size and dimensions.

(c) Recently, the idea of multipurpose roads has been extensively stressed so the scenic values and the ancillary features; i.e. sidewalks, parking areas and so on, have to be considered also.

(d) The bridge structure, material, proportions, etc., must follow some basic principles of aesthetic design in order to please not only those who use the bridge but also those who look at it.

Figure 1 - Old bridge in Florence, Italy.

Figure 2 - Bridge in a natural setting.
- Japanese Garden.

A very unique and complex analysis of bridge aesthetics has been done by Pacholik[6]. Although his analysis deals mostly with bridges in European cities, some comments about the out-of-city and American bridges are included. The principles of some of his ideas are discussed in this paper under analysis of bridge aesthetics, and its practical applicability is used in the Alouette River Crossing study.

6 L. Pacholik, Estetika Mostnich Staveb ("Aesthetics of Bridge Structures") (Prague: Ustav pro Ucebne Pomucky Prumyslovych a Odbornych Skol v Praze, 1946). p. 26 - 84.

Chapter II

ANALYSIS OF BRIDGE AESTHETICS

Aesthetics deals with harmony, and harmony deals with balance. In general, large bridges have been used in analyzing structural aesthetics, since these examples and arguments are more readily understood. However, the same principles apply to small bridges on multipurpose roads, where very few large spans are expected. Obviously, the effect of observation will depend on observing distance.

Each bridge has four elements which have to be designed in a certain sequence of importance[1].

2.1 Roadway and guardrails

2.2 Supporting structure

2.3 Piers and abutments

2.4 Bridge heads

Each higher element is dominant to the others which are below. Changing the sequence of importance, i.e. if a higher element is suppressed by a lesser one, this causes the natural balance of the structure to be aesthetically destroyed and the beauty to be lost.

This division is logical, since it is based on functional sequence, i.e. roadway is most important because it has the main

[1] L. Pacholik, Estetika Mostnich Staveb ("Aesthetics of Bridge Structures") (Prague: Ustav pro Ucebne Pomucky Prumyslovych a Odbornych Skol v Praze, 1946). p. 65.

function, while the supporting structure holds second place because it allows the roadway to be carried over the obstruction and so on.

In Canada, bridges are not usually divided into groups according to the position of the roadway and supporting structure. Since the evaluation has been made for that positioning, Figures 3, 4 and 5 clarify the nomenclature used in the text of this paper.

2.1 Roadway and guardrail

2.1.1 Roadway

The purpose of the bridge is to transfer the route and the traffic safely over an obstruction (river, deep valley, another road).

It is difficult to express the roadway itself artistically. However, it has to be emphasized as much as possible by a continuous line and a properly selected guardrail. The emphasis on the roadway appearance is extremely important because of its main function. The lack of continuity creates an unbalanced-looking structure. Continuity of roadway applies mainly to the side view (Figure 6) and to the three dimensional view (Figure 7). In the perspective view, especially, the continuity with the road line or highway is directly involved.

Sometimes emphasis of the road is neglected, especially in the case of concrete beam or arch bridges, steel trusses or some wooden structures. A common failing is usually the lack of definition of the structural parts, resulting in a uniformity from the lower edge of the supporting structure up to the upper edge of the guardrails (Figure 8). Another common pitfall, is visually breaking the roadway and an otherwise well-designed guardrail by extending the piers up to the top of the

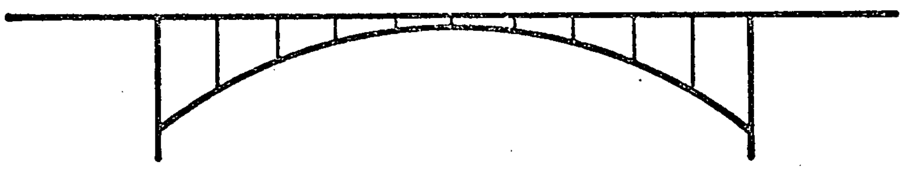


Figure 3 - Roadway-above.

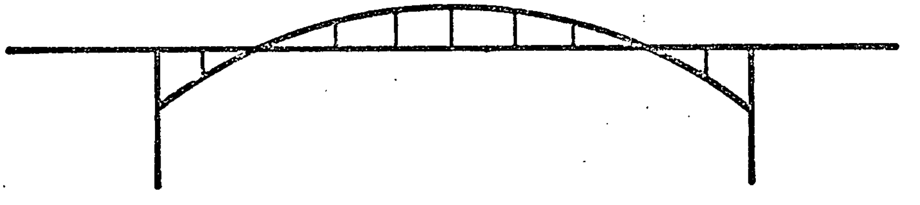


Figure 4 - Half-sunk roadway.

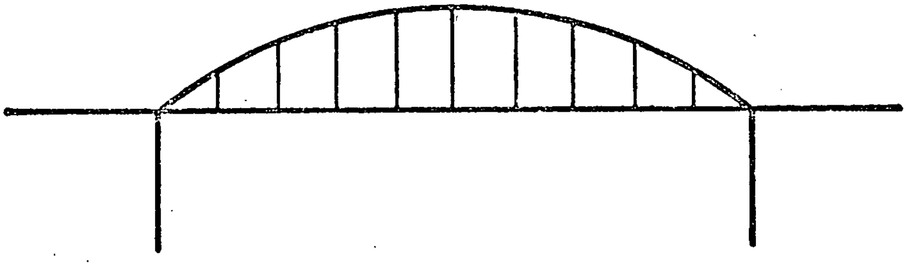


Figure 5 - Roadway-below.

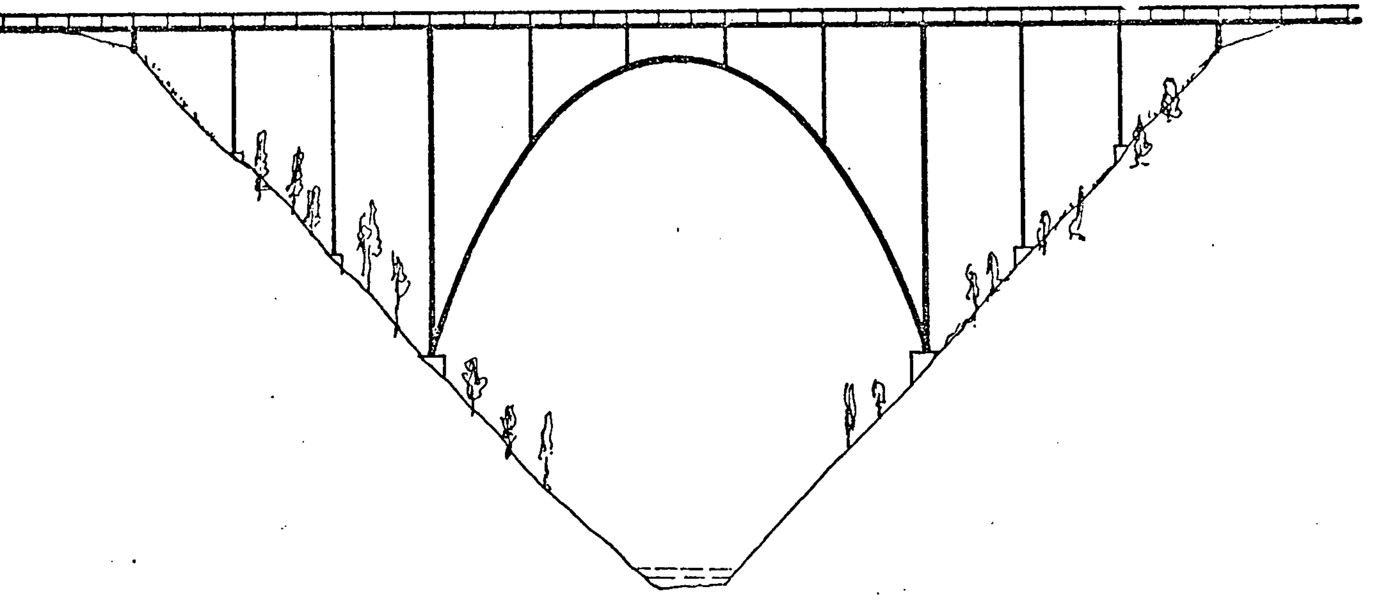


Figure 6 - Side view of the bridge (shape).

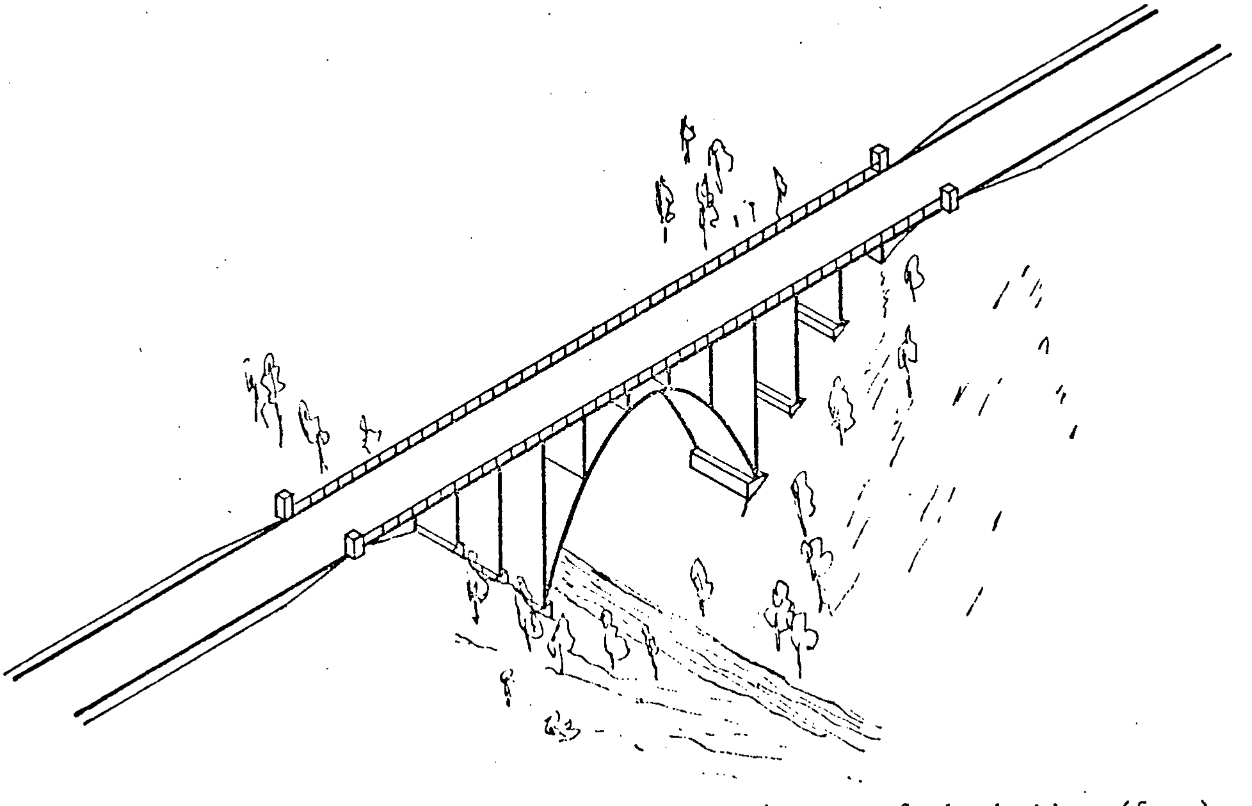


Figure 7 - Three dimensional (perspective) view of the bridge (form).

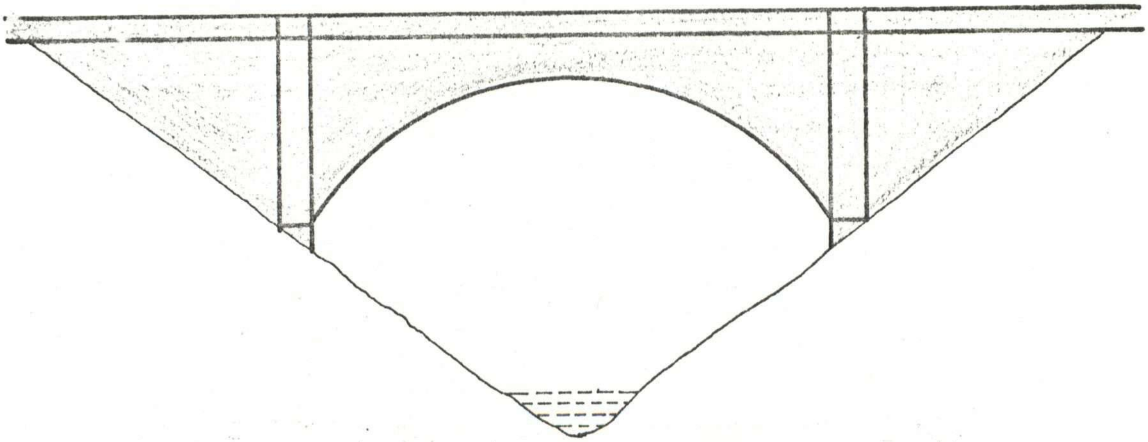


Figure 8 - Full concrete arch and guardrail.

Figure 9 - Railway bridge with extended piers.

guardrail or higher (Figure 9). This serves mainly to anchor the guardrail in the piers but statically this is not necessary.

Other types of visually suppressed roadways occur when the supporting structure intersects the roadway. This type of detraction can be found, of course, with all types of half sunk roadway bridges and can be clearly defined by watching the upper and lower outline (contours) of the bridge. The impression then obtained is of two separate structures (Figures 10 and 11).

As far as the other two types of roadway are concerned (roadway-above and roadway-below), there are basically no problems with roadway aesthetics. Selection of the preferable supporting structure, therefore, depends almost entirely on the landscape (see later). There is one more effect which should be mentioned here and that is the effect of guardrails. Since the guardrail is an efficient tool for underlining the functional importance of the roadway, it can be used more effectively on roadway-above bridges than on roadway-below bridges.

The inside view of the bridge has not been considered very often and yet it has been found that some types of roadway-below bridges, especially steel closed frame structures, have a depressive influence on driving or walking persons (Figure 12). Psychologically, it is quite natural for people to prefer an unobstructed view and an open air feeling than to walk or drive in an iron box. The latter feeling is similar to one which people have while driving in a tunnel.

It should be kept in mind that the psychological effect is slightly different with reinforced concrete bridges since there is a

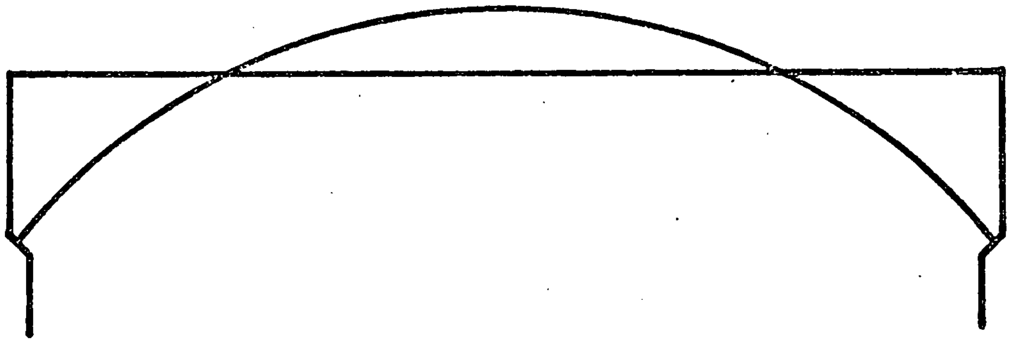


Figure 10 - General view of a bridge with half-sunk roadway.

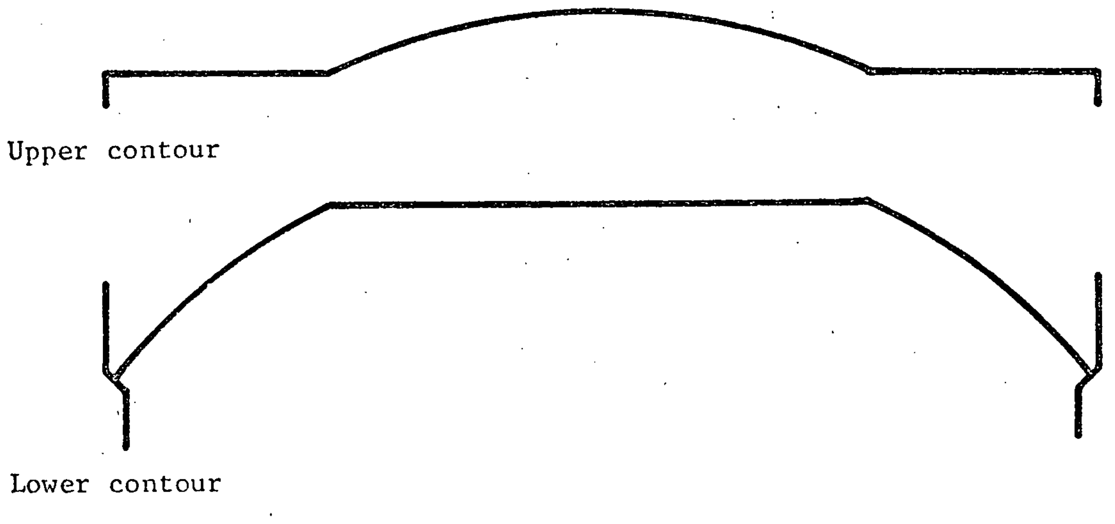


Figure 11 - Upper and lower view of a bridge with a half-sunk roadway.

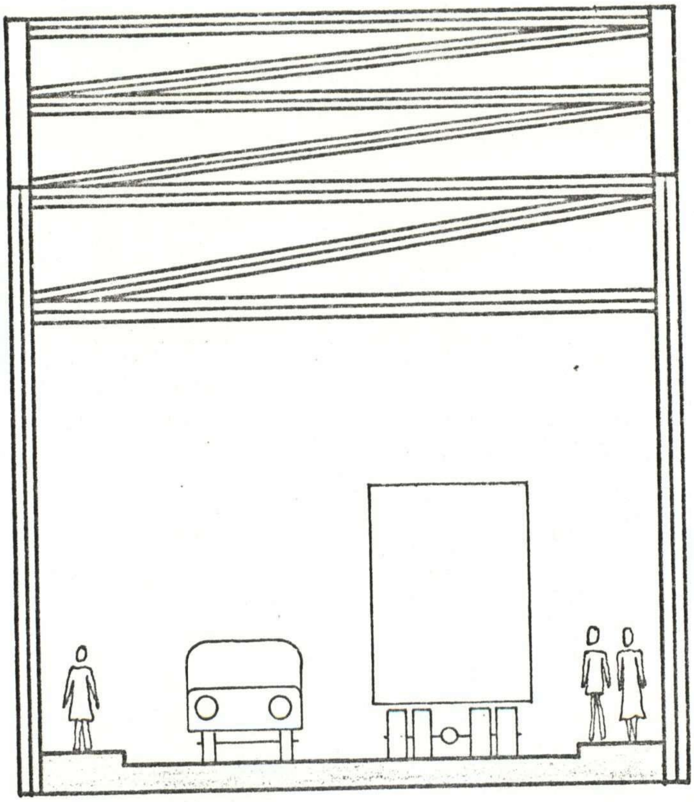


Figure 12 - Inside view of bridge with sidewalks within the structure.

Figure 13 - Sidewalks outside the main structure.

different arrangement of diagonals and wind bracing. A substitute arrangement can be found for steel or wood closed frame structure by locating the sidewalks outside the main supporting structure (Figure 13). This is also safer for the pedestrian.

The profile of the roadway should also be considered along with the inside view. Preferably, the profile should be straight; either horizontal or slightly sloped to one end. Slight sloping to both ends of the bridge is acceptable, but steep sloping should be avoided, as there is limited visibility from one end of the bridge to the other and a sudden appearance of on-coming traffic can be unpleasant.

Last, but not least in the inside view analysis, is the width of the roadway. The wider the roadway the better. The width of the road, of course, is largely dependent upon the number of lanes leading from the road or highway. Long and very expensive structures are sometimes narrower, since the maximum capacity for a given speed on the bridge is precalculated for unbroken traffic (Lions Gate Bridge, Vancouver, B.C., Figure 19). These types of structure may appear to be out of proportion (in width, height and length), and also in overall appearance. However, it would be an expensive proposition to keep proportionality for such structures.

Particularly in roadway emphasis, where the question of proportions arises, the suspension bridge seems to be a convenient structure (Figure 19).

Sometimes a change from the roadway-above to the roadway-below arrangement (Figure 14, 15) and back again is necessary because of the increment in overhead clearance. Such a change can readily

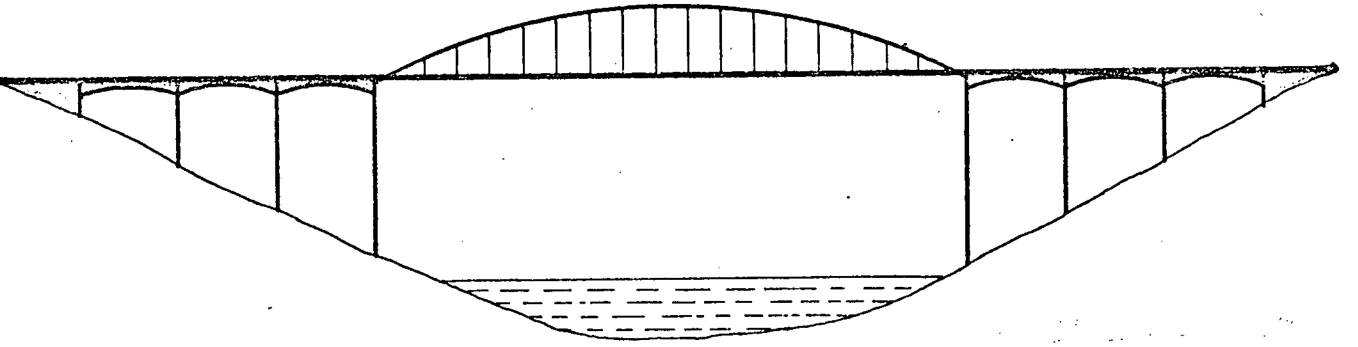


Figure 14 - Change of the position of the roadway.

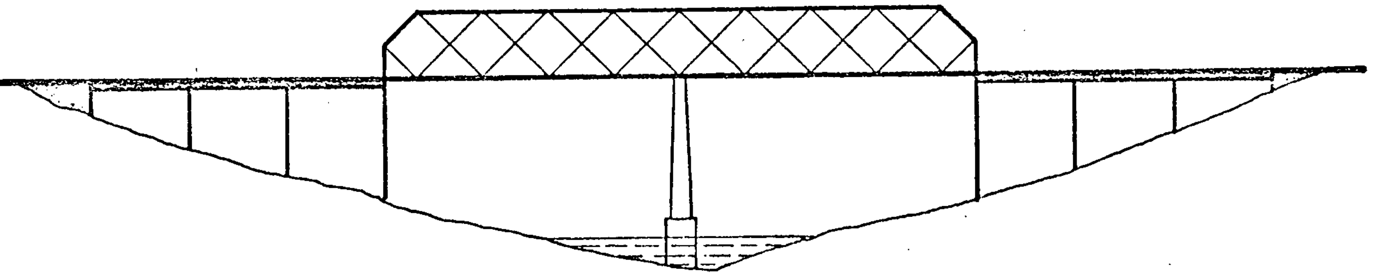


Figure 15 - Alternative solution of changing position of roadway.

affect the aesthetic appearance and there are very limited means of solving this problem from the aesthetic point of view. One of the few possibilities is to set one or more long and dominant spans across the river with the roadway-below arrangement, while maintaining short spans on banks with the roadway-above. Since short spans give the impression of extended abutments, the functional appearance of the bridge is in harmony with the approaches (Figures 14, 15). This solution might seem a bit clumsy but it fully corresponds with the theory of unbroken roadway line. Of course, some flexibility in this solution is to be expected, since different circumstances (e.g. landscape) might bring out different impressions about the same type of construction.

2.1.2 Guardrail

As mentioned before, the guardrail is an important constructive and aesthetic accessory of the roadway because it helps to emphasize the functional appearance of the roadway, especially with the roadway-above bridges. Since the function of the guardrail is also to direct traffic visually, the construction should be light in comparison to the supporting structure and the roadway.

There are many ways of using guardrails properly. The most efficient is the unbroken handrail line (of the guardrail), parallel to the roadway. Figures 9 and 17 do not follow this rule and demonstrate the effect of a broken guardrail (which should be avoided). A full concrete guardrail never looks light (Figure 8) and, therefore, should be articulated in some other way (Figures 16 and 18). The use of different material and/or colours is also very effective.

Figure 16 - Light looking guardrail.

Figure 17 - Interference of the roadway and the guardrail by extended piers.

Figure 18 - Proper solution for the unbroken roadway and guardrail.

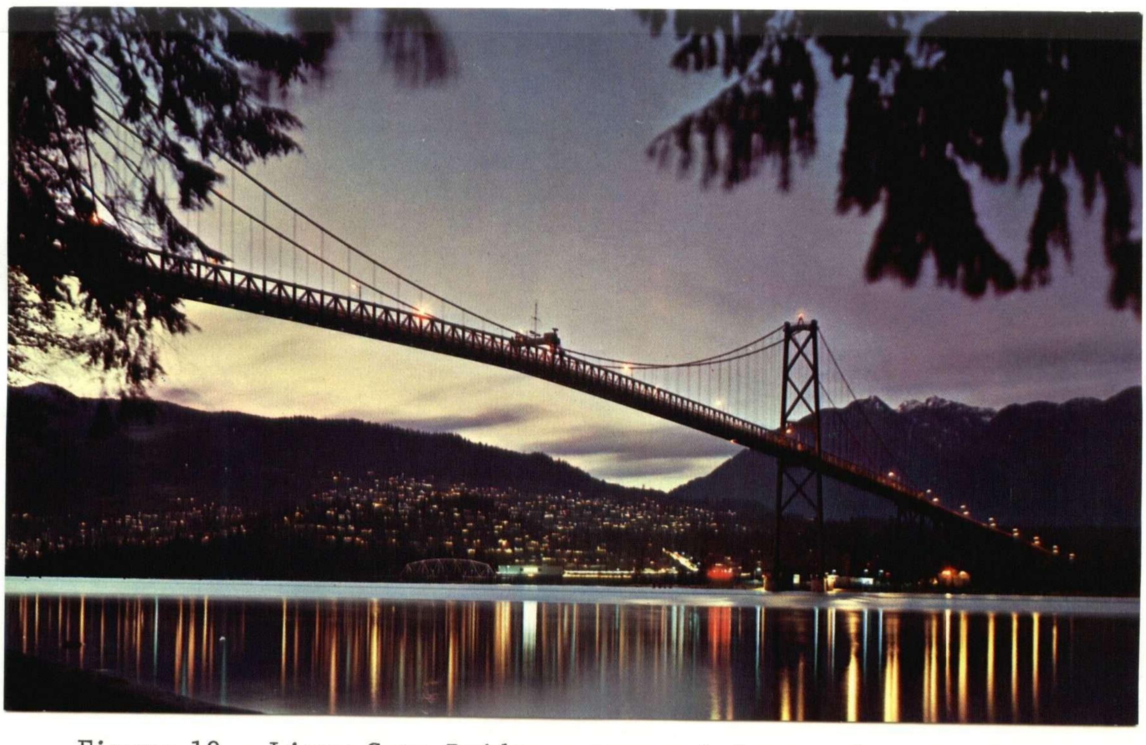


Figure 19 - Lions Gate Bridge - proper balance of a structure.

