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Section I

Fundamentals

1

Conceptual Bridge Design

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1.1 Introduction

Planning and designing of bridges is part art and part compromise, the most significant