The construction material does not need to be of the same nature, but different types of material, if used, must be in harmony. Stone and wood, or concrete and steel, are known to be good combinations, whereas, wood-steel or stone-steel are less preferable. A wood-concrete combination is probably the worst kind.

Since the guardrail is judged not only for outside appearance but also from inside the bridge, it has to create a feeling of safety for pedestrians and drivers. For very high bridges, the heavier type of guardrail is recommended. Short posts do not act in the same way as the extended support on Figure 17, because they are uniformly divided, regardless of supports. Furthermore, this outside view appearance is not as detracting as that of an extended support.

The same criteria apply to the guardrail on the suspension bridge, but the guardrail should not be intersected by supporting cables, otherwise the continuity is disrupted. The different effects are shown in Figures 20 and 21.

In summary, the best aesthetic results for the roadway and the guardrail are generally obtained with the suspension (Figure 19) and the roadway-above bridges (Figure 18), since they allow clear lines which best express the natural beauty of an unbroken roadway.

2.2 Supporting Structure

The supporting structure is the next most significant element which determines the beauty of a bridge. The supporting structure has to express the strength, which the eyes of onlookers subconsciously expect, i.e. supporting elements not only have to be strong enough

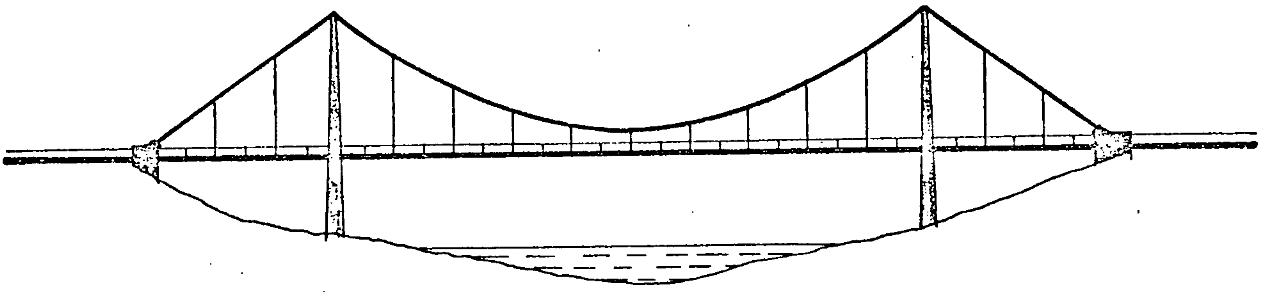


Figure 20 - Proper location of the cable to the roadway and guardrail with suspension bridge.

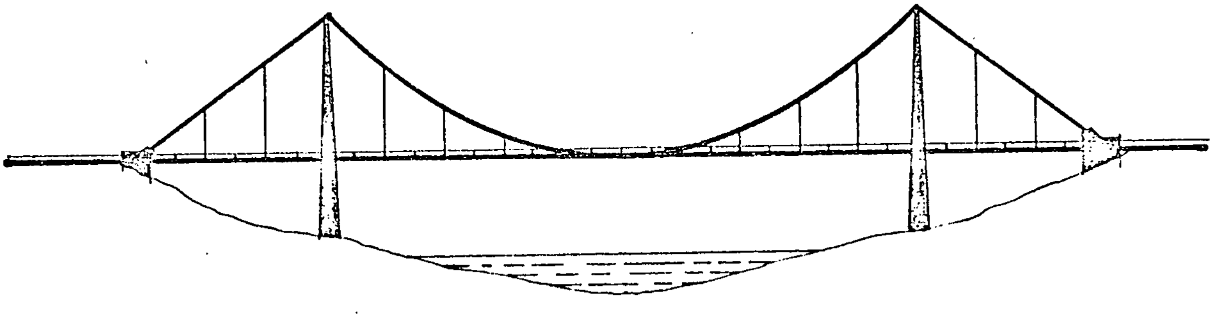


Figure 21 - Improper location of the cable to the roadway and guardrail.

according to static and dynamic calculations, but they also have to look strong. This requirement is not always fulfilled, especially when two supporting elements (beam and arch) share the strength. A proper ratio between these two elements is the most important factor in the aesthetics of bridges (Figures 22 and 23).

There are three basic types of supporting structure which are aesthetically suitable and all of them have thousands of years of history behind them. They are:

2.2.1 Beams

2.2.2 Arches

2.2.3 Suspension structure

All of these have to have clear contours. As mentioned before, the roadway and the supporting structure should not intersect, otherwise the harmony of both is taken away and the clearness of the contours is spoiled.

Contours make the beauty of bridges, and no other civil engineering structures' contours are as important as those of bridges. The bridge is immediately impressive if the contours are correct and expressive. The bridge is then perceived and appreciated. Otherwise it remains unattractive and even offending.

The bridge has two main contours: upper and lower. One is performed by the roadway, the other by the supporting structure which sometimes includes the profile of the piers. The importance of the roadway has been dealt with earlier. It would be a mistake to design a thin looking roadway with strong (thick) looking supporting structure and vice versa (Figures 22 and 23). By referring to and utilizing the

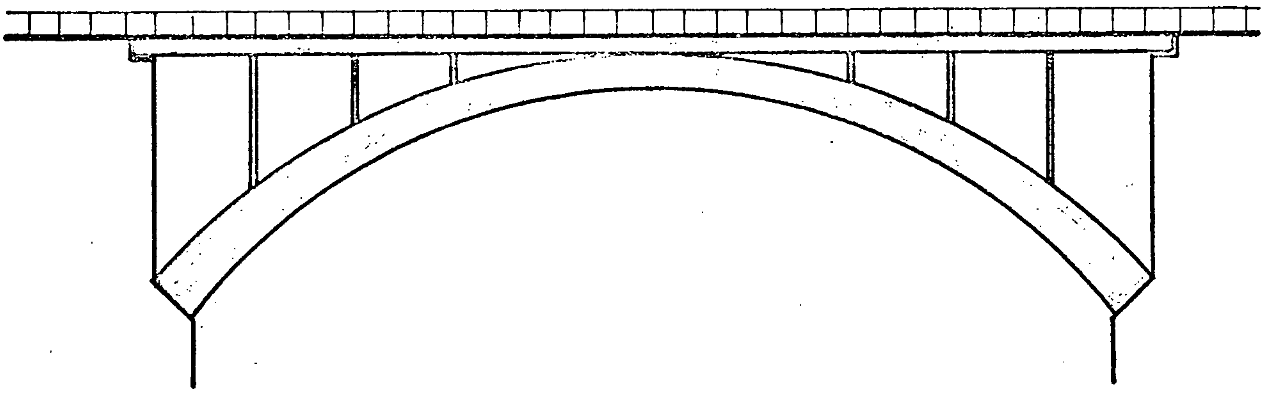


Figure 22 - Improper balance between beam and arch.

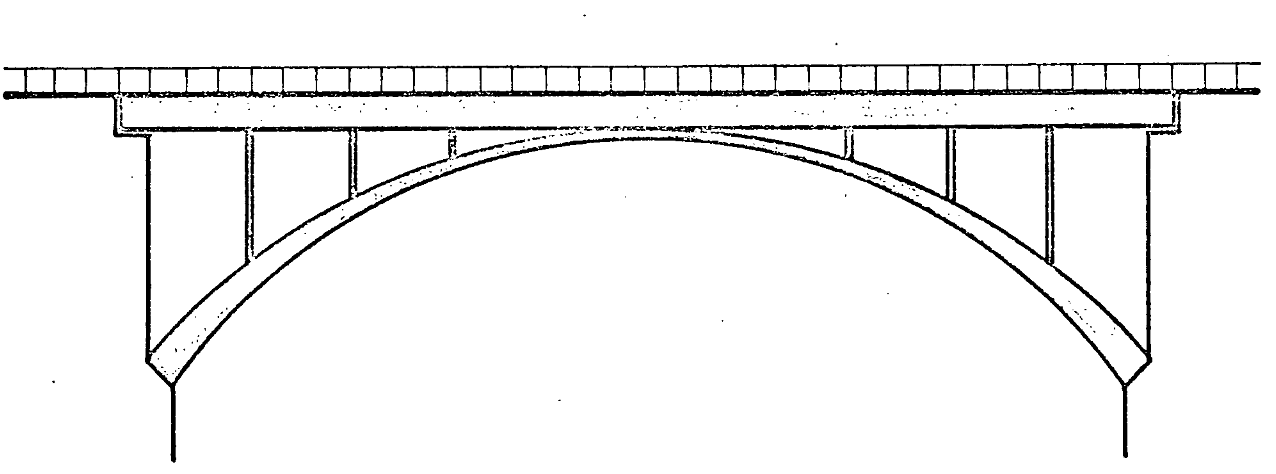


Figure 23 - Improper balance between beam and arch.

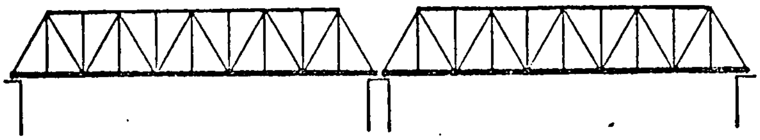
three basic types of supporting structures mentioned above, incorrect lines can more readily be eliminated from bridge design. Beams, arches, and suspension systems have natural precedents in the past, whereby a fallen tree, over a river, served as a beam; two trees bent to form an arch and lianas formed a suspension bridge.

Analogies can be found between the architecture of bridges and buildings. The industrial revolution, which was reflected in the architecture of the second half of the last century as a new architectural trend - "secession" - brought out unnatural and sometimes unnecessary lines. Up to that time, we can follow natural lines in structures. After this "secession" was over, one noticed a slow comeback in architecture through economy on the one hand and natural aesthetic feeling on the other.

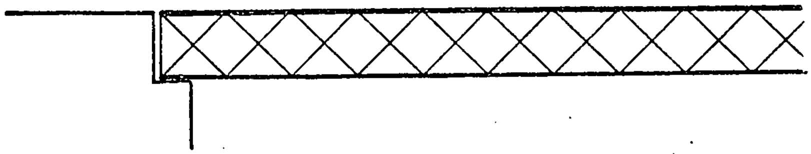
2.2.1 Beams

Straight contours are preferable in the various types of beams whether they be simple beams or straight trusses of long span bridges (Figure 24 (b)). Different heights of the beams (Figure 25 (b)) which may be used on multiple span bridges do not interfere with this principle. On the contrary, beams graded in height, according to span length, with haunches (batters) are more emphatic than the same height of beam in each span. A continuous beam is preferable to a simple beam in each span. Upper straps, with disconnected tops, give the impression of an unfinished structure (Figure 24 (a)).

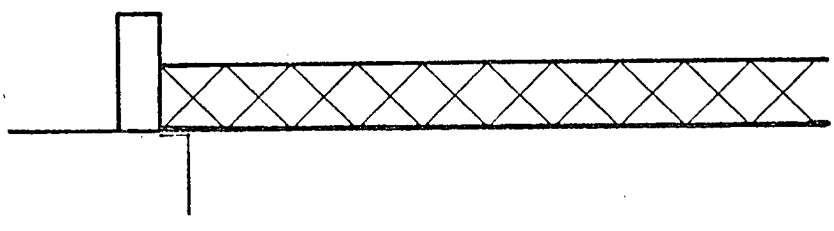
In a roadway-above truss beam, the ends terminate in abutments with a natural effect. However, in a roadway-below truss beam, if the



(a) Disconnected upper straps.



(b) Natural appearance of roadway-above truss.



(c) Border piers with roadway-below.

Figure 24 - Different solutions of truss bridge arrangement.

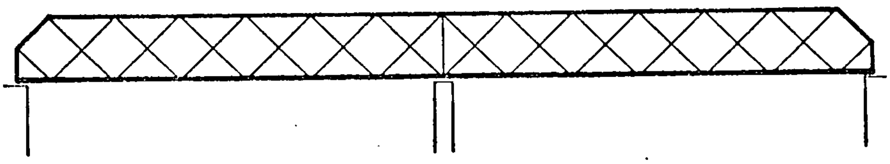
truss has a vertical member, it looks hard and forceful. Border piers or partially oblique ends of the diagonal improve the look of this type of construction (Figure 25 (a)). Aesthetically suitable shapes of beams are shown on pictures 25 (a), (b) and (c).

Sometimes beams are designed according to the relative maximum moment; i.e. applying a constant stress across the length of the entire beam. The largest depth of the beam occurs in the center. This effect is not aesthetically pleasing. Since one expects visually to see strength at the supports, such a beam gives the feeling that it will fail in shear at the support.

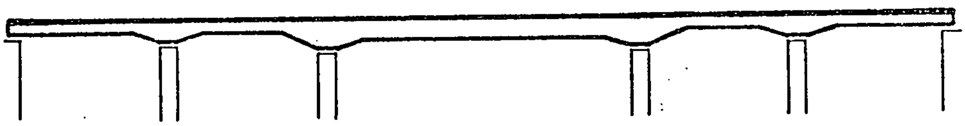
2.2.2 Arches

The arch belongs to a higher, aesthetically more valuable category than the beam. The arch, serving as a support in the roadway-above bridges, creates a most natural appearance in the whole structure. As mentioned before, the proper balance between the arch and beam thickness has to be considered. This applies mainly to a solid type of arch (wood and concrete) while steel truss arches seem to be less sensitive since they are not as obtrusive.

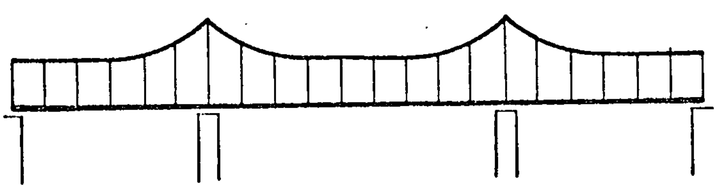
Arches are usually constructed according to equilibrium polygons or moment lines, which vary with different types of arches. Aesthetically, the most pleasing is the fixed end parabolic arch with a thin crown and considerably thicker butts (Figure 26). It gives the feeling of a safe structure, but as a structural type it is statically multiply-indeterminate and requires careful calculations since other influences such as shrinkage and temperature changes have to be considered.



(a)



(b)



(c)

Figure 25 - Aesthetically suitable different shapes of the beams.

The two-hinged arch has the opposite appearance (Figure 27). It is thicker at the crown than at the butts and does not give the same impression of stability as the fixed end arch. The design is simpler since it is only a simply-indeterminate structure; and, if it is carefully designed, it can appear smooth looking and aesthetically pleasing.

The three-hinged arch in a long span is probably the most difficult to accept from the aesthetic point of view and is now rarely used for concrete (Figure 28). It is, however, the simplest to design structurally since it is a statically determined structure, and for short spans visually pleasing contours can be obtained.

The same principles can be applied for roadway-below bridges as for roadway-above. The most important is the proper balance between the roadway and the arch thickness. In the roadway-above arrangements a thick roadway (with beam) and a thin arch can create the impression that the beam is carrying the whole load and that there is no need for the arch (Figure 23). If the thicknesses are interchanged, it then creates the impression that the arch has been built as a monument and the roadway has been forgotten (Figure 22).

Similar visual effects can be created with improper roadway-below arrangements. The shape of the arch is not as important as the relative thickness. If the arch is too thick, it can give the impression that it is actually the roadway, and that the roadway is only a chord holding the arch together. Equal thickness of arch and roadway should be avoided since the supporting structure appears undermined, while the roadway with the beam appears more obvious, all this creating a consequent

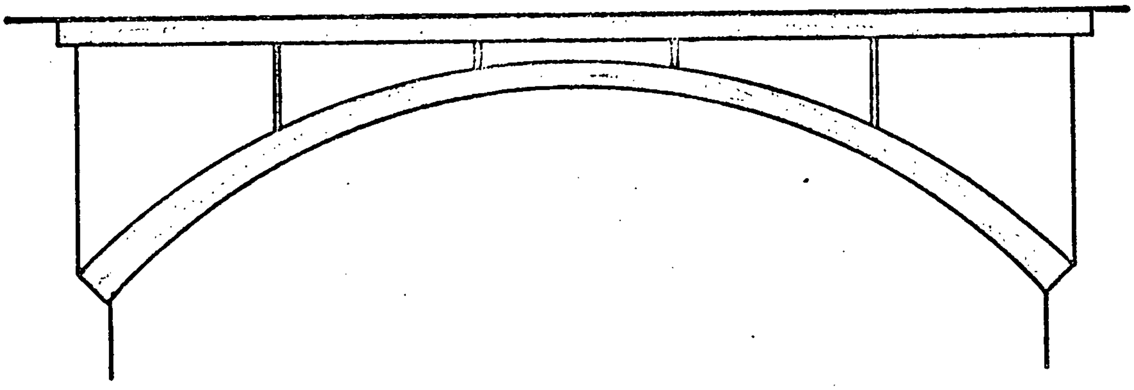


Figure 26 - Fixed end arch bridge.

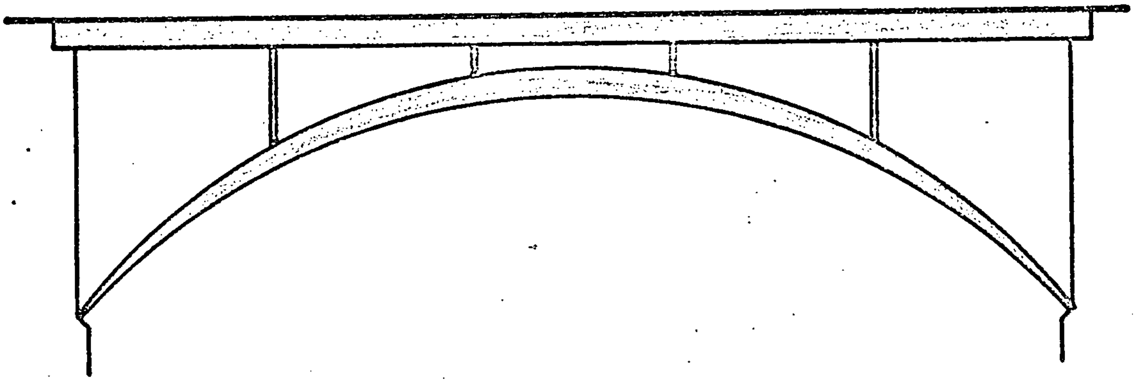


Figure 27 - Two-hinged arch bridge.

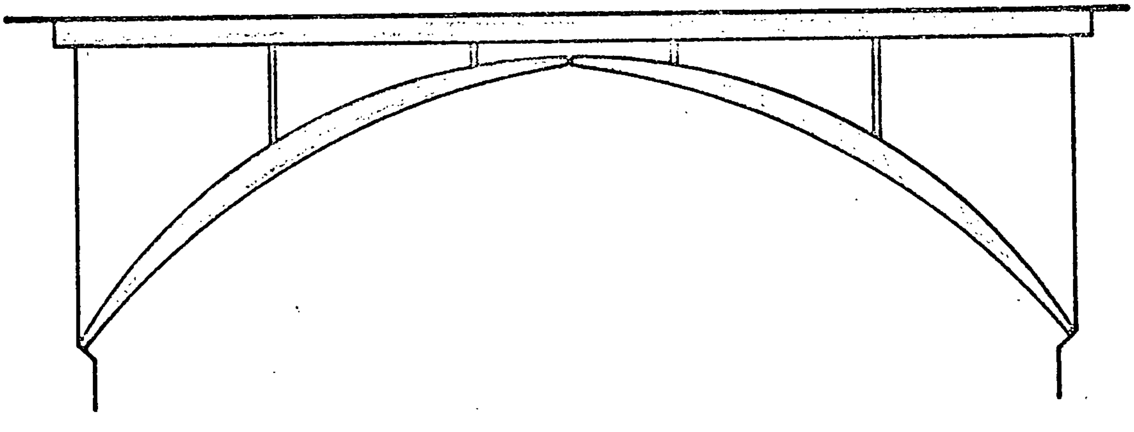


Figure 28 - Three-hinged arch bridge.

lack of balance. The total impression of such a bridge is that of a heavy structure. The best proportion would seem to be a slightly thicker arch than roadway. The vertical connectors should be proportionate so as not to detract from the impression of smooth lines.

Parabolic curves in general look better than simple curves, especially when the ratio between the height of the arch and the span is small. When the ratio is high, the difference is not noticeable. Flat arches are usually more admired than high arches, because to the discriminating eye they show the ability and skill of the designer. Common ratios of the height and the square of the length of the chord are between 1/250 and 1/500. The flattest known arch, in Rome, has a ratio of 1/1000.

Some older types of bridges were designed as full arch with roadway (Figure 29). Elliptic arches were sometimes used for statical reasons but they have an aesthetic disadvantage because they make the piers and the roadway thicker.

2.2.3 Suspension Structure

A suspension bridge (Figure 20) provides the impression of a continuous roadway coupled with the beauty of the thin natural curves of the cable. The vertical connectors are thin and do not interfere with either element. An important consideration is the proper distance between the cable and the roadway. As discussed earlier, the guardrail should not be crossed by the cable (Figure 21). On the other hand, too large a distance between the cable and the roadway is not aesthetically suitable because it loses proportion and the natural appearance of the cable curve.

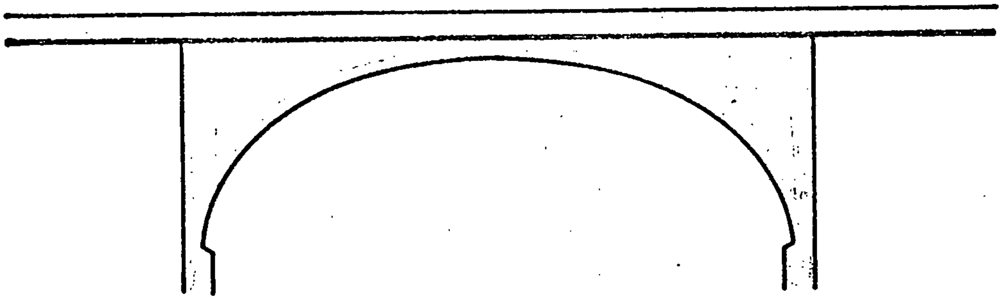


Figure 29 - Elliptic full arch.

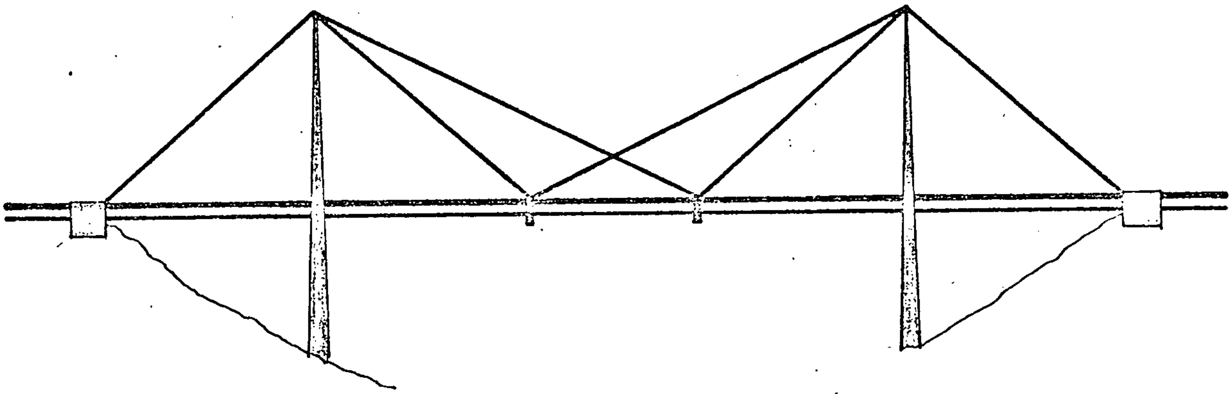


Figure 30 - New type of suspension bridge.

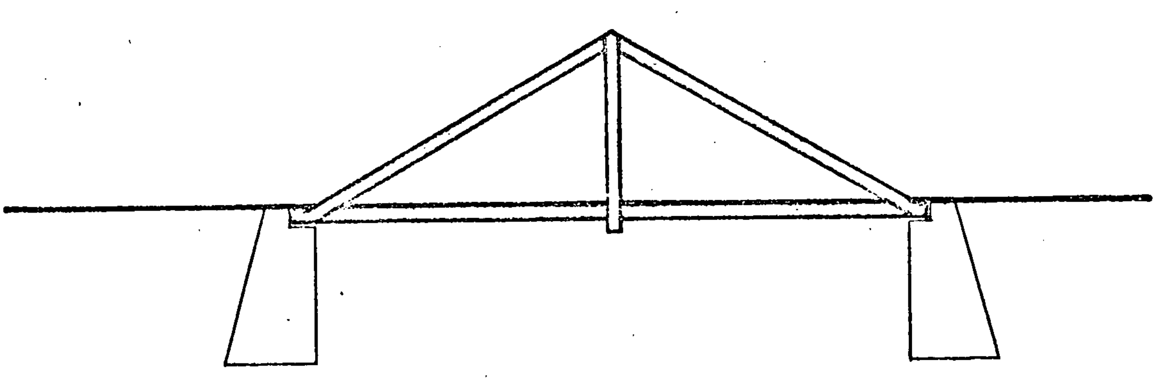


Figure 31 - King truss.

A new type of relatively short span suspension construction has been developed recently. Instead of a continuous arch, the cables are anchored in the beam (Figure 30). Basically, it is a very delicate looking structure and can be used with great technical and aesthetic effect. It is also relatively inexpensive and simple to construct.

Other types of bridges such as king and queen trusses (Figures 31 and 32), even if economical, do not generally correspond to the aesthetic principles which are covered in this paper. They are basic typically-functional engineering structures, simple to design and to construct. They have been often used especially in the past but they always take away from the harmony of the landscape in some way. Comments about the reversed steel trusses can be compared to earlier comments about the beam which is designed according to the moment line. These structures have an unnatural appearance and give the feeling that they could break close to the support.

Inverse strutframe structures (Figures 33 and 34) do not have the same negative effect as those which are described above if cables are used for tensioned parts, but even they cannot be considered as fully aesthetically suitable structures since they do not follow the described aesthetic principles of supporting elements.

2.3 Piers and Abutments

Chiefly because of its function, a pier or abutment is an independent element which acts as a complex unit. If a support is designed as a single column or wall, there is a lack of complexity which gives the feeling that more of the same elements are required since it

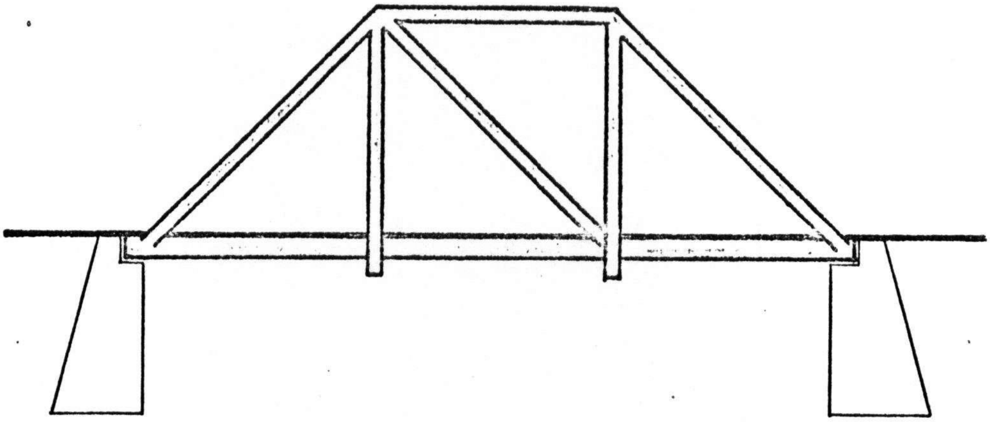


Figure 32 - Queen truss.

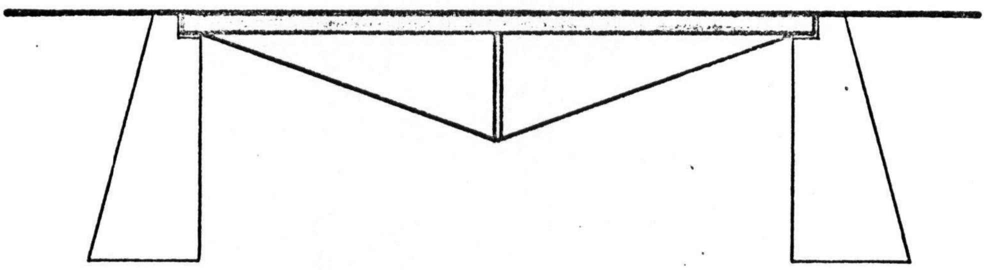


Figure 33 - Inverse king truss.

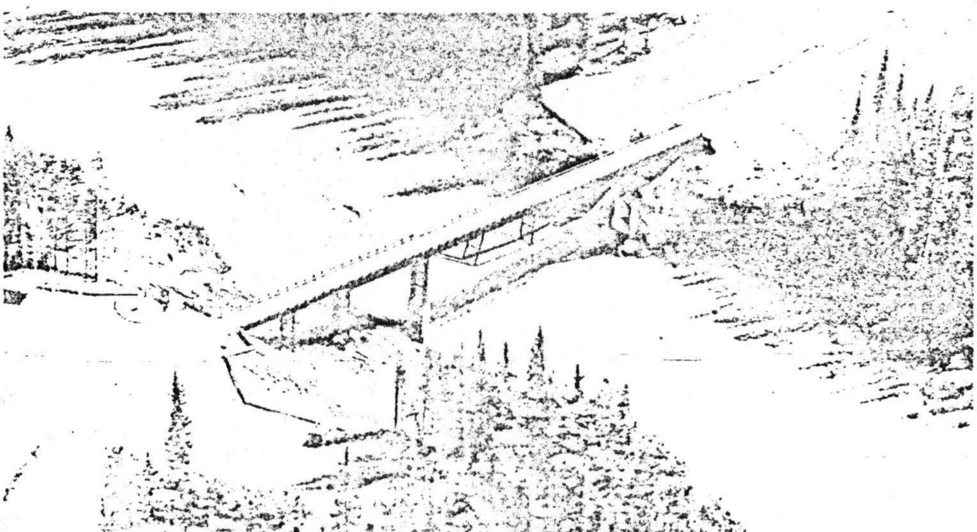


Figure 34 - Trussed girder bridge.

should also act as an enframement. Therefore, piers are built in rows, whether as infill at the ends of arches or to transfer the load from the supporting structure to the footing.

An important question arises regarding selection of material. While the superstructure can be of various materials, concrete or stone are preferable for the supports since it is important that they resist the influence of water. In some types of construction, extensions of the piers can be of wood or steel, especially in deep valleys where high piers are necessary.

It has been mentioned previously that the pier should not disturb the fluency of the roadway. The only acceptable extension of the abutments can be at the ends of the bridge, to emphasize the bridge entrance and monumentality. Solid long piers should be built sloped or in steps, because a straight verticle prism appears to widen at the top and give the feeling of uncertainty and instability. From the aesthetic point, they have to be designed carefully according to the selected bridge type, height of the fill that they are to support, and the type of banks.

Sometimes they have to be massive and also should give a massive impression to keep the proper balance between the type of the bridge and height of abutment. The use of natural outcrops for heavy abutments gives the same effect, however it interferes less with the environment than with pure concrete facing. Sometimes it is better to use divided bank abutments (Figure 6 and 7) which make the construction lighter and airy-looking and which can be very acceptable since air and light can also be considered as construction material.

This applies especially when divided bank abutments are used to eliminate long and high fill in flat valleys.

2.4 Bridge Heads

Approaches should always be marked in some appropriate manner in order to warn the driver of the oncoming bridge. There are different means of accomplishing this, depending upon the roadway arrangement. The roadway-below bridge construction, which is above ground level, is striking in itself and obvious to the approaching driver so that no additional element is necessary, while a proper means of announcing the bridge is needed with the roadway-above bridges. Bridge heads on the pile piers, posts with come representational status, and similar means can be used (Figures 24 (c), 35 and 36). Monumentality, if required, can also be obtained by widening the approaches with the use of landscaping. Functional brow-log or similar types of approaches, which direct traffic onto the roadway, are sometimes used on forest bridges in British Columbia. Such approaches do not interfere aesthetically, since no actual monumentality in high vegetation (forest) cover type is needed (Figures 17 and 18). Therefore these approaches can be used for multi-purpose bridges.

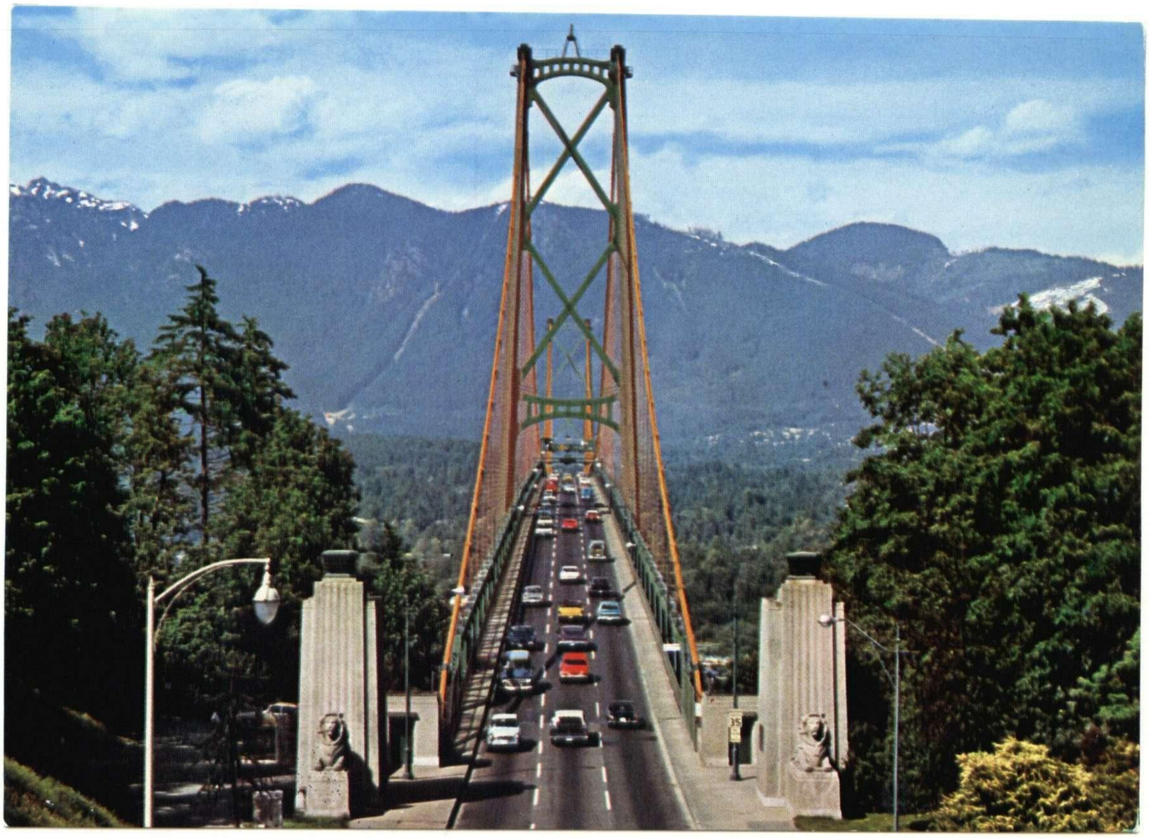


Figure 35 - Bridge head at Lions Gate Bridge.

Figure 36 - Striking suspension bridge structure.

Figure 37 - Proportionality of Lions Gate Bridge.

Chapter III

DIFFERENT TYPES OF BRIDGES IN MAIN LANDSCAPE FORMS

A bridge is a building element which, in its natural surroundings, may improve or mar the landscape. It can be stated both from formerly mentioned aesthetic principles and from the experiences of various authors (Adamovich[1], Newton[2], Lorenz[3] and Pacholik[4]) that, in general, the selection of a bridge type--its shape, proportions, and material--depends directly on the type of terrain (flat, hilly, mountainous), ground cover (rocks, sand, low vegetation, forest), type of transportation (proper balance with connecting road on either side), relationship to neighbouring bridges (Figures 38 and 39) and so on. The road location is influenced by possible river crossings and vice versa.

The far distant view of the bridge should not be neglected, since it offers a refreshing visual moment to long distance travellers.

[1] L. Adamovich, Forest Transportation. Course at the Faculty of Forestry, University of British Columbia, Vancouver, B.C. 1972 - 1973.

[2] N.T. Newton, Design on the Land (Cambridge, Mass.: Harvard University - Press, 1973). p. 2 - 17.

[3] E.H.H. Lorenz, Trassierung und Gestaltung von Strassen und Auto Bahnen ("Layout and Design of Streets and Highways") (Wiesbaden und Berlin Baumverlag, 1971). p. 23 - 52.

[4] L. Pacholik, Estetika Mostnich Staveb ("Aesthetics of Bridge Structures") (Prague: Ustav pro Ucebne Pomucky Prumyslovych a Odbornych Skol v Praze, 1946). p. 13 - 34.

Figure 38 - Neighbourhood of bridges - proper solution.

Figure 39 - Close and distant object observance - non homogenous appearance.

In order to satisfy all the requirements, many alternatives have to be considered. The best grounds for judging the most appropriate bridge type come from ground photogrammetry, plotting the different types with photographic pictures taken from different points or angles[5,6]. Sometimes even a sketch on the photographic picture is sufficient as shown on Figures 54 to 59.

3.1 Flat Country

It is generally accepted that flat country requires flat type bridges (beam or flat arch with roadway-above (Figure 3)), while high arch bridges adapt themselves better to mountainous country. These principles, however, have variations and the most significant one arises from the need or desire to change a monotonous, flat countryside by building some dominant element in order to improve the landscape appearance.

In such cases, several types of bridges may be considered:

3.1.1 Concrete Arch Bridge

A concrete arch bridge, with a roadway-below (Figure 3) would be very effective, especially in low vegetation ground cover. In this instance, one must keep in mind the fact that a series of arches is not aesthetically pleasing.

[5] E.H.H. Lorenz, Trassierung und Gestaltung von Strassen und Auto Bahnen ("Layout and Design of Streets and Highways") (Wiesbaden und Berlin Baumverlag, 1971). p. 72 - 75.

[6] L. Pacholik, Estetika Mostnich Staveb ("Aesthetics of Bridge Structures") (Prague: Ustav pro Ucebne Pomucky Prumyslovych a Odbornych Skol v Praze, 1946). p. 13 -34.

3.1.2 Howe-truss Bridge

A straight steel truss or wooden (Howe-truss) bridge, with its monumental looking end pillars, has the disadvantage of looking suitable from the side view only if the river or the sky is in the background, otherwise they act as disturbing elements.

3.1.3 Suspension Bridge

A suspension bridge, with concrete supports (which in themselves look very impressive), offers a pleasing combination of concrete and steel. This pleasing combination with suspension bridges is quite recent and its outcome is very efficient and effective. It was first introduced in France after the Second World War, apparently following middle European patterns (chain bridges with stone towers, e.g. Budapest, Hungary) in order to cope with the shortage of steel. The same balanced effect may be obtained by using steel supports (Figure 37).

3.2 Hilly Terrain

Hilly and rolling terrain with its changing ground cover seems to be the least demanding when it comes to choice of bridge type. This type of countryside is usually very colourful and almost any type of bridge structure fits well if local conditions are considered except the suspension bridge which is dominating type and, therefore, should not be used between two valleys, where the dominating elements become suppressed and an environmental unbalance results.

With some exceptions, bridges should be built straight, because the side forces of vehicles in curves require additional lateral bracing. Situations, where two segment bridges divided by a short straight road, are required should be avoided and the whole route should be revised. Such an arrangement is not only expensive, but also aesthetically unpleasing.

To improve the distant view of the bridge and to make it more impressive, the curves on both sides of the bridge should be so located that travellers, en route, will be able to admire the beauty of the bridge construction and its environmental effect.

Sometimes symmetry is considered very important and then an odd number of spans is preferred. This is more important with arch bridges and roadway-above (Figure 3) than with any other type of bridges. Where other types are concerned, supplementary arrangements can eliminate this requirement. However, symmetry of the long divided bank abutments is always necessary in order to keep proper balance.

3.3 Mountainous Country

Mountainous country, in general, does not adapt itself to beam type bridges. These bridges (beam type) cut off the view of the valleys and look too forceful while the arch bridges are not as forceful and appear to be in harmony with the landscape (Figure 40). However, even beam bridges may be used in mountainous areas, when properly located and carefully designed, either as contrasting visual elements or where the position of the bridge is low in relation to the background (Figure 41).

3.4 River Crossing

Tunneling or choking the flow, as shown in Figures 42 and 43, is basically environmental interference, and should be avoided. If

Figure 40 - High arch bridge in mountainous terrain.

Figure 41 - Beam bridge in mountainous terrain.

Figure 42 - Tunneling of the stream.

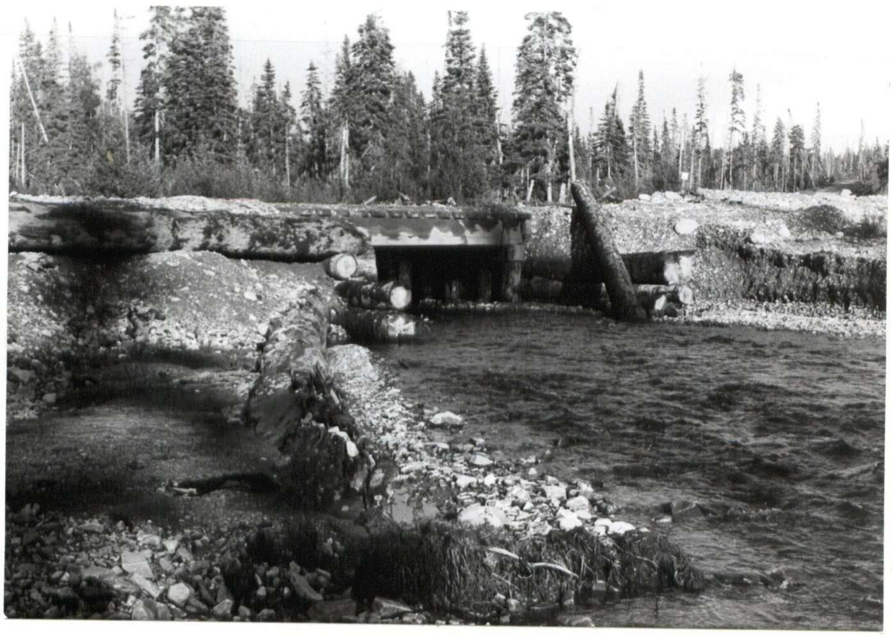


Figure 43 - Tunneling of the stream.

the cantilever beam is used, then the bending moment values are lower and it could be used for longer spans in general. Then, there is no interference in the flow of the river. A comparison between the simple beam and cantilevered beam effect can be seen in the case study of the Alouette River, which follows in the next chapter. Even if the Alouette River is not choked by the introduction of a high bank support, the aesthetic value to the environment is higher when a cantilevered beam type of bridge is used since it opens up the view while diminishing the fill. Apart from the Alouette River case, the tunneling effect can be eliminated by designing the type of bridge that uses individual (Figure 15) intermediate supports, rather than heavy bank supports. Tunneling should be avoided not only because of its adverse effect on the landscape but also for its detrimental effect on fish life. The use of a cantilevered beam or high fill may be a question of economics (either fill or bridge structure costs) but, as mentioned before, the side effects should never be overlooked.

In summary, it may be stated that any basic type of bridge structure can be selected for any particular countryside. However, proportionality and balance, with the immediate surroundings and the background, has to be considered in order to fulfill the requirements of environmental aesthetics.

Chapter IV

ANALYSIS OF ALOUETTE RIVER CROSSING

The general principles discussed in the chapters on aesthetics are applied in design comparisons of the new bridge across the Alouette River. For this particular case, several types have been selected in order to show the suitability of each. Individual types are drawn to scale (1 inch = 30 feet), for purposes of visual comparison and to aid in selecting the most suitable one.

Basically, two bridge lengths were considered. Most of the types considered were 80 feet long, between two high supports, but two types (cantilevered and suspension) were considered for 160 feet total length. The disadvantages of the different height of supports on each bank can be seen on the drawings along with a supplementary solution for each case.

4.1 Description of the Landscape Area and Alouette River Crossing

The area of the U.B.C. Research Forest is basically hilly, covered by a mixed forest. The fast flowing Alouette River, which crosses this area, follows a path of continuous rapids, embanked by a rocky canyon. As for the landscaping of a particular area, marked in Appendix I, the mountainous type has to be considered, since the main view of the bridge from the northern part of the approach road has a rugged, irregular topography in the background. The mountainous landscape is underlined by the appearance of the dominating Mount Blanshard in the far distance to the north of the bridge.

4.2 Present Situation

The Alouette River forms a natural border between the eastern area (see Appendix I) and the main western part of the U.B.C. Research Forest. Until now the eastern area has seen a limited amount of logging while many plots serve research purposes. However, in the near future an increase in logging is expected.

The existing approach leads almost to the geographical center of the eastern area and the present bridge across the Alouette River is economically located at the shortest river crossing. The location of the bridge is marked on the aerial photograph in Appendix I. Because the crib abutments and some of the stringers have rotted, the Director of the Forest has decided to have a new bridge built in the same place.

The present layout of the approach road is substandard since the new hauling trucks, as shown in Figure 64, require a bigger radius curve than the older types. In addition, the 18% slope of the road section south of the river does not meet proper safety requirements, road stability and vehicle mechanics.

As no final decision about a new bridge has yet been made, this paper introduces some ideas for its possible design and materials; these, supplemented by calculations and aesthetic analysis, may prove to be useful in this or other similar cases.

In the analysis, visual quality has been considered as an important additional intangible value, since the area is frequented by visitors from all parts of the world.

4.3 Proposed Alignment of the Route

The basic data for the bridge design and road alignment were obtained by terrain reconnaissance and stadia survey.

To improve the present situation, the horizontal and verical alignment of the road has been redesigned as shown on the plan and profile in Appendix I. A minimum radius of 100 feet has been considered for the horizontal curve, with spiral transition curves of 50 foot lengths on the south side of the river. On the north side, a spiral curve has been designed. To avoid side forces on the bridge, a straight section, the length of one truck (50 feet), as shown in Appendix I, has been allowed at each end of the bridge. The new alignment allows a maximum 25 m.p.h. speed of trucks in that section with a 6% superelevation in the curve.

At both sides of the river, the road grade has been partly maintained in order to avoid excessive costs for earth work. To obtain a smooth profile, the running surface of the bridge has been designed with a 3% slope, and parabolic transition curves were introduced in the slope changes. The main benefit obtained from such an alignment is the elimination of the 18% grade between stations 5 + 50 and 7 + 00 (Appendix I).

An alternate solution involving a shorter transition curve was considered with the possibility of providing additional short spans at both ends of the bridge and the elimination of heavy abutments and extreme fill behind them. In this case, the abutments could be much smaller and the aesthetics of the beam bridge would improve.

4.4 Engineering Calculations on Proposed Types of Bridges

Different types of glulaminated bridges have been selected for design comparison. Since the distance between the main abutments is 80 feet, the bridge is on the economic borderline of the simple beam and other bridge types[1]. In addition two types of bridges with overall length of 160 feet have been analyzed.

The calculations presented in the appendices are limited to the main bridge elements. These calculations show only the dimensions for purposes of the aesthetic comparison of structural balance, overall appearance and for preliminary cost estimate.

The calculation for each type of bridge is listed in the appendices as follows:

(a) simple beam

(b) strutframe (two equal span continuous beam)

(c) double strutframe (three span continuous beam)

(d) three-hinged arch with three span continuous beam)

(e) cantilevered beam

Suspension bridge has not been considered for comparative design because of its aesthetic impropriety in the given landscape.

Results were obtained by analytical calculations and by the use of graphs (e.g. influence lines).

[1] I. Barber, Forest Transportation. Course at the Faculty of Forestry, University of Toronto. 1969 - 1970.

In the final chapter, the selection of the type of bridge most suited is made by balancing the technical, aesthetic and economic requirements.

4.5 Material

To find out whether the material for the bridge meets the technical, aesthetic and economic requirements in acceptable balance, it has to be chosen simultaneously with the form of the bridge.

Glulaminated timber material for the bridge has been chosen mainly because of its technical advantages, natural beauty and reasonable costs in B.C. As opposed to log stringers, which are widely used on short span bridges in B.C., glulaminated beams can be obtained in a wide range of lengths and cross-section dimensions. The greater strength afforded by the selected material allows more load per smaller dimension. The required span, which cannot be obtained by use of log stringers, is available through the use of glulaminated beam so that the re-channeling of the river often seen beneath logging bridges can be avoided.

Higher durability may be obtained by using treated material for laminates. Treatment of this material is more efficient and therefore more resistant to rot than pressure treated logs or sawn timber material.

Due to the shape of the beams, manipulation of glulaminated material during the construction is simpler and faster than that of log stringers. The economic advantage of choosing glulaminated material can be seen also in using higher strength lumber (e.g. Douglas Fir) for the more exposed laminates of the beam, while less exposed laminates can be made of lower strength lumber (e.g. Pine). Thus the chosen material for the case in question has satisfactorily fulfilled all the above requirements. Concrete abutments for the bridge would be based on the solid rocky foundation (basis) on either side of the river.

To avoid unpleasant wood-concrete combination, rock rip-rap of abutments would be used.

4.6 Aesthetic Analysis of Considered Types of Bridges

4.6.1 Simple Beam Bridge

The simple beam bridge (Figures 44 and 52) is balanced, according to structural aesthetics. Engineering calculations are shown in Appendix II. It does not look aesthetically suitable, however, for this designed crossing, since it is not in harmony with the rocky valley in the background. It cuts the view of the valley and is not as impressive an engineering structure because of the high fill on the banks. Since the new bridge is designed on a higher level than the old one, the negative impression would be amplified.

4.6.2 Single Strutframe Bridge

The single strutframe bridge (Figure 45) has been designed using two single spans. The continuous beam is supported by two struts, each at a different angle with the roadway. Engineering calculations are shown in Appendix III. This type is aesthetically balanced because the supporting elements are almost of the same depth as the beams but the asymmetry of the struts is aesthetically unacceptable. Setting the basis of the struts at the same distance from the roadway (Figure 46 and 53), making it symmetrical, greatly improves the appearance of this type

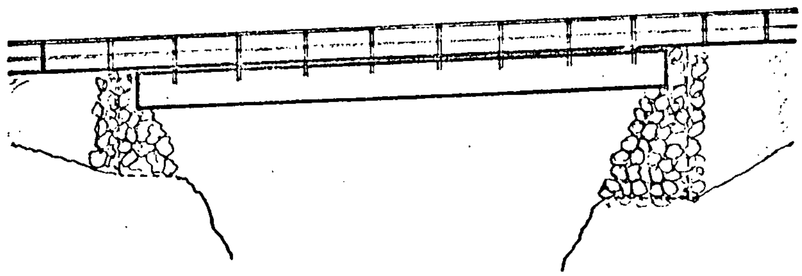


Figure 44 - Simple beam bridge.

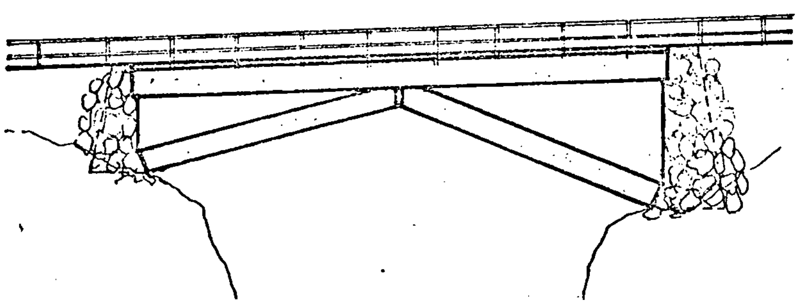


Figure 45 - Asymmetrical single strutframe bridge.

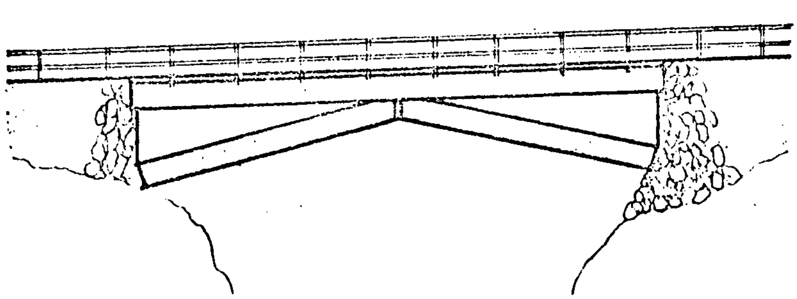


Figure 46 - Symmetrical single strutframe bridge.

of bridge. It also fits in better with the surroundings because it softens the straight lines of the simple beam.

4.6.3 Double Strutframe Bridge

The double strutframe bridge (Figures 47 and 54) is designed as a three-span continuous beam. External spans have equal length L_1 and inner span length is $L_2 = 0.75\ L_1$ as recommended in various textbooks on statics[2,3]. The double strutframe bridge was calculated mainly to provide a comparison in elements, and to show the difference in appearance between it and the single strutframe (Appendix IV). The double strut type looks more balanced and lighter in appearance. The overall concept is more pleasing than the single strut because the steeper and shorter struts soften the rigidity of the beam, at the same time producing a logical arrangement, structurally.

4.6.4 Three-hinged Arch Bridge

The three-hinged arch bridge (Figures 49 and 55) with a continuous beam is used in the same manner as the double strutframe bridge. The appearance of this type of bridge is only slightly affected by the different level of arch bases (Figures 48 and 56). The smooth lines have the same effect as with the two-hinged arch. It seems that dividing both supporting elements (arch and beam) has a good effect on emphasizing the different function of both of them. For aesthetic reasons, the depth of both parts of the arch is not set according to the moment diagram, as is

[2] L. Adamovich, Erdeszeti Hideptes, ("Lectures on Forest Bridges") (Sopron, Hungary: University of Sopron, 1949). p. 44. (Mimeographed.)

[3] Z. Bazant, F. Klokner, and J. Kolar, Statika Stavebnich Konstrukt, ("Statics of Civil Engineering Structures") (Prague: Ceska Matice Technicka, 1930).

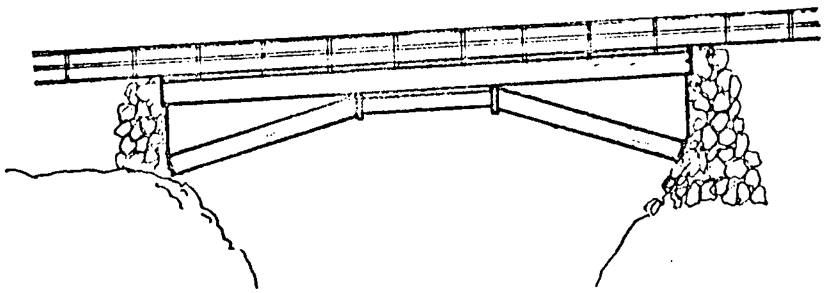


Figure 47 - Symmetrical double strutframe bridge.

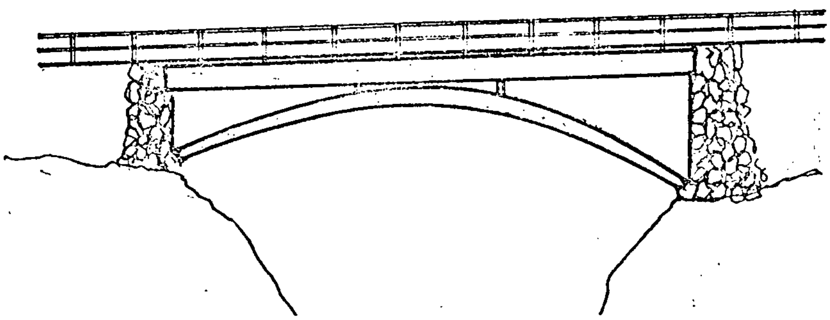


Figure 48 - Asymmetrical three-hinged arch bridge.

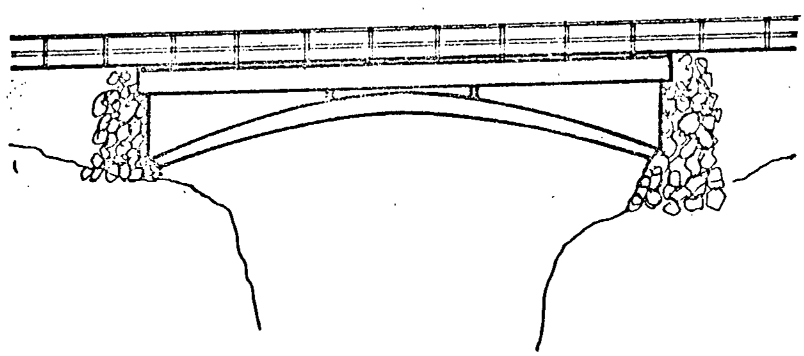


Figure 49 - Symmetrical three-hinged arch bridge.

customary. Maximum depth is maintained throughout the top of the arch. The ratio between both supporting elements corresponds with the principles of structural aesthetics.

4.6.5 Cantilevered Beam Bridge

The cantilevered beam bridge (Figure 50) has fundamentally the same effect in cutting the view of the valley as the single beam bridge. However, the elimination of the high abutments and heavy fills results in a much greater viewing area as well as projecting a sense of "lightness" in the engineering design (Appendix V). From a structurally aesthetic point of view, this design, with its slender looking piers, is perfectly balanced. With its light contrasting effect, this type of the bridge seems to fit this area the best.

4.6.6 Suspension Bridge

The suspension bridge (Figure 51) does not fit this area aesthetically because it is too dominant a structure, as mentioned in the chapter on aesthetics. This becomes very apparent when travelling downhill on the approach road, where the dominating effect, which this type of structure normally creates in other landscapes, is lost. This type also would not be economically justified for this case study. Otherwise this type of bridge is properly balanced, especially if the cables are anchored above the guardrail as shown on the alternative drawn in full line (Figure 53).

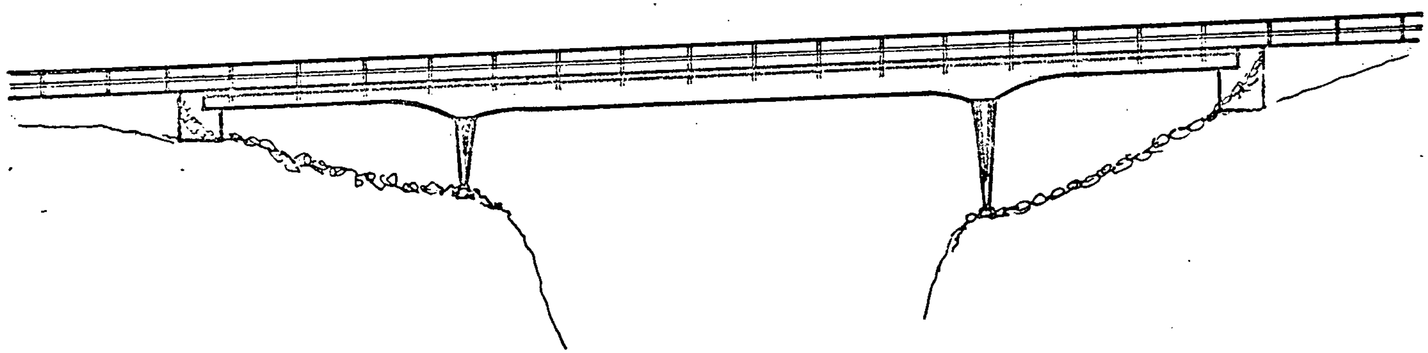


Figure 50 - Cantilevered beam bridge.

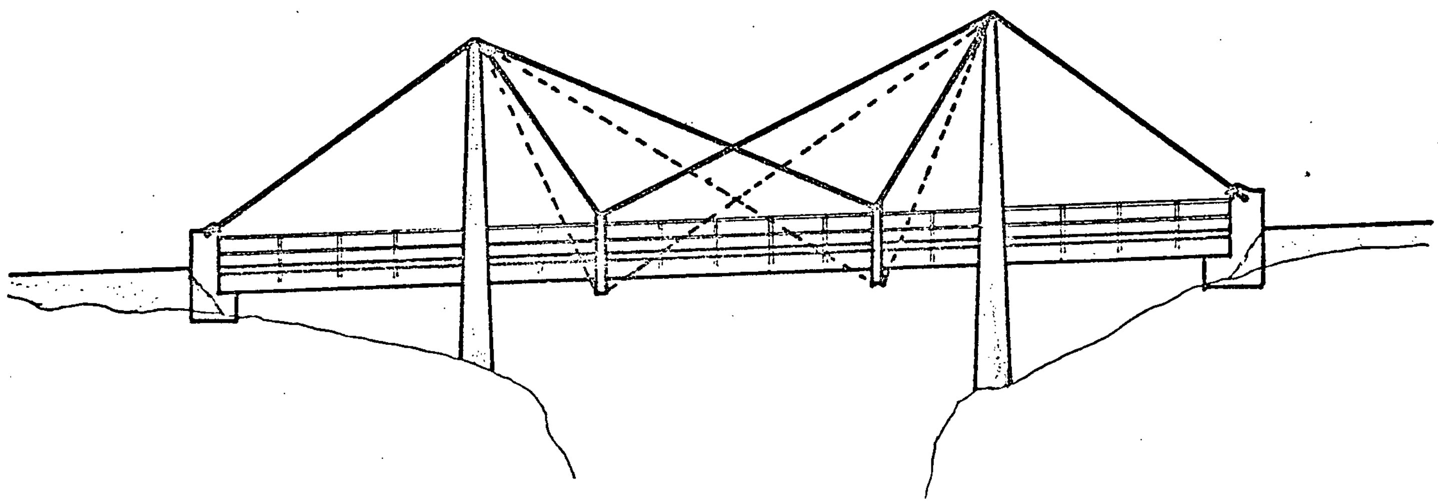


Figure 51 - Simple suspension bridge.

Figure 52 - Simple beam bridge.

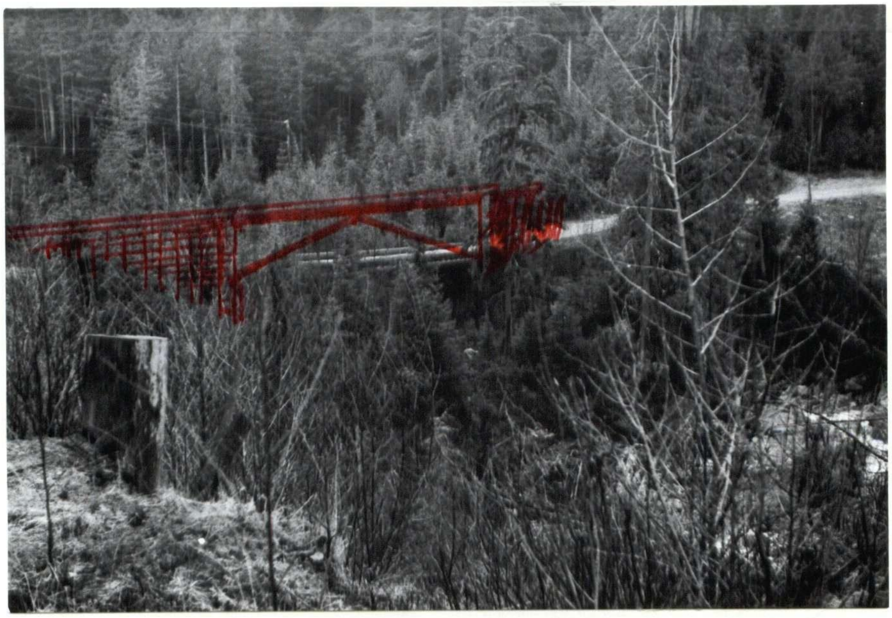


Figure 53 - Single strutframe bridge.

Figure 54 - Double strutframe bridge.

Figure 55 - Symmetrical three-hinged arch bridge.

Figure 56 - Asymmetrical three-hinged arch bridge.

Figure 57 - Cantilevered beam bridge.

Chapter V

SUMMARY AND CONCLUSION

Upon completion of the Alouette River Crossing study, from the aesthetic point of view two types of bridges can be considered appropriate for this particular case, namely, the arch bridge and the cantilevered beam bridge.

The arch bridge with roadway-above looks very neat and blends in appearance with this mountainous area. It is structurally balanced and the arch seating partly eliminates the negative effect of high abutments as they appear in bridges with simple beam. Natural rock rip-rap fits into the rocky surroundings and eliminates the unnatural look of pure concrete facing.

On the other hand, cantilevered beam bridge has a slightly contrasting effect which does not interfere with the mountainous type of landscape in the way the simple beam bridge type would, but since it is structurally perfectly balanced, it underlines the beauty of the engineering structure and is, therefore, most favourable.

From the technical point of view cantilevered beam bridge would be least demanding because of the small abutments and the minimum fill. Construction would be faster and simpler than with the other types considered.

Economically, the cantilevered beam bridge is most feasible because of the big saving on concrete abutments and earth fill material.

As per preliminary estimates in appendices, costs of individual types are as follows:

Simple beam bridge (Appendix II)	$108,262
Strutframe bridge (Appendix III)	$130,711
Double strutframe bridge (Appendix IV)	$127,174
Arch beam bridge (Appendix IV)	$114,592
Cantilevered beam bridge (Appendix V)	$101,557

In summary, the cantilevered beam bridge appears to be the most superior from each point of view and therefore would, undoubtedly, be recommended for the Alouette River Crossing.

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APPENDIX I

Present Situation

Design Specifications

Vertical & Horizontal Alignment

Figure 58 - Aerial picture of southern part of U.B.C. Research Forest with bridge location.
- Scale 1" = 1,090 feet.

Figure 59 - View of the present bridge from the south bank.

Figure 60 - Side view of the bridge and valley from the east.

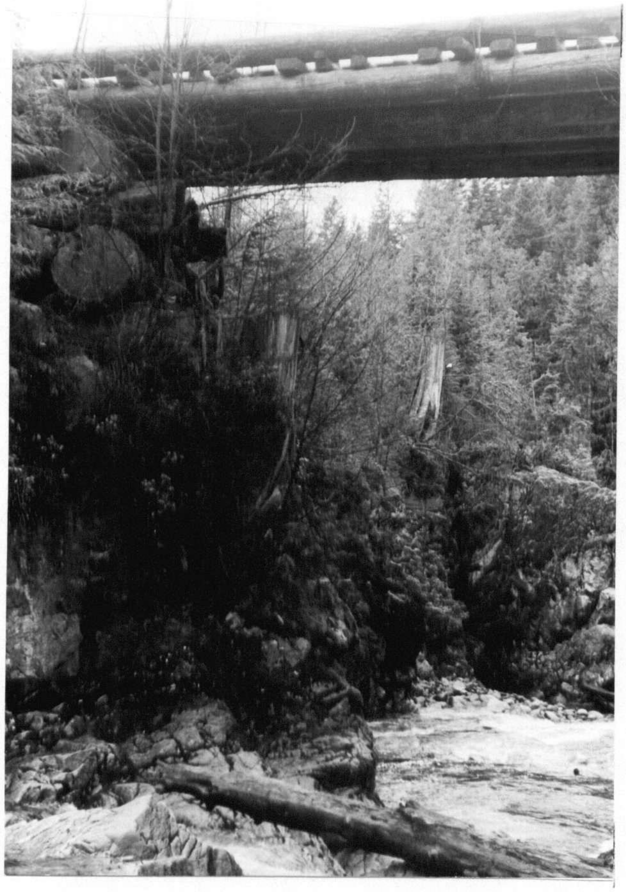


Figure 61 - Detail of south abutment.

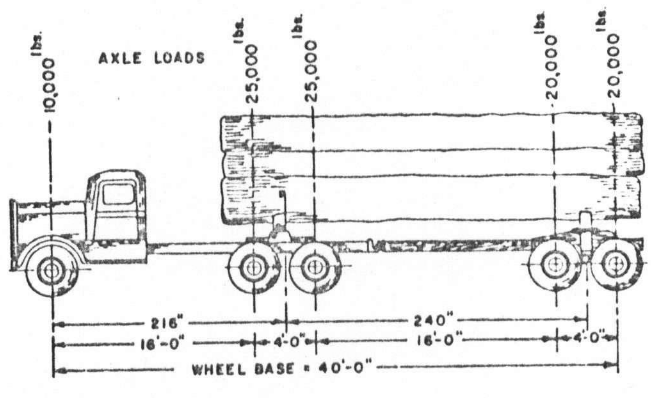


Figure 62 - Design vehicle - 50 ton 5 axle truck.

DESIGN SPECIFICATIONS

One lane bridge with wheel guards and guardrails.

Total length: (a) 1 span - 80 ft.

(b) 3 spans - 40 - 80 - 40 ft.

Total width: 16 ft.

Clear width: 14 ft.

Design vehicle: 50 ton 5 axle on-highway truck[1] (Figure 62)

Material:

Running deck 3" untreated pine

4" treated D. fir

Ties 8" x 6" (on edge) - 12" c.c. treated D. fir

Stringers: Glulaminated D. fir

Allowable stresses of the design material[2]

Douglas Fir - wet service conditions

Bending	1,900 psi
Longitudinal shear	145 psi
Compression parallel to grain	1,200 psi
Compression combined with bending	1,400 psi
Compression perpendicular to grain	305 psi
Modulus of elasticity	1,690,000 psi

Cost estimates are based on average construction and material costs recorded in Takla Logging Company Ltd., Prince George, B.C.

[1] Forestry Handbook for British Columbia, The Forest Club, University of British Columbia, 1971 (Vancouver, Canada). p. 676.

[2] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 13.

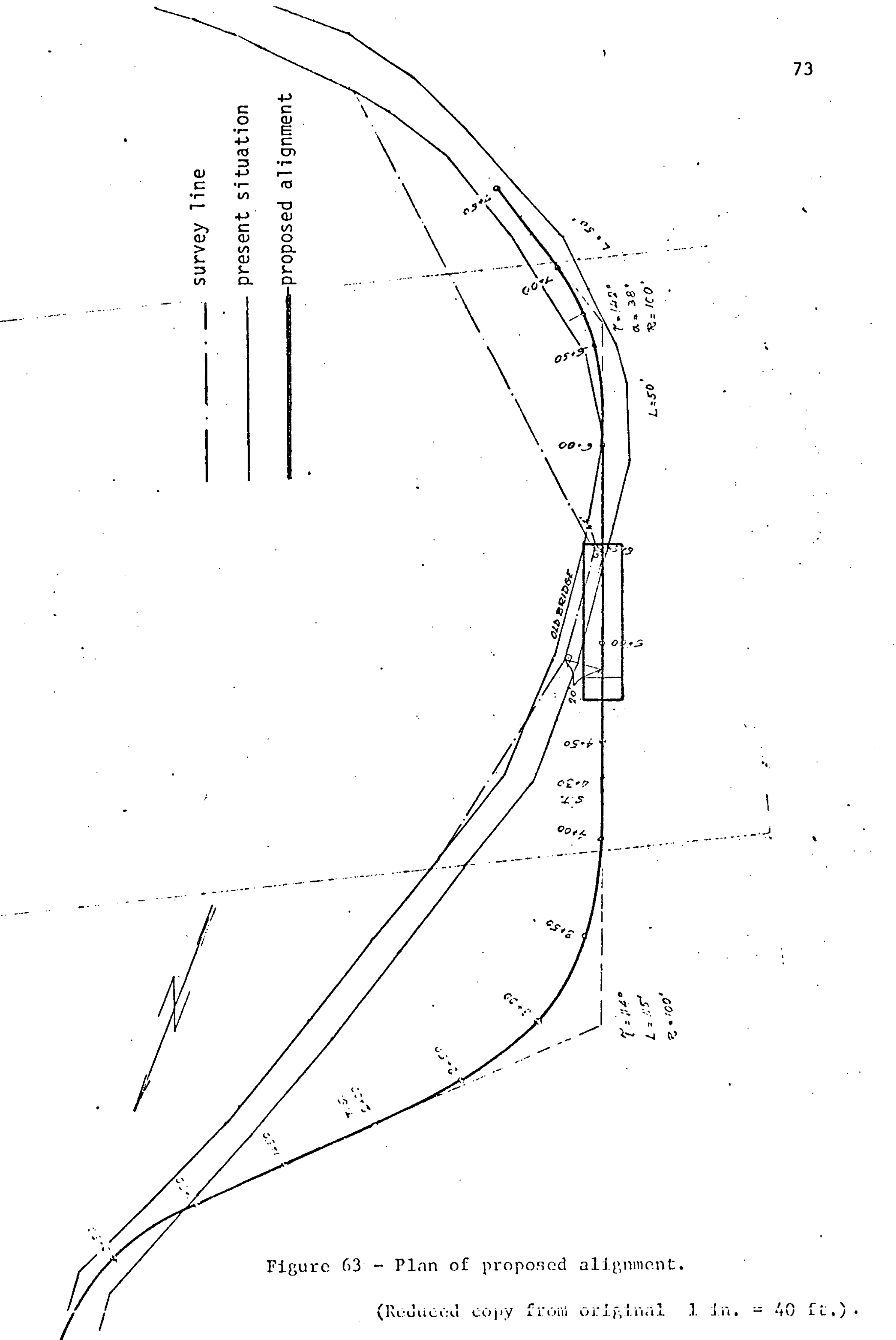


Figure 63 - Plan of proposed alignment.

(Reduced copy from original 1 in. = 40 ft.).

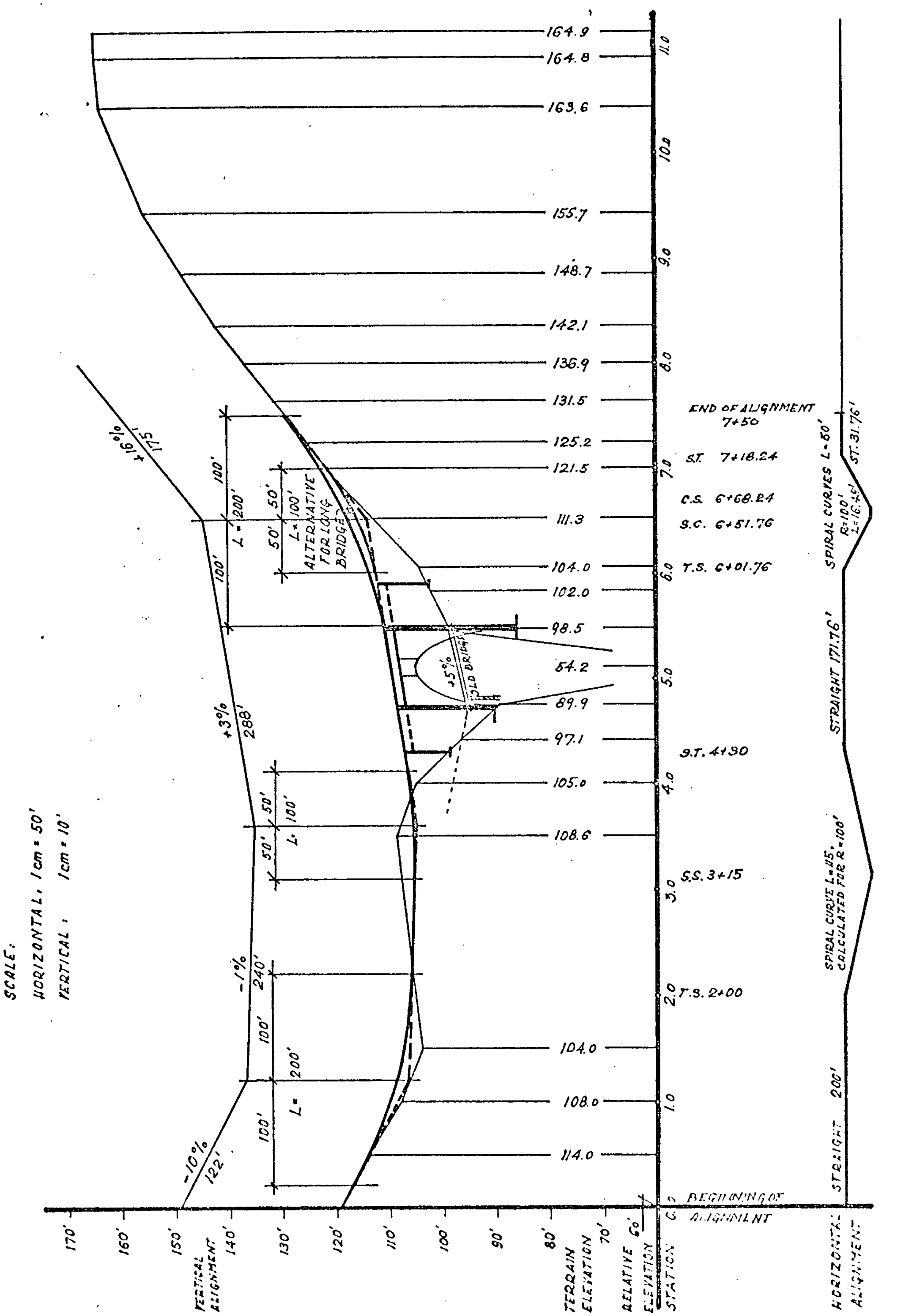


Figure 64 - Profile of proposed alignment.

APPENDIX II

Simple Beam Bridge

SIMPLE BEAM BRIDGE

STRINGERS:

Dead load calculation:

Running planks treated 3" x 14' (48 lbs./cu.ft.)	168 lbs./ln.ft.
untreated 4" x 14' (58 lbs./cu.ft.)	270 lbs./ln.ft.
Ties 6" x 8" x 16' (58 lbs./cu.ft.)	309 lbs./ln.ft.
Stringer - interior	212 lbs./ln.ft.
- exterior	160 lbs./ln.ft.
Diaphragms 8 3/4" x 63" (130 lbs./cu.ft.)	
$5\ (3)\ \frac{4.0 \times 140}{80} =$	98 lbs./ln.ft.
Wheel guards and guardrails (one side)	82 lbs./ln.ft.
Total: Interior stringer	
(56 + 90 + 103 + 212 + 33)	494 lbs./ln.ft.
Exterior stringer	
(28 + 45 + 52 + 160 + 17 + 82)	384 lbs./ln.ft.

Live load calculation: 50 tons = 100 kips = R

$$M_{max} = \frac{Rx^2}{L} - P_L\ e_L$$

$$x = \frac{L}{2} - \frac{P_r\ e_r - P_L\ e_L}{2R}$$

$$x = 40 - \frac{20 \times 20 + 20 \times 16 - 4 \times 25 - 20 \times 10}{2 \times 100} = 40 - 2.1$$

$$x = 37.9 \text{ ft.}$$

$$M_{max} = \frac{100\ (37.9)^2}{80} - 300 = 1,795 - 300 = 1,495 \text{ ft. kips}$$

Interior stringer:

Distribution factor[1] $\frac{S}{5} = \frac{5.0}{5} = 1.0$

Unbalanced load factor .65

$M_{max_{LL}} = 0.65\ (1,495) = 971.8$ ft. kips

$M_{DL} = \frac{.494\ (80)^2}{8} = \underline{395.2 \text{ ft. kips}}$

$M_{Total} = 1,367.0$ ft. kips

$S_{req} = \frac{1,367.0\ (12,000)}{1,900} = 8,634 \text{ in.}^3$

$S_{holes\ for\ rods} = \underline{750 \text{ in.}^3}$

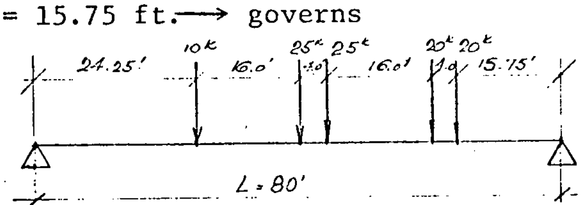
$S_{Total} = 9,384 \text{ in.}^3$

From TDM tables[2]: 14 1/4" x 63"; S = 9,426.4 in.^3

Check for shear stresses:

L/4 = 20 ft.

3d = 15.75 ft. ⟶ governs



$V_{max} = \frac{10(24.25) + 25(40.25 + 44.25) + 20(60.25 + 64.25)}{80} = 60.56$ kips

$V_{LL} = 0.65\ (60.56) = \quad = 39.36$ kips

$V_{DL} = \frac{.494\ (80)}{2} = \underline{19.76 \text{ kips}}$

$V_{Total} = 59.12$ kips

$f_v = \frac{1.5\ (59,120)}{897.8} = 98.8 \text{ psi} < 125 \text{ psi} \longrightarrow$ O.K.

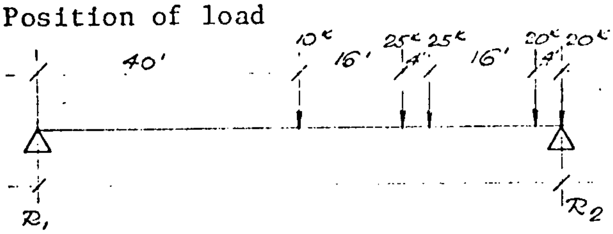
For interior stringers use 14 1/4" x 63" x 82'

[1] Design of highway bridges: CSA Standards S6, 1966 (Ottawa, Canada). p. 29.

[2] Timber Design Manual: Laminated Timber Institute of Canada, 1972 (Ottawa, Canada). p. 25.

Check for bearing:

Position of load



$$R_{2_{LL}} = \frac{10(40) + 25(56 + 60) + 20(76 + 80)}{80} = 80.25 \text{ kips}$$

Interior stringer:

$R = 0.65\ (80,250)$ = 52,162 lbs.

$R_{2_{DL}} = \frac{WL}{2} = \frac{494\ (80)}{2}$ = <u>19,760 lbs.</u>

R_{Total} = 71,922 lbs.

$A = \frac{71,922}{305} = 236 \text{ in.}^2$

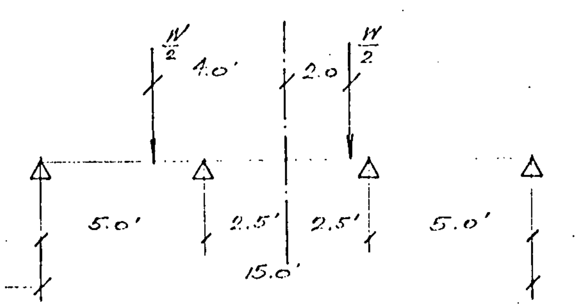
b = 12.25 in.; a = 19.25 in.

bearing plates 12 1/4" x 20" or

caps 12" x 20" x 16'

Exterior stringer:

Eccentricity 2 ft.



by eccentric rivet:

$$R_1 = W\left(\frac{1}{4} + \frac{2(7.5)}{2(7.5)^2 + 2(2.5)^2}\right) =$$

$(0.25 + 0.12)W = 0.37\ W$

$M_{LL} = 1{,}495(.37) = 553.2$ ft. kips

$M_{DL} = \frac{.384(80)^2}{8} = \underline{307.2 \text{ ft. kips}}$

$M_{Total} = 860.4$ ft. kips

$S_{req} = \frac{860.4(12{,}000)}{1{,}900} = 5{,}434 \text{ in.}^3$

$S_{holes} = \underline{\quad 700 \text{ in.}^3}$

$S_{Total} = 6{,}134 \text{ in.}^3$

From TDM tables[3]: 10 3/4" x 63"; $S = 7111.1 \text{ in.}^3$ ⟶ O.K.

Check for shear stresses:

$V_{LL} = 0.37\ V_{max} = 0.37(60.56) = 22.40$ kips

$V_{DL} = \frac{.384(80)}{2} = \underline{15.36 \text{ kips}}$

37.76 kips

$f_v = \frac{1.5(37{,}760)}{677.3} = 84 \text{ psi} < 125 \text{ psi}$ ⟶ O.K.

For exterior stringers use 10 3/4" x 63" x 82'

Check for bearing:

$R_{LL} = 0.37(80.25) = 29{,}692$ lbs.

$R_{DL} = V_{DL} = \underline{15{,}360}$ lbs.

R_{Total} 45,052 lbs.

$A_{req} = \frac{45{,}052}{305} = 147.7 \text{ in.}^2$

b = 10.75 in.; a = 13.74 in.

bearing plates 10 3/4" x 14" or

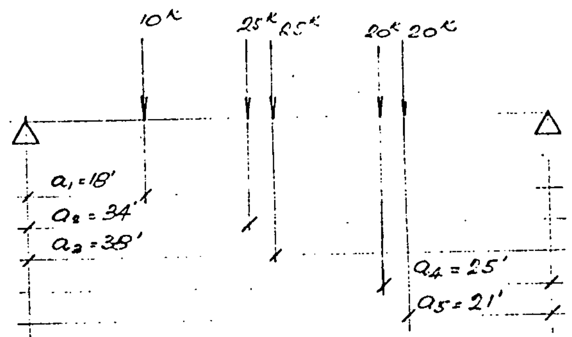
caps 12" x 20" x 18' ⟶ O.K.

[3] Timber Design Manual: Laminated Timber Institute of Canada, 1972 (Ottawa, Canada). p. 24.

Check for deflection: (From TDM tables[4])

$$\Delta = \frac{5PL^3}{n384\ EI} K_\Delta + \frac{5wL^4}{n384\ EI} K_\Delta$$

$$K_{\Delta_{LL}} = 1.6 \frac{a}{L} \left(3 - 4\left(\frac{a}{L}\right)^2\right);\ K_{\Delta_{DL}} = 1.0$$



$$K_{\Delta_1} = 1.6 \frac{18}{80} \left(3 - 4\left(\frac{18}{80}\right)^2\right) = 1.007$$

$$K_{\Delta_2} = 1.6 \frac{34}{80} \left(3 - 4\left(\frac{34}{80}\right)^2\right) = 1.549$$

$$K_{\Delta_3} = 1.6 \frac{38}{80} \left(3 - 4\left(\frac{38}{80}\right)^2\right) = 1.594$$

$$K_{\Delta_4} = 1.6 \frac{25}{80} \left(3 - 4\left(\frac{25}{80}\right)^2\right) = 1.304$$

$$K_{\Delta_5} = 1.6 \frac{21}{80} \left(3 - 4\left(\frac{21}{80}\right)^2\right) = 1.144$$

$$\Delta_1 = \frac{5(10{,}000)(80 \times 12)^3}{4 \times 384(1.69)\ 10^6(296{,}931)} 1.007 = 0.06 \text{ in.}$$

$$\Delta_{2+3} = \frac{5(25{,}000)(80 \times 12)^3}{4 \times 384(1.69)\ 10^6(296{,}931)} 3.143 = 0.45 \text{ in.}$$

$$\Delta_{4+5} = \frac{5(20{,}000)(80 \times 12)^3}{4 \times 384(1.69)\ 10^6(296{,}931)} 2.448 = \underline{0.28 \text{ in.}}$$

$$\Delta_{LL} = 0.79 \text{ in.}$$

[4] Timber Design Manual: Laminated Timber Institute of Canada, 1972 (Ottawa, Canada). p. 127 - 128.

$$\Delta_{LL} \qquad\qquad\qquad\qquad\qquad\qquad = 0.790 \text{ in.}$$

$$\Delta_{DL} = \frac{5(73.2)(80 \times 12)^4}{4 \times 384(1.69)10^6(296,931)} \; 1.000 = \underline{0.806 \text{ in.}}$$

$$\Delta_{Total} \qquad\qquad\qquad\qquad\qquad = 1.596 \text{ in.} < 1.6 \longrightarrow \text{O.K.}$$

$$\Delta_{ALL} = \frac{L}{600} = \frac{80 \times 12}{600} = 1.6 \text{ in.}$$

RUNNING PLANKS:

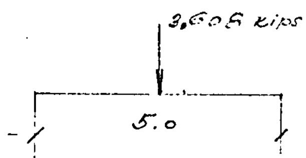
2 layers 3" untreated pine

4" treated D. fir

Wheel load (considering unbalanced load) = 0.65(25) = 16.25 kips

Distribution factor[5] $\frac{S}{4.5} = \frac{1.00}{4.5} = 0.222$

Acting load 0.222(16.25) = 3.608 kips



$$M_{max} = 3.608(1.25) = 4.51 \text{ ft. kips}$$

$$S_{req} = \frac{4.51(12,000)}{1,300} = 41.62 \text{ in.}^3$$

Ties 6" x 8" on edge, 12" c.c.

Check for shear stresses:

$$V = \frac{10P(L - x)(x/d)^2}{9L(2 + (x/d)^2)} = \frac{10(3,608)(5-2.5)(2.5/.66)^2}{9(5.0)(2 + (2.5/.66)^2)} = 1,722 \text{ lbs.}$$

$$A_{req} = \frac{1.5 \times 1,722}{125} = 20.7 \text{ in.}^2 < 48 \text{ in.}^2 \longrightarrow \text{O.K.}$$

Check for bearing:

$$f_{c_1} = \frac{3,608}{6 \times 12} = 50 \text{ psi} < 280 \text{ psi} \longrightarrow \text{O.K.}$$

[5] Design of highway bridges: CSA Standards S6, 1966 (Ottawa, Canada). p. 29.

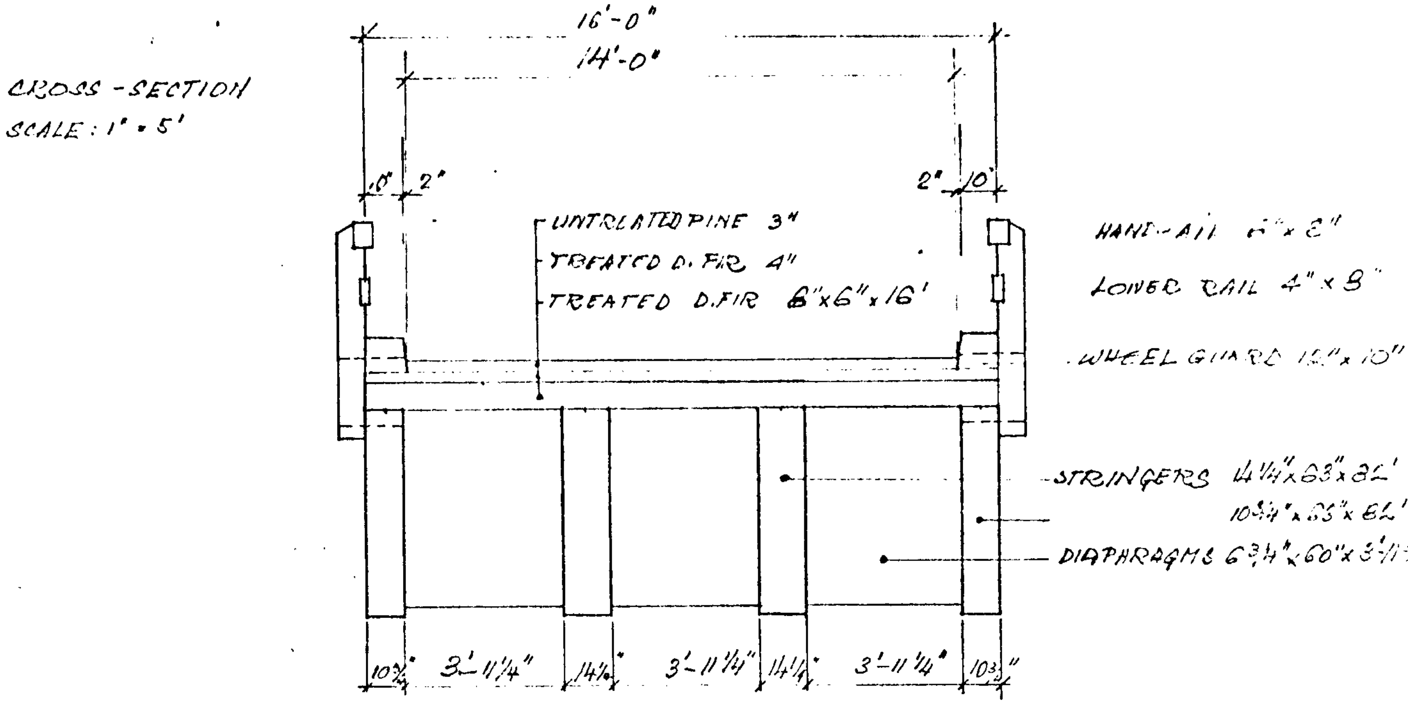
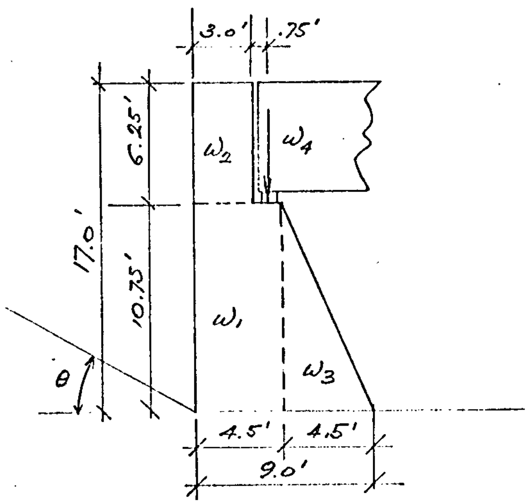


Figure 65 - Arrangement of roadway with wheel guards and guardrails.

ABUTMENTS:

North Abutment



Soil back fill

Pack course sand - 135 lbs./cu.ft.

$\theta = 32^{o}30'$

Additional pressure from truck calculated for substitution height of soil

$P_{max} = 2 \times 25^{k} + 20 \times 20^{k} =$

$= 90{,}000$ lbs. for 4 axles

$V_s = \frac{P}{w_{soil}} = \frac{90{,}000}{135} = 621$ cu.ft.

$w_s = \frac{621}{400} = 1.69$ ft.

Total "h" for acting soil is 18.68 ft.

Resultant of earth pressure is considered horizontal as the angle of overfill is too small to be considered. Friction between soil and concrete wall was considered zero considering wet soil conditions.

Earth pressure calculation:

$$P = R = k\,\frac{wh^2}{2}\ ;\ k = \cos\delta\,\frac{\cos\delta - \sqrt{\cos^2 - \cos^2}}{\cos\delta + \sqrt{\cos^2 - \cos^2}}$$

$\cos\delta = 1.00$; $\cos\theta = 0.8434$; $k = 1 \times \frac{.463}{1.537} = 0.302$

$R = 0.302\,\frac{135 \times 18.68^2}{2} = 7{,}100$ lbs/ln.ft. of abutment

Moment from pressure of soil:

$M_s = 7{,}100\,\frac{18.68}{3} = 44{,}100$ lb.ft.

Moments acting against soil pressure around point A.

Weight of components: $w_1 = 4.5 \times 10.75 \times 0.15 = 7.26$ kips

$w_2 = 3 \times 6.25 \times 0.15 = 2.81$ kips

$w_3 = \frac{1}{2} \times 4.5 \times 10.75 \times 0.15 = 3.63$ kips

$w_4 = \frac{70,240}{16} = 4.39$ kips

$w_{Total} = 18.09$ kips

$M_1 = 7.26 \times 6.75 = 49.00$ ft. kips

$M_2 = 2.81 \times 7.5 = 21.08$ ft. kips

$M_3 = 3.63 \times 3.0 = 10.89$ ft. kips

$M_4 = 4.4 \times 5.25 = 23.1$ ft. kips

$M_{Total} = 104.07$ ft. kips

Location of resultant in footing bottom - distance from A - "x".

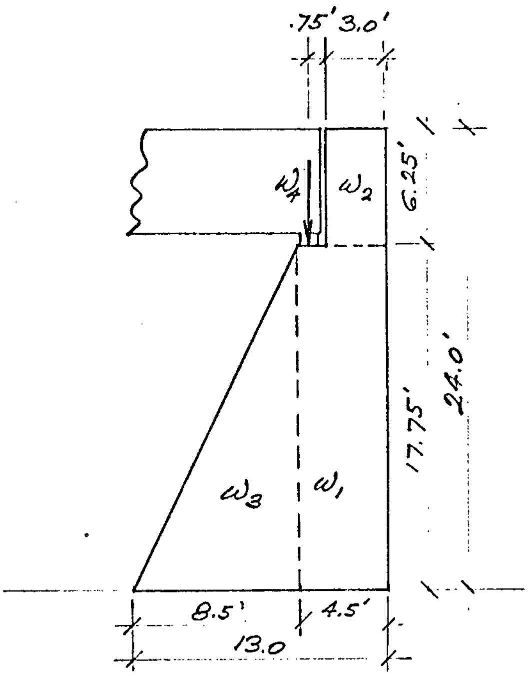
$M_{Total} - M_s = w_{Total}(x)$

$104.07 - 44.1 = 16.8(x)$

$x = \frac{59.97}{18.09} = 3.32$ ft.

Therefore resultant lies within middle 1/3 $\longrightarrow$ O.K.

South Abutment



Same conditions as for North Abutment.

Additional pressure from truck = 2 ft.

Total h = 26 ft.

Earth pressure:

$$P = 0.302 \times \frac{135 \times 26^2}{2} = 13.7 \text{ kips}$$

$$M_{soil} = 13.7 \times \frac{26}{3} = 119.2 \text{ ft. kips}$$

Weight components:

$$w_1 = 4.5 \times 17.75 \times 0.15 = 11.98 \text{ kips}$$

$$w_2 = 3.0 \times 6.25 \times 0.15 = 2.81 \text{ kips}$$

$$w_3 = \frac{8.5 \times 17.75}{2} \times 0.15 = 11.32 \text{ kips}$$

$$w_4 = \frac{70,240}{16} = \underline{4.39 \text{ kips}}$$

$$w_{Total} = 30.5 \text{ kips}$$

$$M_1 = 11.98 \times 10.75 = 128.78 \text{ ft. kips}$$

$$M_2 = 2.81 \times 11.5 = 32.34 \text{ ft. kips}$$

$$M_3 = 11.32 \times 5.66 = 64.05 \text{ ft. kips}$$

$$M_4 = 4.39 \times 9.25 = \underline{40.61 \text{ ft. kips}}$$

$$M_{Total} = 266.22 \text{ ft. kips}$$

$$M_{soil} = 119.2 \text{ ft. kips}$$

$$x = \frac{266.22 - 119.2}{30.5} = 4.82 \text{ ft.} > 4.33 \text{ ft.} \longrightarrow \text{O.K.}$$

BILL OF MAIN MATERIAL AND PRELIMINARY COST ESTIMATE

Running deck (untreated) 3" x 14' x 82'	= 3,444 fbm @ \$230/Mfbm	= \$ 792
(treated) 4" x 16' x 82'	= 4,592 fbm @ \$340/Mfbm	= \$ 1,561
Ties 82 (8" x 6" x 16')	= 5,248 fbm @ \$380/Mfbm	= \$ 1,994
Guardrail (untreated) 2 x 10 (8" x 8" x 5')	= 1,440 fbm @ \$260/Mfbm	= \$ 659
2 (82' x 6" x 8")	= 656 fbm	
2 (82' x 4" x 8")	= 437 fbm	
Total	= 2,533 fbm	
Wheel guard (treated) 2 (82' x 10" x 12")	= 1,640 fbm @ \$380/Mfbm	= \$ 623
Total		= \$ 5,629
Stringers: Interior 2 (14 1/4" x 63" x 82')	= 1,023 cu.ft.	
Exterior 2 (10 3/4" x 63" x 82')	= 772 cu.ft.	
Diaphragms 15 (6 3/4" x 60" x 5')	= 210 cu.ft.	
Total	2,005 cu.ft.@ \$ 27	= \$54,135

Concrete Abutments

North Abutment: $\frac{1}{27}(4.5 \times 10.75) + (3 \times 6.25) + (\frac{4.5 \times 10.75}{2})\, 16 = 55.1$ cu.yd.

South Abutment: $\frac{1}{27}(4.5 \times 17.75) + (3 \times 6.25) + (\frac{8.5 \times 17.75}{2})\, 16 = 103.2$ cu.yd.

Total = 158.3 cu.yd.

@ \$250 = \$39,575

Total fill 2,741 CCY[1] = 4,056 LCY[2] @ \$2.20 = \$ 8,923

Total for simple beam bridge = \$108,262

[1] CCY - Compacted cubic yards

[2] LCY - Loose cubic yards

APPENDIX III

Continuous Beam (Two Equal Spans)

Single Strutframe Bridge

CONTINUOUS BEAM

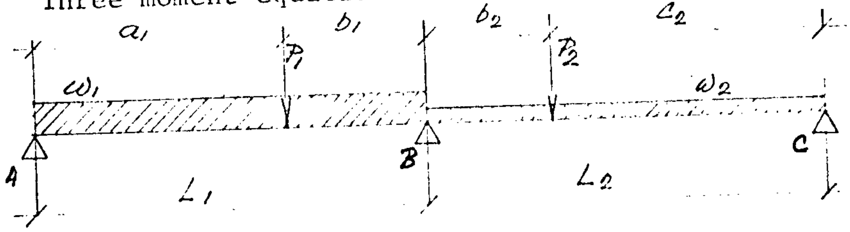
TWO EQUAL SPANS:

Conditions are the same as for single beam calculations. Solve for design truck 50 ton. Find M_{max} (negative and/or positive) according to the theorem of three moments using influence lines.

$$M_{max} = (P_1 y_1 + P_2 y_2 \cdots\cdots P_n y_1)\ L$$

Superposition of the truck (position in which the maximum moment occurs) has been found by trial and error. Values used for influence lines (Figures 66 and 67) were calculated by Adamovich[1]. Negative moment is always governing when the same height of the beam is designed. For changing height also positive moment (between supports) has to be found.

Three moment equation.



$$M_A L_1 + 2M_B (L_1 + L_2) + M_C L_2 = 1/4\ (w_1 L_1^3 + w_2 L_2^3) -$$

$$- \Sigma \left[\frac{P_1 a_1}{L_1} (L_1^2 - a_1^2) \right] - \Sigma \left[\frac{P_2 b_2}{L_2} (L_2^2 - c_2^2) \right]$$

[1] L. Adamovich, Erdeszeti Hideptes, ("Lectures on Forest Bridges") (Sopron, Hungary: University of Sopron, 1949). p. 43. (Mimeographed.)

Since $L_1 = L_2$ and $w_1 = w_2$ and $M_A = 0$, $M_c = 0$.

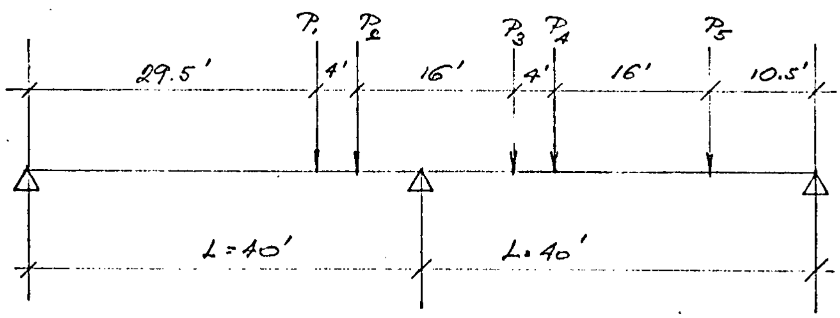
Dead load moment.

$$M_{max} = -\ 1/8\ wL^2$$

Live load moment.

$$M_{max} = \frac{1}{4L}\left(-\ \Sigma\left[\frac{Pa}{L}\ (L^2 - a^2)\right]\ -\ \Sigma\left[\frac{Pc}{L}\ (L^2 - c^2)\right]\right)$$

Superposition of the design vehicle (Appendix I).

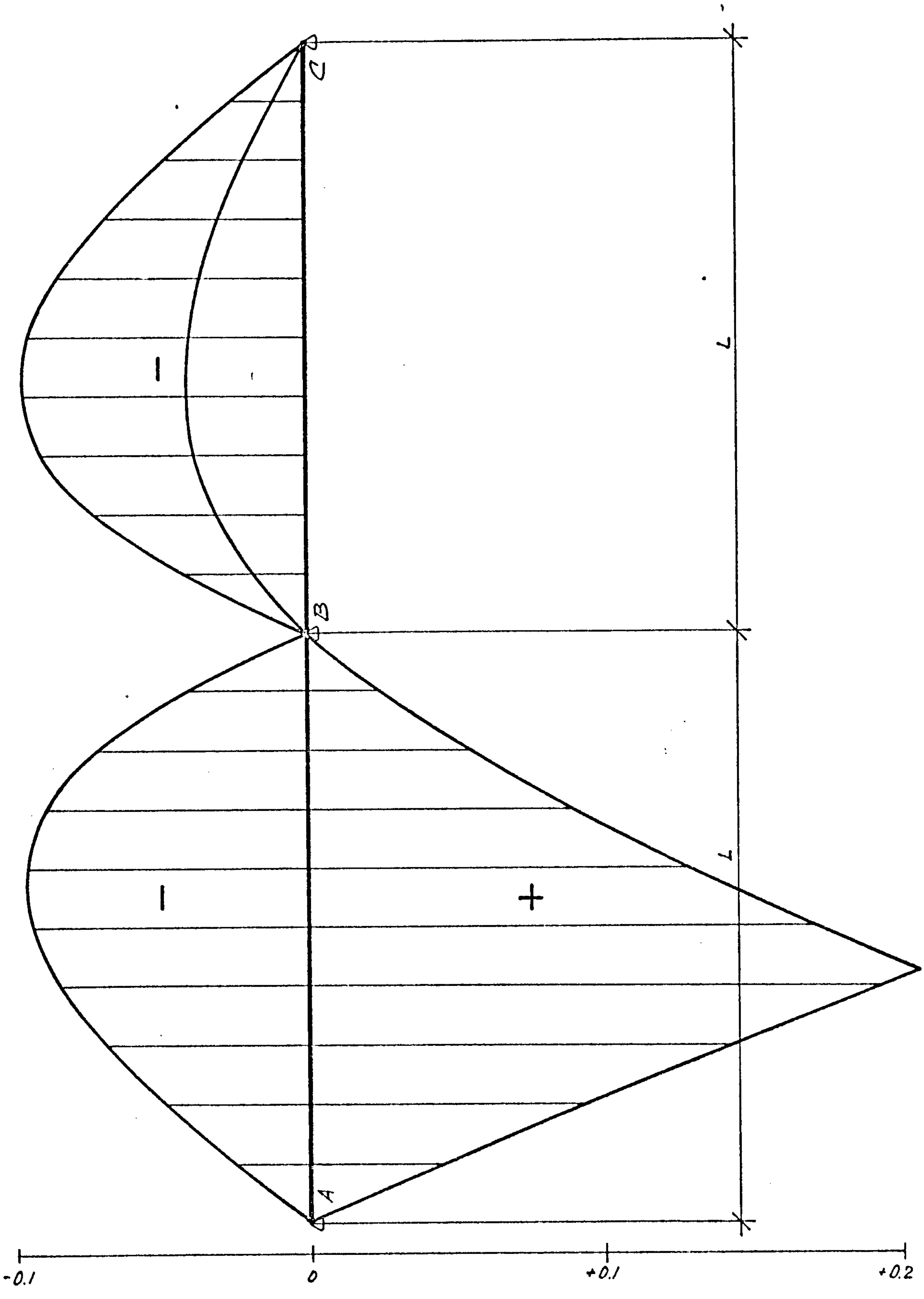


$P_1 = P_2 = 20$ kips

$P_3 = P_4 = 25$ kips

$P_5 = 10$ kips

$$M_{max}\ (\text{live}) = -\ [(0.084 + 0.066)\ 20 + (0.080 + 0.092)\ 25 + 0.063 \times 10]\ 40 = -329.2\ \text{ft. kips}$$



re 66 - Two equal spans continuous beam moment influence lines.
(Values plotted on deciles of each span).

Distribution of the load between interior and exterior stringers is the same as calculated for simple beam bridge (Appendix II).

Interior stringer:

$M_{LL} = -.65\ M_{max} = -.65\ (329.2) = -213.98$ ft. kips

Dead load.

Deck and ties	249 p.l.f. or lbs./cu.ft.
Stringers	84 p.l.f. or lbs./cu.ft.
Diaphragms	16 p.l.f. or lbs./cu.ft.
Total	349 p.l.f. or lbs./cu.ft.

$M_{DL} = -1/8\ wL^2 = -1/8\ (.349)(40)^2 = -72.80$ ft. kips

$M_{Total} = -286.78$ ft. kips

$S_{req} = \frac{286.76(12,000)}{1,900} = 1,811\ \text{in.}^3$

10 3/4" x 33"; $S = 1,951.1\ \text{in.}^3$; $A = 354.8\ \text{in.}^2$

Check for shear stresses:

Dead load.

Using tabulated coefficients from TC[2].

$V_A = .219\ wL = .219\ (.349)\ 80 = 6.11$ kips

$V_B = .315\ wL = .315\ (.349)\ 80 = 8.79$ kips

Live load.

Using shear influence lines calculated by Adamovich[3] (Figure 66).

[2] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 115.

[3] L. Adamovich, Erdeszeti Hideptes, ("Lectures on Forest Bridges") (Sopron, Hungary: University of Sopron. 1949). p. 44. (Mimeographed.)

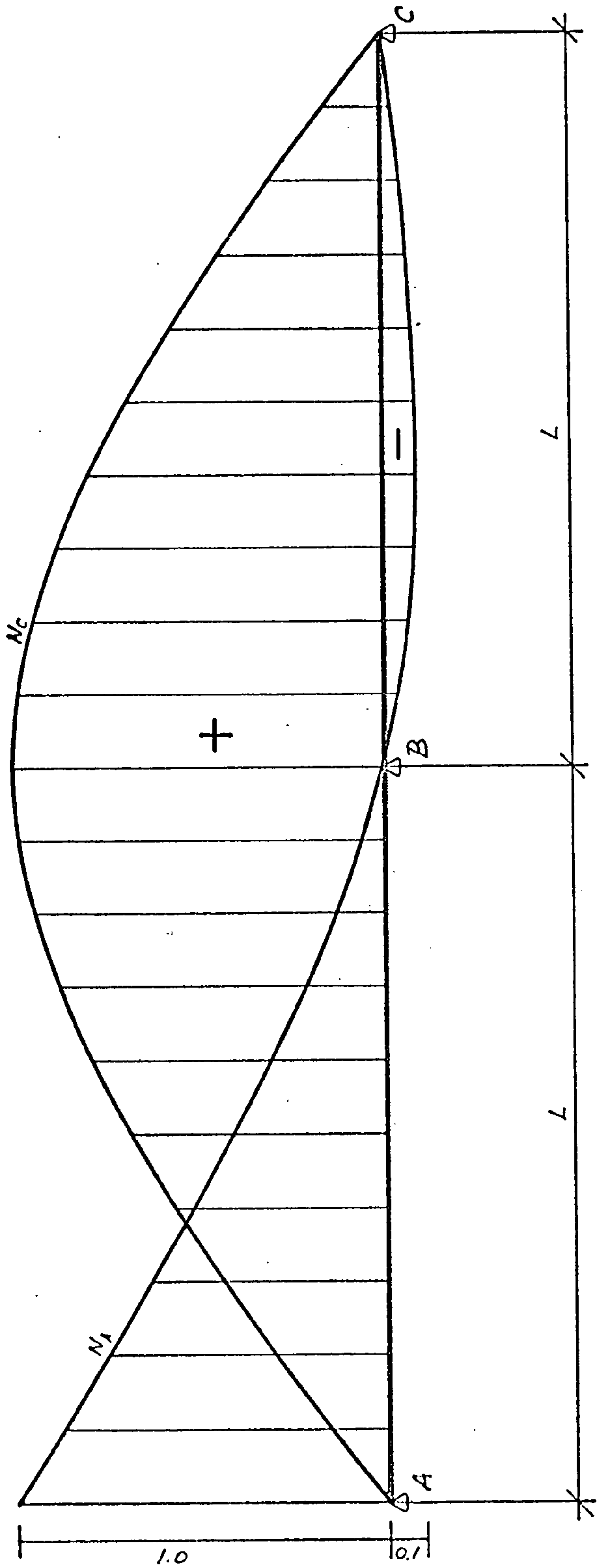
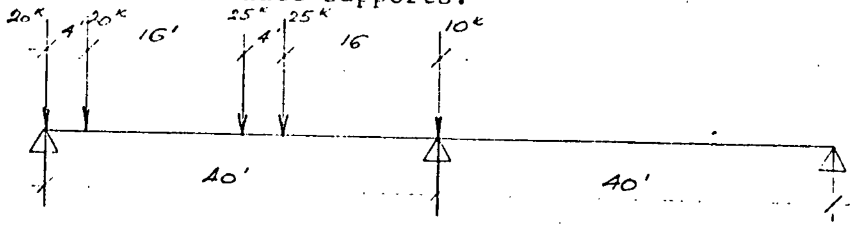


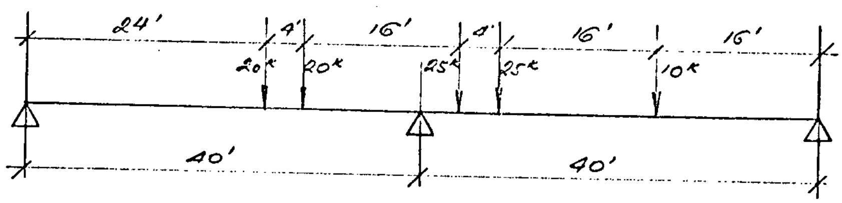
Figure 67 - Two equal spans continuous beam shear influences lines.

(Values plotted on deciles of each span).

Superposition of design vehicle has been considered separately for outer and intermediate supports.



V_A = (1.00 + .88) 20 + (.42 + .31) 25 = 55.85 kips



V_B = (.79 + .87) 20 + (.99 + .95) 25 + (.56) 10 = 87.30 kips

Shear for interior stringer.

V = .65 x 87.30 = 56.745 kips

Governing shear occurs at R_B.

V_{DL} = 8.790 kips

V_{LL} = <u>56.745 kips</u>

V_{Total} = 65.535 kips

$$fv = \frac{1.5\ V_{max}}{n \times A} = \frac{1.5(65.535)}{354.8} = 277 \text{ psi} > 145 \text{ psi} \longrightarrow \text{N.G.}$$

As per the calculation, shear forces are governing factor over the moment with continuous beam, whilst with the simple beam the situation is opposite.

Try:

14 1/4" x 49 1/2"; A = 705.4 in.^{2}; w = 162 p.l.f.

V_{DL} = .315 (432) 80 = 10,886 lbs.

V_{LL} = (as per above) = <u>56,745 lbs</u>.

V_{Total} = 67,631 lbs.

$$f_v = \frac{1.5(67,631)}{705.4} = 143.8 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

For interior stringers use 14 1/4" x 49 1/2" x 82'.

Exterior stringer:

Dead load.

Deck and ties	125 p.l.f.	(as calculated for simple beam bridge, Appendix II)
Stringers	102 p.l.f.	
Diaphragms	8 p.l.f.	
Handrail and wheel guard	82 p.l.f.	
	317 p.l.g.	

$M_{DL} = 1/8\ (.317)(40)^2 = \quad 63.4$ ft. kips

$M_{LL} = .37\ (M_{max}) = .37\ (329.2) = 121.8$ ft. kips

$M_{Total} = 185.2$ ft. kips

$$S_{req} = \frac{185.2(12,000)}{1,900} = 1,169 \text{ in.}^3$$

For equal height of stringers choose:

8 3/4" x 49 1/2"; $S = 3,573.3$ in.^{3}; $A = 433.1$ in.^{2}

Check for shear at reaction B:

$V_{DL} = .315\ (317)\ 80 = 7,988$ lbs.

$V_{LL} = .37\ (V_{max}) = 0.37\ (87,300) = 32,301$ lbs.

$V_{Total} = 40,289$ lbs.

$$f_v = \frac{1.5(40,289)}{433.1} = 139.5 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

Reactions:

Dead load - using tabulated coefficients from TC[4].

[4] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 115.

$R_A = .219\ wL$

$R_B = .625\ wL$

Live load - since shear stresses caused by moving load are approximate equal reactions, values of V_{max} at A = R_A and V_{max} at B = R_B (governs).

R_B - Interior stringer: $R_{LL} = .65\ (V_{max}) = 56.74$ kips

$R_{DL} = .625(.432)(80) = \underline{21.60 \text{ kips}}$

$R_{Total} = 78.34$ kips

Exterior stringer: $R_{LL} = .37\ (V_{max}) = 32.30$ kips

$R_{DL} = .625(.317)(80) = \underline{15.85 \text{ kips}}$

$R_{Total} = 48.15$ kips

Check for bearing:

Interior stringer:

$A_{req} = \frac{78,340}{305} = 257 \text{ in.}^2 = 14\ 1/4'' \times 18''$

Exterior stringer:

$A_{req} = \frac{48,150}{305} = 158 \text{ in.}^2 = 8\ 3/4'' \times 18.1'' \longrightarrow$ governs

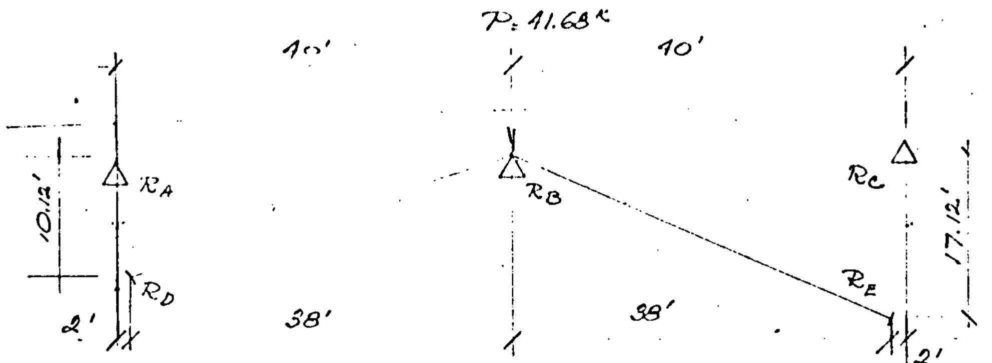
Cross-element in the middle span will be glulam beam 10 3/4" x 19 1/2" with elements positioned horizontally.

Struts:

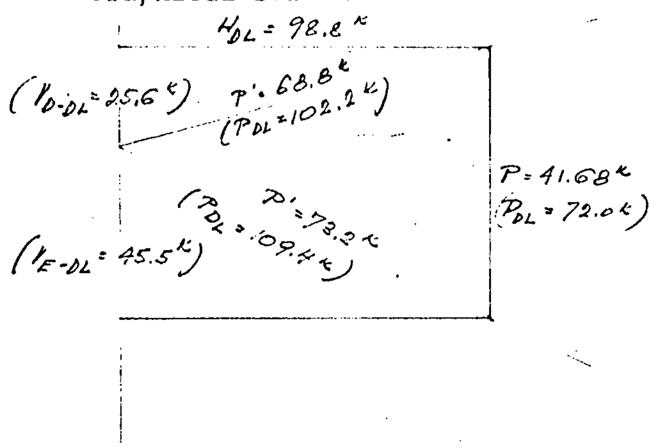
Solved as long simple columns[5].

Loading on struts considered equally distributed in regard with previously calculated eccentricity.

[5] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada), p. 117.



Graphical solution:



$$L_1 = \sqrt{(38)^2 + (10.12)^2} = 39.32 \text{ ft.}$$

$$L_2 = \sqrt{(38)^2 + (17.12)} = 41.68 \text{ ft.} \longrightarrow \text{governs}$$

Interior stringer:

Slenderness ratio:

$$\frac{L_2}{a} = \frac{41.68 \times 12}{10.75} = 46.53$$

$$K = .641 \sqrt{E/Fc} = .641 \sqrt{\frac{1,690,000}{1,400}} = 22.27 < 50 \longrightarrow \text{O.K.}$$

$$\frac{P}{A} = \frac{.274\ E}{(\frac{L}{d})^2} = \frac{.274\ (1,690,000)}{(46.53)^2} = 213.9 \text{ psi}$$

$$A_{req} = \frac{P'}{213.9} = \frac{73,200}{213.9} = 342 \text{ in.}^2$$

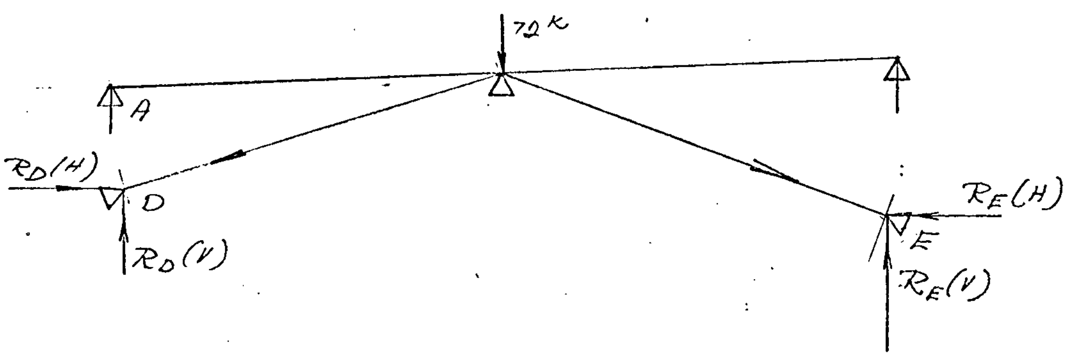
To obtain slenderness ratio K > 50 glulaminated member of d_{min} = 10 3/4" has to be used.

Use: 10 3/4" x 33" x 40' and 42'

w = 83.8 p.l.f.; S = 1,951.1 $in.^3$;

A = 354.8 $in.^3$ > 342 $in.^2$ ⟶ O.K.

Dead load reactions[6]:



$R_c = R_A$ = .219 wL = .219 (1.44) (80) = 25.2 kips = 1.59 kips/ln.ft.

R_B = .625 wL = .625 (1.44) (80) = 72.0 kips = 4.50 kips/ln.ft.

From graphical solution:

$R_D(H)$ = 98.8 kips = 6.18 kips/ln.ft.

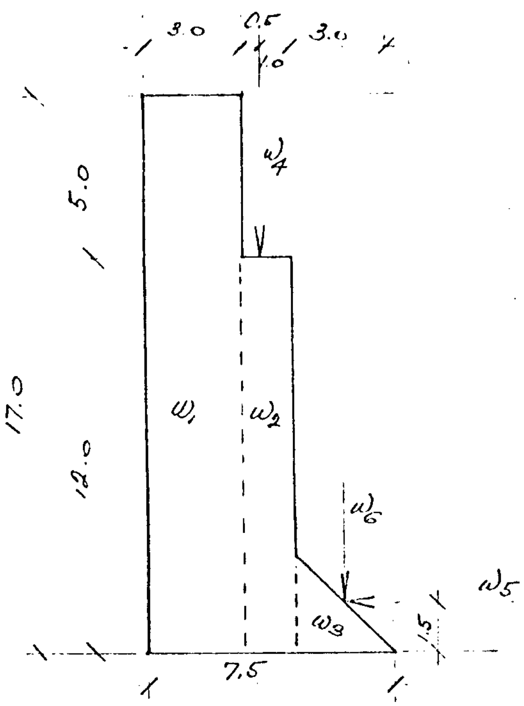
$R_D(V)$ = 25.6 kips = 1.60 kips/ln.ft.

$R_E(H)$ = 98.8 kips = 6.18 kips/ln.ft.

$R_E(V)$ = 45.5 kips = 2.84 kips/ln.ft.

6 Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 115.

North Abutment



M_{soil} = 44.1 ft. (as calculated in Appendix II)

Weight of components:

$w_1 = 3.0(17.0)(0.15) = 7.65$ kips/ln.ft.

$w_2 = 1.5(12.0)(0.15) = 2.70$ kips/ln.ft.

$w_3 = 1.5(3.0)(0.15) = .68$ kips/ln.ft.

$w_4 = R_A = 1.59$ kips/ln.ft.

$w_5 = R_D(H) = 6.18$ kips/ln.ft.

$w_6 = R_D(V) = \underline{1.60}$ kips/ln.ft.

$w_{Total} = 20.06$ kips/ln.ft.

$M_1 = 7.65(6.0) = 45.90$ ft. kips

$M_2 = 2.7(3.75) = 10.12$ ft. kips

$M_3 = .68(1.5) = 1.02$ ft. kips

$M_4 = 1.59(4.0) = 6.36$ ft. kips

$M_5 = 6.18(1.5) = 9.27$ ft. kips

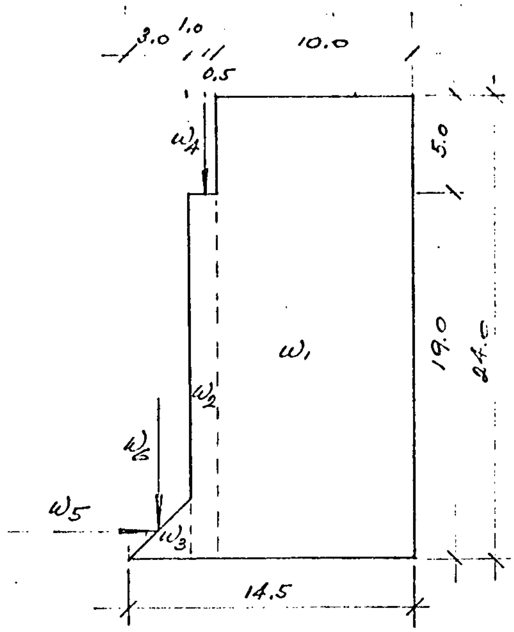
$M_6 = 1.6(1.5) = \underline{2.40}$ ft. kips

M_{Total} 75.08 ft. kips

$M_{Total} - M_{soil} = 75.08 - 20.06 = 55.02$ ft. kips

$x = \frac{55.06}{20.06} = 2.74$ ft.> 2.5 ft. ⟶ O.K.

South Abutment



M_{soil} = 119.2 ft. kips

Weight of components:

w_1 = 10.0(24.0)(.15) = 36.00 kips/ln.ft.

w_2 = 1.5(17.0)(.15) = 3.82 kips/ln.ft.

w_3 = 3.0(1.5)(.15) = 0.68 kips/ln.ft.

$w_4 = R_c$ = 1.59 kips/ln.ft.

$w_5 = R_E(H)$ = 6.18 kips/ln.ft.

$w_6 = R_E(V)$ = 2.84 kips/ln.ft.

w_{Total} = 51.11 kips/ln.ft.

M_1 = 36.0(9.5) = 342.0 ft. kips

M_2 = 3.82(3.75) = 14.32 ft. kips

M_3 = .68(1.5) = 1.02 ft. kips

M_4 = 1.59(4.0) = 6.36 ft. kips

M_5 = 6.18(1.5) = 9.27 ft. kips

M_6 = 2.84(1.5) = 4.26 ft. kips

M_{Total} = 377.23 ft. kips

$M_{Total} - M_{soil}$ = 377.23 - 119.2 = 258.03 ft. kips

$x = \frac{258.03}{51.11}$ = 5.05 ft.> 4.83 ft.⟶O.K.

BILL OF MAIN MATERIAL AND PRELIMINARY COST ESTIMATE

Running deck, ties, wheel guard and guardrail			= $ 5,629
Stringers:	Interior 2 (14 1/4" x 49 1/2" x 82')	= 803 cu.ft.	
	Exterior 2 (8 3/4" x 49 1/2" x 82')	= 493 cu.ft.	
	Diaphragms 15 (6 3/4" x 45" x 5')	= 158 cu.ft.	
	Struts 4 (10 3/4" x 33" x 42')	= 413 cu.ft.	
	4 (10 3/4" x 33" x 40')	= 394 cu.ft.	
	Diaphragms 18 (6 3/4" x 30" x 5')	= 127 cu.ft.	
	Cross element 8 3/4" x 30" x 16'	= 29 cu.ft.	
Total		2,417 cu.ft. @ $27	= $ 65,259
Abutments			
North Abutment:	([3 x 17] + [1.5 x 12] + [1.5 x 3]) 16	= 43.6 cu.yd.	
South Abutment:	([10 x 24] + [1.5 x 17] + [1.5 x 3]) 16	= 160.0 cu.yd.	
Total		= 304.6 cu.yd.	
		@ $250	= $ 50,900
Total fill (From Appendix II)			= $ 8,923
Total for strutframe bridge			= $130,711

APPENDIX IV

Continuous Beam - Three Spans

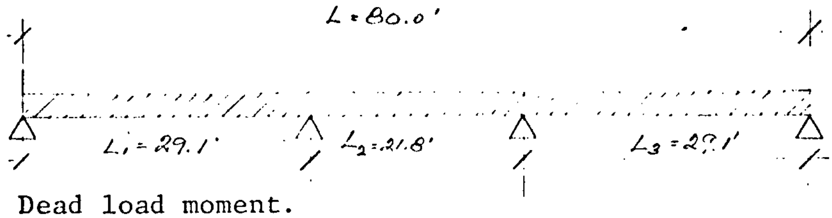
Double Strutframe Bridge

Three-hinged Arch Bridge

CONTINUOUS BEAM

THREE SPANS:

$L_1 = L_3$; $L_2 = 0.75\ L_1$;



Dead load moment.

$$M_A L_1 + 2M_B\ (L_1 + L_2) + M_C\ L_2 = 1/4\ w\ (L_1^{\ 3} + L_2^{\ 3}) =$$

$$101.80\ M_B + 21.80\ M_C = 1/4(750)(35{,}000) =$$

$$M_B = \frac{6{,}570}{101.80} - \frac{21.80}{101.80}\ M_c$$

$$M_B = 64.6 - 0.214\ M_C$$

$$M_B L_2 + 2M_C\ (L_2 + L_3) + M_D L_3 = -1/4\ w\ (L_2^{\ 3} + L_3^{\ 3})$$

$$21.80\ M_B + 101.8\ M_C = -6{,}570$$

$$M_C = -\frac{6{,}570}{101.80} - \frac{21.8}{101.80}\ M_B$$

$$M_C = -64.6 - 0.214\ M_B$$

$$M_B = -64.6 - 0.214\ (64.6 - 0.214\ M_B)$$

$$M_B = -64.6 - 13.8 + 0.0458\ M_B$$

$$.954\ M_B = -78.4 \text{ ft. kips}$$

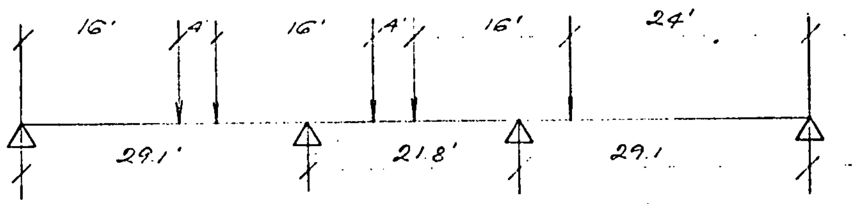
$$M_B = -82.2 \text{ ft. kips}$$

$$M_C = -64.6 - 0.214 \times 82.2 = -82.2 \text{ ft. kips}$$

Live load M_{max}.

According to influence lines (Figure 68).

Superposition of the design vehicle.



$$M_{max} = - [(0.085 + 0.086)\ 25 + (0.063 + 0.067) \times 20 -$$
$$- 0.012 \times 10)L_2 = [4.27 + 2.60 - 0.12] \times 21.80 = -147.1 \text{ ft. kips}$$

Live M_{max} = -147.1 ft. kips

Dead M_{max} = -82.2 ft. kips

M_{Total} =-229.3 ft. kips

Interior stringer:

M_{max} = .65 (229.3) = 149.04 ft. kips

$$S_{req} = \frac{149.04(12,000)}{1,900} = 941 \text{ in.}^3$$

S_{holes} approximately = 300 in.^{3}

8 3/4" x 30"; w = 62.0 p.l.f.; A = 262.5 in.^{2};

S = 1,312.5 in.^{3} > 1,241 in.^{3} ⟶ O.K.

Exterior stringer:

M_{max} = .37(229.3) = 84.84 ft. kips

$$S_{req} = \frac{84.84(12,000)}{1,900} = 535 \text{ in.}^3$$

S_{holes} approximately = 200 in.^{3}

5" x 30"; w = 35.4 p.l.f.; A = 150.0 in.^{2};

S = 750.0 > 735 in.^{3} ⟶ O.K.

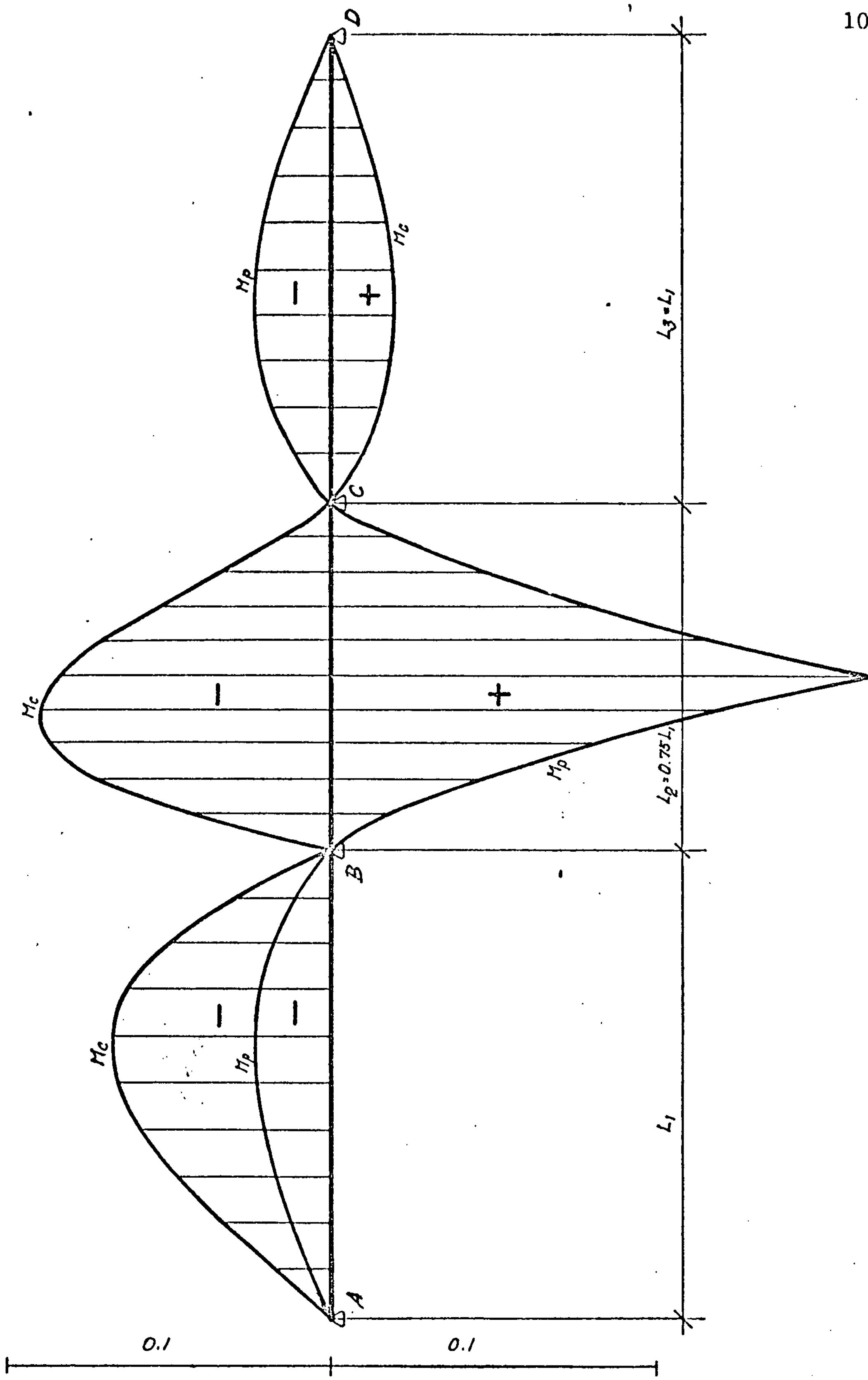
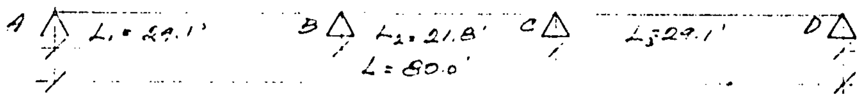


Figure 68 - Three span continuous beam moment influence lines.

(Values plotted on deciles of each span).

Shear and reactions[1].



D = A = .1606 x w x L = 10.0 kips w = .75 kips/ft.

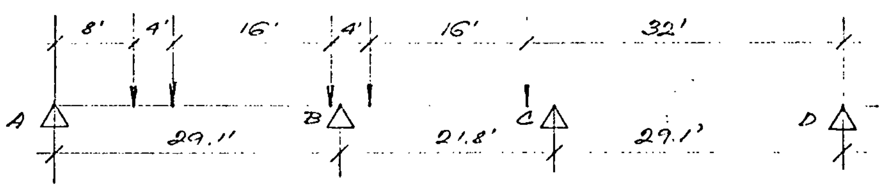
$B_{(L_1)}$ = .2180 x w x L = 13.1 kips L = 80 ft.

$B_{(L_2)}$ = .183 x w x L = 11.0 kips

$R_C = R_B = B_{(L_1)} + B_{(L_2)}$ = 24.1 kips

Live load (using influence lines, Figure 69).

Superposition of the design vehicle.



[(0.37 + .55) 20 + (.98 + .99) 25 + 0.14 x 10] = 79 kips

$V_{max} = V_{DL} + V_{LL}$ = 13.1 + 79.0 = 92.1 kips = 92,000 lbs.

R_B = 24.1 + 79.0 = 103.1 kips = 103,100 lbs.

Check for shear stresses:

Interior stringer:

$V = 0.65\ V_{max} = 0.65(92,000) = 59.8$ kips

$$f_v = \frac{1.5(59,800)}{223.1} = 402 \text{ psi} > 145 \text{ psi} \longrightarrow \text{N.G.}$$

[1] Steel Construction: American Institute of Steel Construction, 1951 (New York, N.Y., U.S.A.). p. 383.

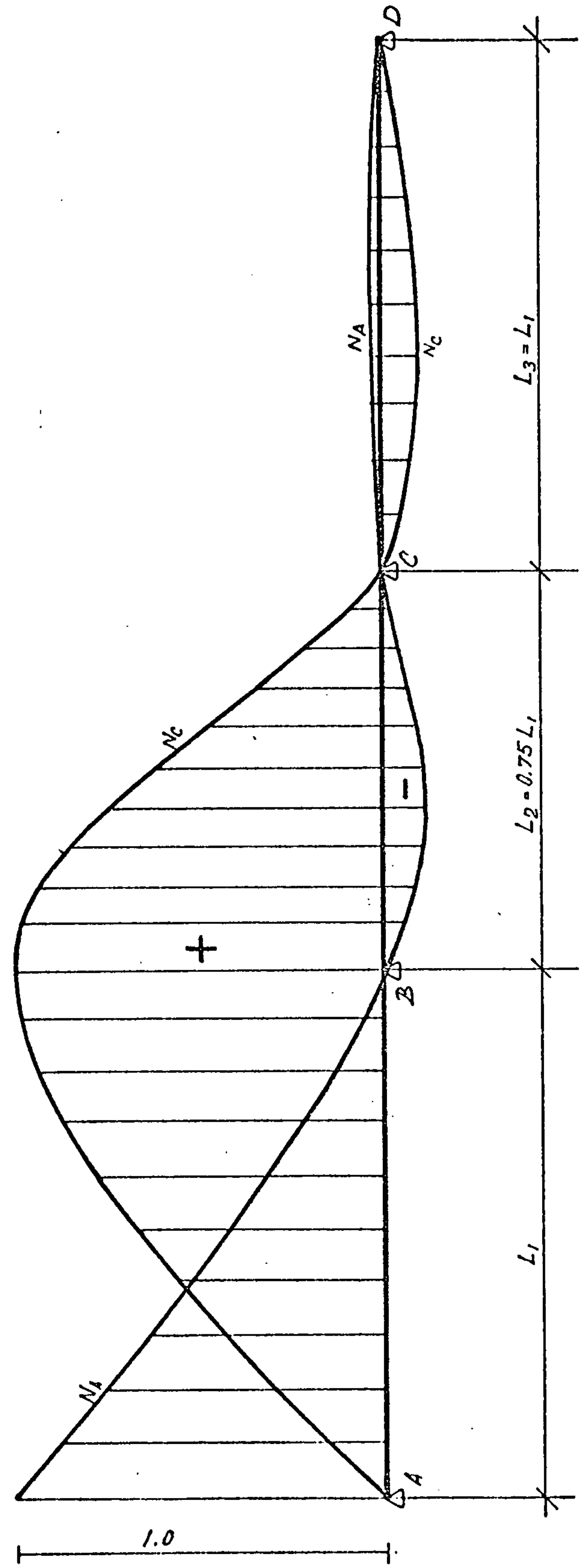


Figure 69 - Three span continuous beam shear influence lines.

(Values plotted on deciles of each span).

Use:

14 1/4" x 43 1/2"; w = 146 p.l.f.; S = 4,494.1 in.^{3}; A = 619.9 in.^{2}

$$f_v = \frac{1.5(59,800)}{619.9} = 144.7 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

Exterior stringer:

$$V = 0.37\ V_{max} = .37(92,000) = 34.04 \text{ kips}$$

$$f_v = \frac{1.5(34,040)}{127.5} = 400.4 \text{ psi} > 145 \text{ psi} \longrightarrow \text{N.G.}$$

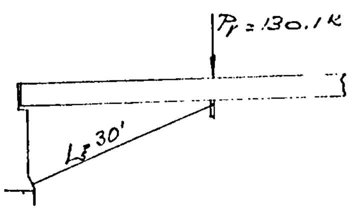
Use:

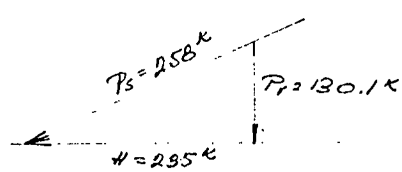
8 3/4" x 43.5"; w = 89.9 p.l.f.; S = 2,759.5 in.^{3}; A = 380.6 in.^{2}

$$f_v = \frac{1.5(34,040)}{380.6} = 134.2 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

Struts: solved as long simple columns[2].

Forces in columns considered equally distributed as per calculation of eccentric rivet in Appendix II.





Compression:

$$C = .37(258) = 95.46 \text{ kips}$$

$$K = .641 \sqrt{\frac{E}{FC} \times \frac{K_{GE}}{K_{GC}}} = .641 \sqrt{\frac{1.69 \times 10^6}{1,400} \times \frac{1.0}{1.0}} = 22.27$$

Slenderness ratio:

$$C_C = \frac{Ls}{d} = \frac{30(12)}{8.75} = 41.14 < 50 \text{ and } > K$$

[2] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 117.

Use slenderness factor:

$$K_C = \frac{0.274\ E}{(C_C)^2} = \frac{0.274(1.69 \times 10^6)}{(41.14)^2} = 273.6$$

$$A_{req} = \frac{P_s}{K_C} = \frac{95,460}{273.6} = 348.9 \text{ in.}^2$$

Use:

8 3/4" x 40 1/2"; w = 83.7 p.l.f.; S = 2,392.0 in.^{3};

A = 354.4 in.^{2} > 348.9 in.^{2} ⟶ O.K.

Horizontal struts:

C = .37(235) = 86.95 kips

$$C_C = \frac{L}{d} = \frac{20(12)}{8.75} = 27.4$$

Use the same K_C = 273.6

$$A_{req} = \frac{86,950}{273.6} = 317.8 \text{ in.}^2$$

Use:

8 3/4" x 37 1/2"; w = 77.5 p.l.f.; S = 2,050.8 in.^{3};

A = 328.1 in.^{2} > 317.8 in.^{2} ⟶ O.K.

Check for bearing:

$$f_{c\perp} = \frac{86,950}{328.1} = 265.1 \text{ psi} < 305 \text{ psi} \longrightarrow \text{O.K.}$$

Cross-elements.

6 3/4" x 45"; w = 71.7 p.l.f.; S = 2,278.1 in.^{3}; A = 303.8 in.^{2}

BILL OF MAIN MATERIAL AND PRELIMINARY COST ESTIMATE

Running deck, ties, wheel guard and guardrail (From Appendix II)				= $ 5,629
Stringers:	Interior 2 (14 1/4" x 43 1/2" x 82')	=	706 cu.ft.	
	Exterior 2 (8 3/4" x 43 1/2" x 82')	=	433 cu.ft.	
	Diaphragms 15 (6 3/4" x 39" x 5')	=	137 cu.ft.	
	Sloped struts 8 (8 3/4" x 40 1/2" x 30')	=	590 cu.ft.	
	Diaphragms 18 (6 3/4" x 36" x 5')	=	142 cu.ft.	
	Horizontal struts 4 (8 3/4" x 37 1/2" x 21')	=	191 cu.ft.	
	Diaphragms 12 (6 3/4" x 33" x 5')	=	87 cu.ft.	
Total		=	2,286 cu.ft.	
			@ $27	= $ 61,722
Concrete Abutments (From Appendix III)				= $ 50,900
Total fill (Fromp Appendix II)				= $ 8,923
Total for double strutframe bridge				= $127,174

THREE-HINGED ARCH

Calculation of reactions:

$$\Sigma M_E = V_D\ (76) - 38.1\ (48.9) - 8.9\ (27.1) = 0$$

$$V_D = 24.98 \text{ kips}$$

$$\Sigma M_D = 38.1\ (27.1) + 8.9\ (48.9) - V_E\ (76)$$

$$V_E = 19.31 \text{ kips}$$

$$\sum_D^C M_B = - H_D\ (10.5) + V_D\ (38) - 38.1\ (10.8) = 0$$

$$= - 10.5\ H_D + 24.98\ (38) - 411.48 = 0$$

$$H_D = 51.22 \text{ kips}$$

$$H_E = H_D$$

$$M_S = V_D\ (38) - 38.1\ (10.8)$$

$$= 24.98\ (38) - 38.1\ (10.8) = 537.76 \text{ ft. kips}$$

$$H = \frac{M_S}{h} = \frac{537.76}{10.5} = 51.22 \text{ kips} \longrightarrow \text{O.K.}$$

$$M_S \text{ (at } P_1) = 24.98\ (27.1) = 676.96 \text{ ft. kips}$$

$$h^1 = \frac{676.96}{537.76}\ (10.5) = 13.22 \text{ ft.}$$

$$H = \frac{676.96}{13.22} = 51.22 \text{ kips} \longrightarrow \text{O.K.}$$

$$\eta = h^1 - 9.6 = 13.22 - 9.6 = 3.62 \text{ ft.}$$

$$M_{max} = H\eta = 51.22\ (3.62) = 185.3 \text{ ft. kips} = 2{,}223{,}600 \text{ lb.in.}$$

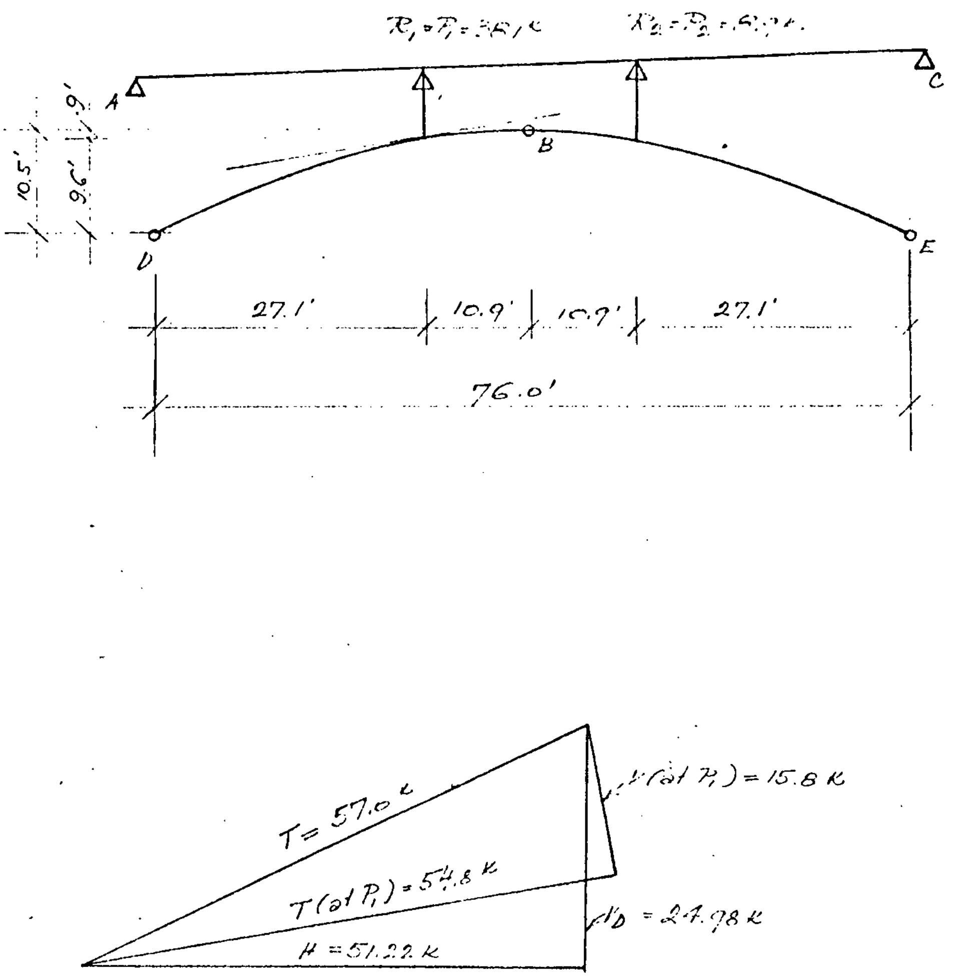


Figure 70 - Graphical solution of forces in three-hinged arch.

Thrust from graph T = 54.8 kips

Check for bending moment and thrust:

$$\frac{\frac{M_{max}}{S}}{F_b} + \frac{\frac{T}{A}}{F_c} \leq 1$$

$$\frac{\frac{2,223,600}{\frac{b\,x^2}{6}}}{1,900} + \frac{\frac{54,800}{bx}}{1,200} = 1$$

b = 6.75 in.

Solve for "x".

$$6.75\,x^2 - 45.67\,x - 7,022 = 0$$

$$x_{112} = \frac{-b \pm \sqrt{b^2 - 4aC}}{2a} =$$

$$= \frac{45.67 \pm \sqrt{(45.67)^2 + 4\,(6.75)\,(7,022)}}{2\,(6.75)} = 35.81 \text{ in.}$$

Use: 6 3/4" x 36"

$$\frac{\frac{2,223,600}{1,458}}{1,900} + \frac{\frac{54,800}{243}}{1,200} < 1$$

.803 + .188 = .991 <1 ⟶ O.K.

Check for shear:

$$f_v = \frac{1.5\,(15,800)}{243} = 97.5 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

Profile at "D": 6 3/4" x 24"

Check for thrust; from graph T = 57.0 kips

$$\frac{57,000}{162} = 352 \text{ psi} < 1,200 \text{ psi} \longrightarrow \text{O.K.}$$

Profile at "B": 6 3/4" x 39"

Check for shear; from graph V = 25.0 kips

$$f_v = \frac{1.5\,(25,000)}{263.3} = 142.4 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

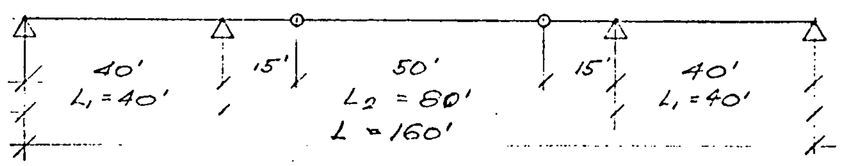
BILL OF MAIN MATERIAL AND PRELIMINARY COST ESTIMATE

Running deck, ties, wheel guard and guardrail (From Appendix II)			= $ 5,629
Stringers & Diaphragms (From double strutframe bridge)	= 1,276 cu.ft.		
Arch beam 4 (6 3/4" x $[\frac{24 + 39}{2}$ x 77])	= 455 cu.ft.		
Diaphragms 3 (6 3/4" x 34 1/2" x 5')	= 24 cu.ft.		
6 (6 3/4" x 27" x 5')	= 38 cu.ft.		
6 (6 3/4" x 19 1/2" x 5')	= 27 cu.ft.		
Total	= 1,820 cu.ft.		
		@ $27	= $ 49,140
Concrete Abutments (From Appendix III)			= $ 50,900
Total fill (From Appendix II)			= $ 8,923
Total for arch bridge			$114,592

APPENDIX V

Cantilevered Beam Bridge

CANTILEVERED BEAM



Dead load calculation according to TC tables[1].

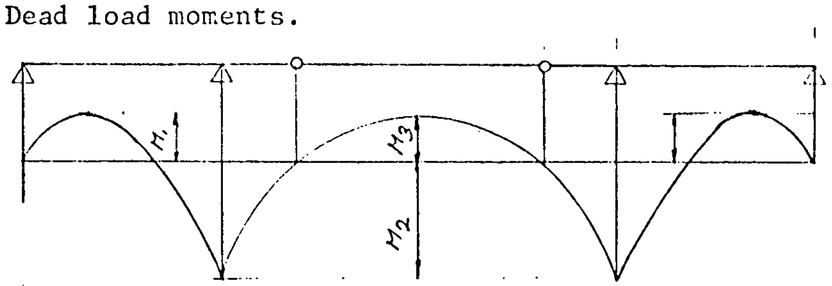
Interior stringer:

DL - Decking and ties (as calculated in App. II)	249 p.l.f.
Stringers	160 p.l.f.
Diaphragms	34 p.l.f.
Total	443 p.l.f.

Exterior stringer:

DL - Decking and ties	125 p.l.f.
Stringers	110 p.l.f.
Diaphragms	17 p.l.f.
Guardrail and wheel guards	82 p.l.f.
Total	334 p.l.f.

Dead load moments.



[1] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 110.

Interior stringer:

$$M_1 = \frac{W}{8L_1^{\,2}}\left(L_1^{\,2} - aL_2 + a^2\right)^2 = \frac{.443}{8(40)^2}\left((40)^2 - 15(80) + (15)^2\right)^2 =$$

13.5 ft. kips

$$M_2 = -\frac{W}{2}\left(aL_2 - a^2\right) = -\frac{.443}{2}\left(15(80) - (15)^2\right) = -216.0 \text{ ft. kips}$$

$$M_3 = \frac{W}{8}\left(L_2 - 2a\right)^2 = \frac{.443}{8}\left(80 - 2(15)\right)^2 = 138.4 \text{ ft. kips}$$

Exterior stringer:

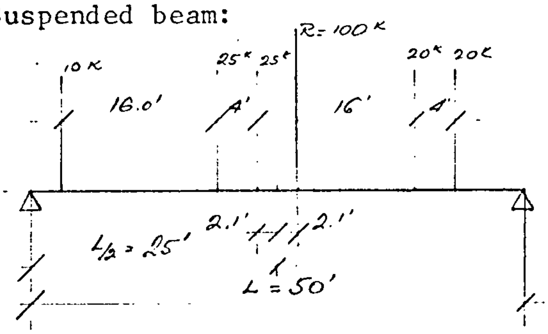
$$M_1 = \frac{.334}{8(40)^2}\left((40)^2 - 15(80) + (15)^2\right)^2 = 10.2 \text{ ft. kips}$$

$$M_2 = -\frac{.334}{2}\left(15(80) - (15)^2\right) = -162.8 \text{ ft. kips}$$

$$M_3 = \frac{.334}{8}\left(80 - 2(15)\right)^2 = 104.4 \text{ ft. kips}$$

Live load moments.

Suspended beam:



d = 2.1 feet (as calculated in Appendix II)

x = 25 - 2.1 = 22.9 ft.

$$M_{max} = \frac{100\,(22.9)^2}{50} - 300 = 748.8 \text{ ft. kips}$$

Portion of total load (as shown in Appendix II).

Interior stringer:

$M_{LL} = .65\ M_{max} = .65(748.8) = 486.7$ ft. kips

$M_{DL} =$ (for W = 398 p.l.f.) $= \underline{124.3 \text{ ft. kips}}$

$M_{Total} = 611.0$ ft. kips

$$S_{req} = \frac{611.0\ (12,000)}{1,900} = 3,858 \text{ in.}^3$$

S_{holes} approximately = 450 in.^{3}

10 3/4" x 49 1/2"; A = 532.1 in.^{2}; W = 126 p.l.f.;

S = 4,390 in.^{3} > 4,308 in.^{3} → O.K.

Exterior stringer:

$M_{LL} = .37\ M_{max} = .37(748.8) = 277.1$ ft. kips

$M_{DL} =$ (for W = 298 p.l.f.) $= \underline{93.1 \text{ ft. kips}}$

$M_{Total} = 370.2$ ft. kips

$$S_{req} = \frac{370.2(12,000)}{1,900} = 2,338 \text{ in.}^3$$

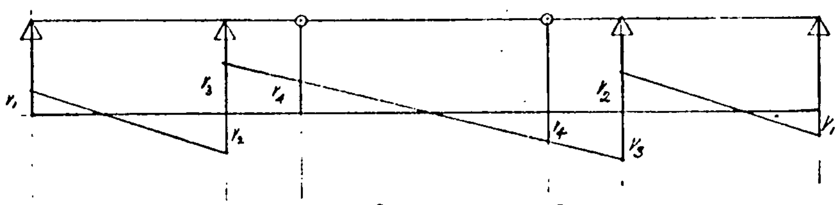
S_{holes} approximately = 400 in.^{3}

6 3/4" x 49 1/2"; A = 334.1 in.^{2}; W = 79 p.l.f.;

S = 2,756.0 in.^{3} > 2,738 in.^{3} → O.K.

Check for shear stresses:

V_{DL} according to TC tables[2],



$$V(1) = \pm \frac{W}{2L_1} (L_1^2 - aL_2 + a^2)$$

$$V(2) = \pm \frac{W}{2L_1} (L_1^2 + aL_2 - a^2)$$

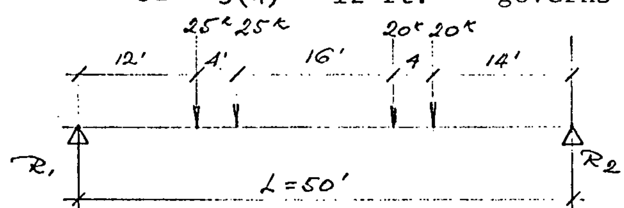
$$V(3) = \pm \frac{WL_2}{2}$$

$$V(4) = \pm \frac{W}{2} (L_2 - 2a)$$

Live load.

$$\frac{L}{4} = \frac{50}{4} = 12.5 \text{ ft.}$$

3d = 3(4) = 12 ft. ⟶ governs



$$(R_1)\ V_{max} = \frac{20(14 + 18) + 25(34 + 38)}{50} = 48.8 \text{ kips}$$

Interior stringer:

$$V_{LL} = .65\ (48.8) = 31.72 \text{ kips}$$

$$V(4)_{DL} = \frac{.398}{2}(50) = \underline{9.95 \text{ kips}}$$

$$V_{Total} = 41.67 \text{ kips}$$

[2] Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada). p. 110.

$$f_v = \frac{1.5(41,670)}{532.1} = 117 \text{ psi} < 145 \text{ psi} \rightarrow \text{O.K.}$$

Exterior stringer:

$$V_{LL} = .37(48.8) = 18.06 \text{ kips}$$

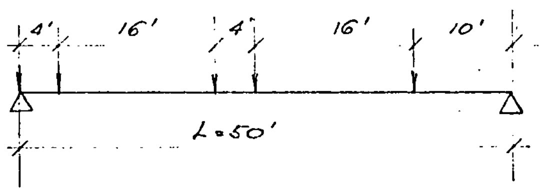
$$V(4)_{DL} = \frac{.298}{2}(50) = \underline{7.45 \text{ kips}}$$

$$V_{Total} = 25.51 \text{ kips}$$

$$f_v = \frac{1.5(25,510)}{334.1} = 114 \text{ psi} < 145 \text{ psi} \rightarrow \text{O.K.}$$

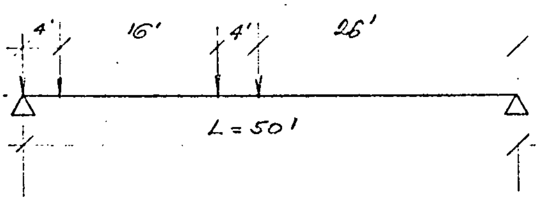
Reactions (for effect on cantilevered beam).

Position (a):



$$R_c = \frac{10(10) + 25(26 + 30) + 20\ (46 + 50)}{50} = 68.4 \text{ kips}$$

Position (b):



$$R_c = \frac{20\ (26 + 30) + 25(46 + 50)}{50} = 70.4 \text{ kips} \rightarrow \text{governs}$$

Interior stringer:

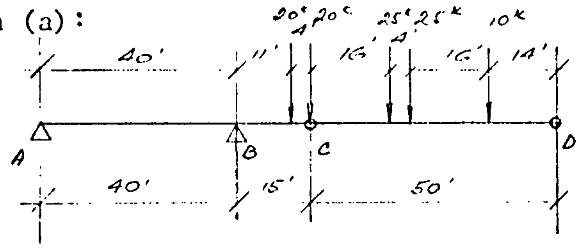
$$R_c = 0.65(70.4) = 45.76 \text{ kips}$$

Exterior stringer:

$$R_c = 0.37(70.4) = 26.05 \text{ kips}$$

Cantilevered beam - part BC.

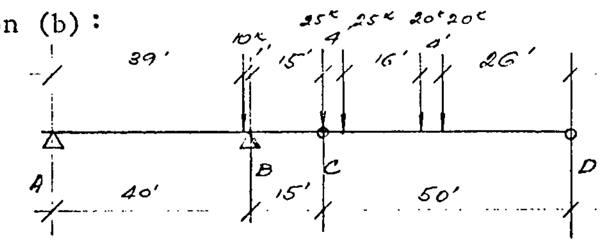
Position (a):



$$R_c = \frac{14(10) + 25(30 + 34) + 20(50)}{50} = 54.8 \text{ kips}$$

$$M_{max} = 20(11) + 54.8(15) = 1{,}042 \text{ ft. kips}$$

Position (b):



M_{max} = Pa = 15(70.4) = 1,056 ft. kips ⟶ governing position

Interior stringer:

M_{LL} = 0.65(1,056) = -686.4 ft. kips

M_{DL} = (for W = 428 p.l.f.) = <u>-208.6 ft. kips</u>

M_{Total} = -895.0 ft. kips

$$S_{req} = \frac{895.0(12{,}000)}{1{,}900} = 5{,}652 \text{ in.}^3$$

S_{holes} approximately = 700 in.^{3}

10 3/4" x 60"; A = 645 in.^{2}; W = 152 p.l.f.;

S = 6,450 in.^{3} > 6,352 in.^{3} ⟶ O.K.

Exterior stringer:

M_{LL} = 0.37(1,056) = -390.7 ft. kips

M_{DL} = (for w = 334 p.l.f.) = -162.8 ft. kips

M_{Total} = -553.5 ft. kips

$S_{req} = \frac{553.5(12,000)}{1,900} = 3,496 \text{ in.}^3$

S_{holes} approximately = 650 in.^{3}

8 3/4" x 60"; A = 525.0 in.^{2}; W = 124 p.l.f.;

S = 5,250 in.^{3} > 3,496 in.^{3} ⟶ O.K.

(chosen for same height as interior stringer)

Check for shear stresses:

Live load.

V_{LL} = R of suspended beam = 70.4 kips

Interior stringer:

V_{LL} = 45.76 kips

$V(3)_{DL} = \frac{.410(80)}{2}$ = 16.4 kips

V_{Total} = 62.16 kips

$f_v = \frac{1.5(62,160)}{645} = 144.6 \text{ psi} < 145 \text{ psi}$ ⟶ O.K.

Exterior stringer:

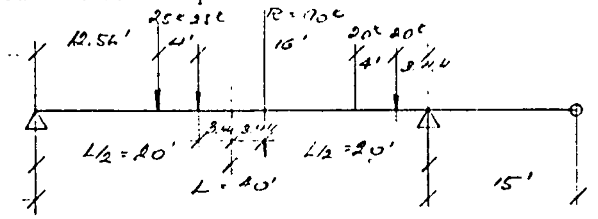
V_{LL} = 26.05 kips

$V(3)_{DL} = \frac{.312(80)}{2}$ = 12.48 kips

V_{Total} = 38.53 kips

$f_v = \frac{1.5(38,530)}{525} = 110 \text{ psi} < 145 \text{ psi}$ ⟶ O.K.

Cantilevered beam - part AB.



$$d = \frac{20(16 + 20) - 25(4)}{180} = 3.44 \text{ ft.}$$

$$x = \frac{L}{2} - d = 20 - 3.44 = 16.56 \text{ ft.}$$

$$M_{max} = \frac{Rx^2}{L} - 2 \leq P_L \; e_L = \frac{90(16.56)^2}{40} = 517.02 \text{ ft. kips}$$

Interior stringer:

M_{LL} = 0.65(517.02) = 336.06 ft. kips

$M(1)_{DL}$ = 11.42 ft. kips

M_{Total} = 347.48 ft. kips

$$S_{req} = \frac{347.48(12{,}000)}{1{,}900} = 2{,}194 \text{ in.}^3$$

S_{holes} approximately = 300 in.^{3}

10 3/4" x 37 1/2"; A = 403.1 in.^{2}; W = 95.2 p.l.f.;

S = 2,519.5 in.^{3} > 2,494 in.^{3} $\longrightarrow$ O.K.

Exterior stringer:

M_{LL} = .37(517.02) = 191.3 ft. kips

M_{DL} = 9.1 ft. kips

M_{Total} = 200.4 ft. kips

$$S_{req} = \frac{200.4(12{,}000)}{1{,}900} = 1{,}266 \text{ in.}^3$$

S_{holes} approximately = 250 in.^{3}

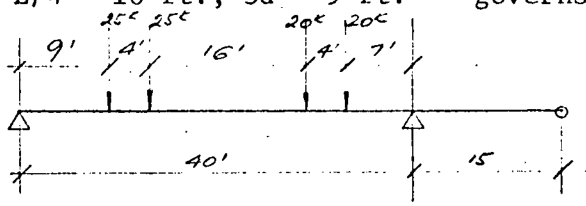
8 3/4" x 37 1/2"; $A = 328.1\ \text{in.}^2$; $W = 77.5$ p.l.f.;

$S = 2{,}050.8\ \text{in.}^3 > 1{,}266\ \text{in.}^3 \longrightarrow$ O.K.

(chosen for the same height as interior stringer; width given by part BC)

Check for shear at R_A.

$L/4 = 10$ ft.; $3d = 9$ ft. $\longrightarrow$ governs



$$V = \frac{20(7 + 11) + 25(27 + 31)}{40} = 45.25 \text{ kips}$$

Interior stringer:

$$V_{LL} = .65(45.25) = 29.41 \text{ kips}$$

$$V(1)_{DL} = \frac{.4\left((40)^2 - 15(80) + (15)^2\right)}{2(40)} = 3.12 \text{ kips}$$

$$V_{Total} = 32.53 \text{ kips}$$

$$fv = \frac{1.5(32{,}530)}{403.1} = 121 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

Exterior stringer:

$$V_{LL} = .37(45.25) = 16.74 \text{ kips}$$

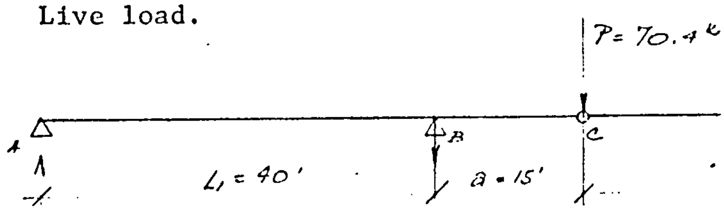
$$V(1)_{DL} = \frac{.3\left((40)^2 - 15(80) + (15)^2\right)}{2(40)} = 2.34 \text{ kips}$$

$$V_{Total} = 19.08 \text{ kips}$$

$$fv = \frac{1.5\ (19{,}080)}{328.1} = 87 \text{ psi} < 145 \text{ psi} \longrightarrow \text{O.K.}$$

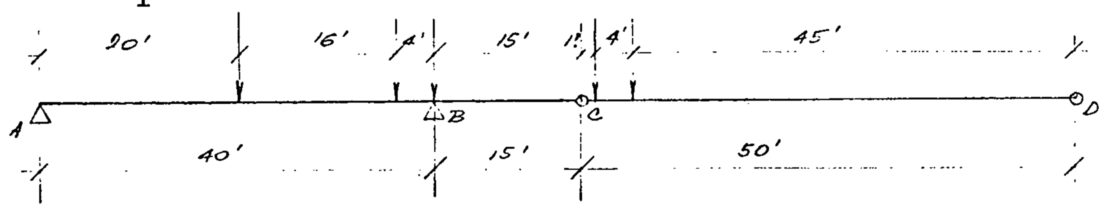
Reactions:

Live load.



$$R_A = \frac{Pa}{L_1} = \frac{70.4(15)}{40} = -2.14 \text{ kips}$$

$$R_B = \frac{P}{L_1}(L_1 + a) = \frac{70.4(55)}{40} = 96.8 \text{ kips}$$



$$R_C = \frac{20(49 + 45)}{50} = 37.6 \text{ kips}$$

$$R_B = \frac{25(40 + 36) + 10(20)}{40} + \frac{37.6(55)}{40} = 104.2 \text{ kips} \longrightarrow \text{governs}$$

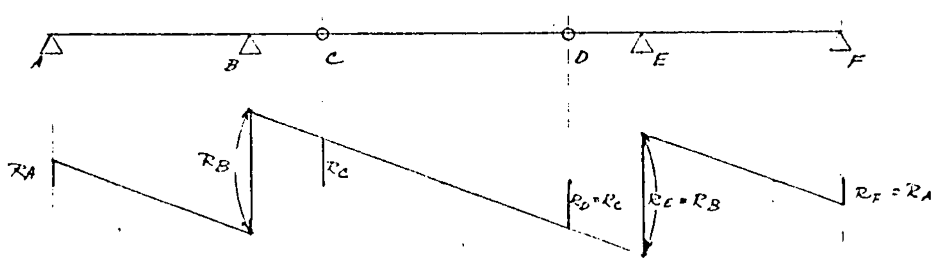
Interior stringer:

$$R_B = .65(104.2) = 67.73 \text{ kips}$$

Exterior stringer:

$$R_B = .37(104.2) = 38.55 \text{ kips}$$

Dead load (calculation according to TC tables[3]).



3 Timber Construction: Canadian Institute of Timber Construction, 1963 (Ottawa, Canada), p. 110.

$$R_A = \frac{W}{2L_1}(L_1^2 - aL_2 + a^2)$$

$$R_B = \frac{W}{2L_1}(L_1 + a)(L_1 + L_2 - a)$$

Interior stringer:

$$R_A = \frac{.410}{2(40)}[(40)^2 - 15(80) + (15)^2] = 3.20 \text{ kips}$$

$$R_B = \frac{.410}{2(40)}(55)\ (105) = 29.60 \text{ kips}$$

Exterior stringer:

$$R_A = \frac{.310}{2(40)}[(40)^2 - 15(80) + (15)^2] = 2.42 \text{ kips}$$

$$R_B = \frac{.310}{2(40)}(55)\ (105) = 22.38 \text{ kips}$$

Total reactions at "A":

$$R_{DL} - R_{LL} = 2(3.20) + 2(2.42) - 2.14 = 9.10 \text{ kips}$$

Total reactions at "B":

$$R_{Total} = R_{LL} + R_{DL}$$

Interior stringer:

$$R_{Total} = 67.73 + 29.60 = 97.33 \text{ kips}$$

Exterior stringer:

$$R_{Total} = 38.55 + 22.38 = 60.93 \text{ kips}$$

"V" supports (solved as short columns).

Interior stringer:

$$A_{req} = \frac{97,330}{1,400} = 70 \text{ in.}^2$$

Base of column 12" x 10 3/4" = 129 in.^{2} > 70 in.^{2} ⟶ O.K.

Exterior stringer:

$$A_{req} = \frac{60,930}{1,400} = 44 \text{ in.}^2$$

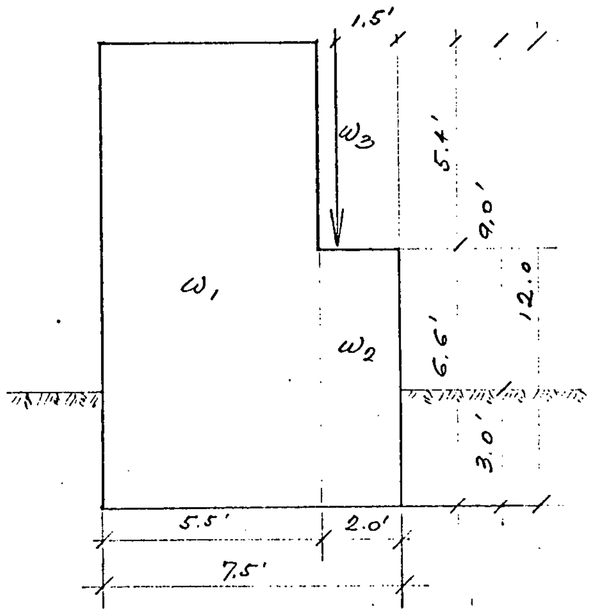
Base of column 12" x 8 3/4" = 105 in.^{2} > 44 in.^{2} ⟶ O.K.

CONCRETE ABUTMENTS:

Backfill soil conditions same as considered in Appendix II. Abutments calculated for $R_{DL} - R_{LL}$ at A (see above). Base of abutments is solid rock.

$\Theta = 32^{o}\ 30'$; w = 135 p.c.f.; K = .302

North Abutment



$h_{Total} = 12.0 + 1.7 = 13.7$ ft.

$P = \frac{kwh^2}{2} = \frac{.302(.135)(13.7)^2}{2} = 3.82$ kips

$M_{soil} = 3.82\ \frac{13.7}{3} = 17.47$ ft. kips

Weight components:

$w_1 = 5.5(12.0)(.15) = 9.90$ kips

$w_2 = 2.0(6.6)(.15) = 1.98$ kips

$w_3 = \frac{R_{DL}}{width} = \frac{9.10}{16.0} = .57$ kips

$w_{Total} = 12.45$ kips

$M_1 = 9.9(4.75) = 47.03$ ft. kips

$M_2 = 1.98(1.0) = 1.98$ ft. kips

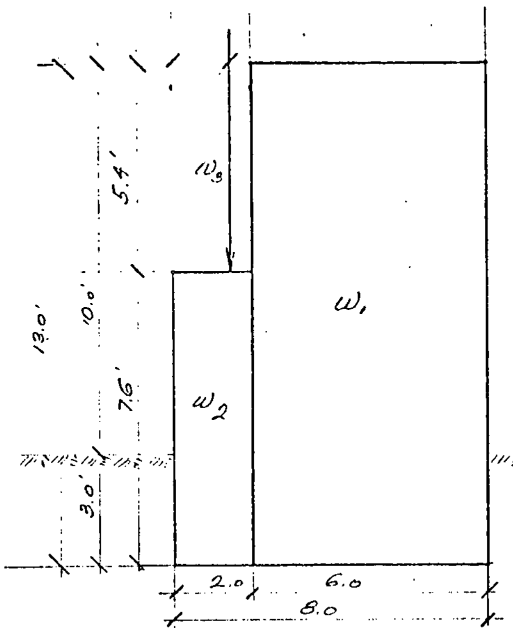
$M_3 = .57(1.5) = .86$ ft. kips

$M_{Total} = 49.87$ ft. kips

$M_{Total} - M_{soil} = 49.87 - 17.47 = 32.4$ ft. kips $= w_{Total}\,(x)$

$x = \frac{32.40}{12.45} = 2.60$ ft. > 2.33 ft. → O.K.

South Abutment



$h = 13.0 + 1.7 = 14.7$ ft.

$P = \frac{.302(.135)(14.7)^2}{2} = 4.40$ kips

$M_{soil} = \frac{4.40(14.7)}{3} = 21.58$ ft. kips

Weight components:

$w_1 = 6(13)(.15) = 11.70$ kips/ln.ft.

$w_2 = 2(7.6)(.15) = 2.28$ kips/ln.ft.

$w_3 = .57$ kips/ln.ft.

w_{Total} 14.55 kips/ln.ft.

$M_1 = 5(11.70) = 58.50$ ft. kips

$M_2 = 1(2.28) = 2.28$ ft. kips

$M_3 = 1.5(.57) = .86$ ft. kips

$M_{Total} = 61.64$ ft. kips

$M_{Total} - M_{soil} = 61.64 - 21.58 = 40.06$ ft. kips

$d = \frac{40.06}{14.55} = 2.75$ ft. $> 2.67 \longrightarrow$ O.K.

BILL OF MAIN MATERIAL AND PRELIMINARY COST ESTIMATE

Running deck, ties, wheel guard and guardrail (From Appendix II)

$\frac{\$5,629}{82 \text{ ft.}}$ (162 ft.) = \$ 10,410

Stringers: Cantilevered beams

Area of beams in profile

(37 1/2" x 21') + 1/2 (37 1/2" + 60') 20

+ 1/2 (60' + 49 1/2") 15 = 215.31 ft.^{2}

Interior stringers 4 (10 3/4") 21.5.31 ft.^{2} = 772 cu.ft.

Exterior stringers 4 (8 3/4") 215.31 ft.^{2} = 628 cu.ft.

Suspended beams

Interior stringers 2 (10 3/4" x 49 1/2" x 50') = 369 cu.ft.

Exterior stringers 2 (6 3/4" x 49 1/2" x 50') = 232 cu.ft.

"V" supports

At B

Area in profile

1/2 (12" + 30") 9.75 = 17.1 ft.^{2}

Interior support 2 (10 3/4" x 17.1 ft.^{2}) = 30 cu.ft.

Exterior support 2 (8 3/4" x 17.1 ft.^{2}) = 25 cu.ft.

At E

Area in profile

1/2 (12" + 40") 14.75' = 31.96 ft.^{2}

Interior support 2 (10 3/4" x 31.96 ft.^{2}) = 57 cu.ft.

Exterior support 2 (8 3/4" x 31.96 ft.^{2}) = 47 cu.ft.

Diaphragms 24 (6 3/4" x 33" x 5') = 186 cu.ft.

9 (6 3/4" x 45" x 5') = 95 cu.ft.

2 (6 3/4" x 54" x 5') = 25 cu.ft.

Total = 2,466 cu.ft.

@ \$27 = \$ 66,582

Concrete Abutments

North Abutment: $\frac{1}{27}$ ([4.5 x 12] + [1.5 x 6.6]) 16 = 37.9 cu.yd.

South Abutment: $\frac{1}{27}$ ([5.5 x 13] + [1.5 x 7.6]) 16 = 49.1 cu.yd.

Foundations under "V" supports

$\frac{1}{27}$ (1.5 x 1.0 x 16) 2 = 1.8 cu.yd.

Total = 88.8 cu.yd. @ \$250 = \$ 22,200

Total fill 726 CCY = 1,075 LCY @ \$2.20 = \$ 2,365

Total for cantilevered bridge = \$101,557

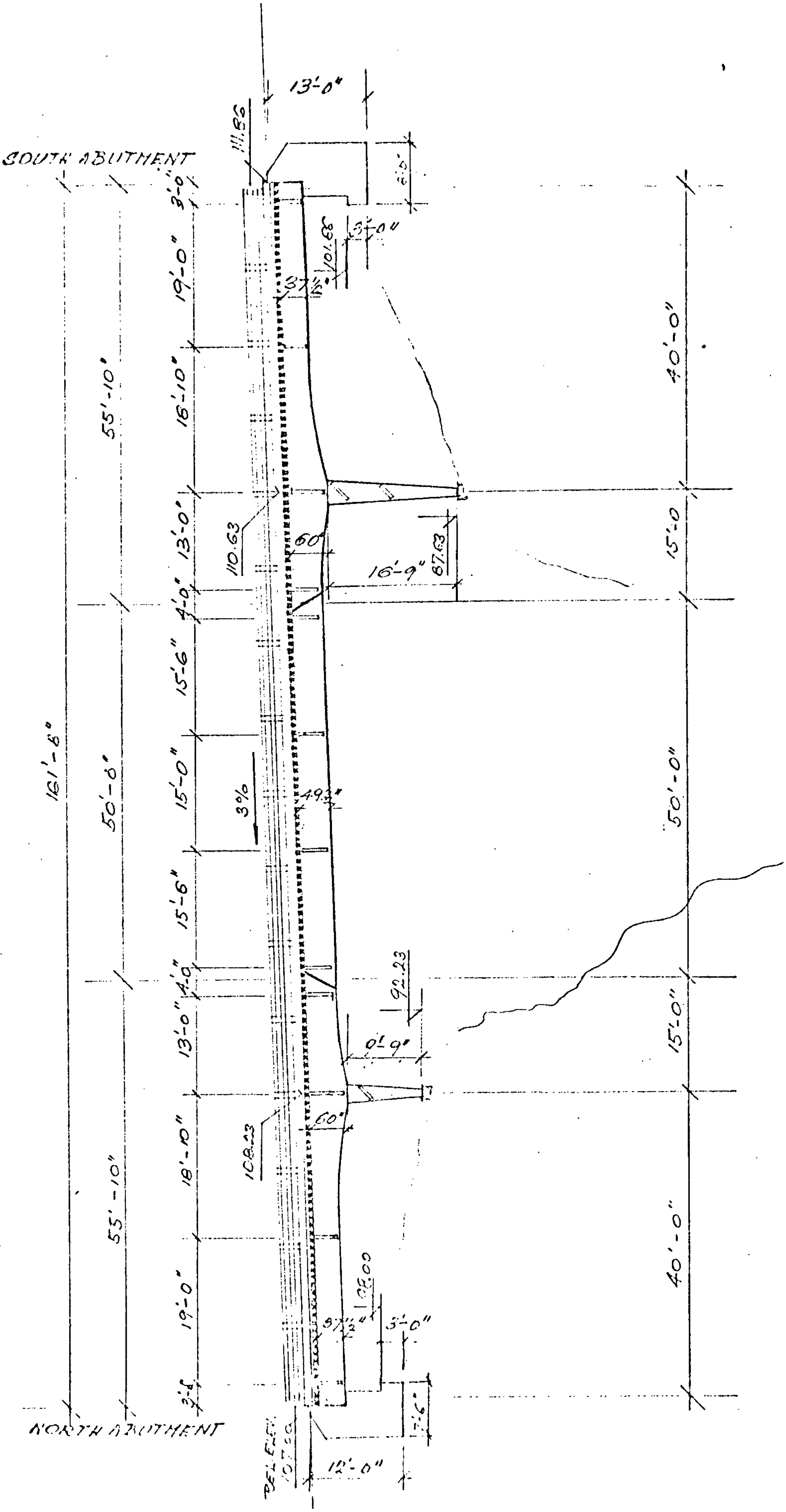


Figure 71 - Cantilevered beam bridge - profile.
Scale 1 in. = 20 ft.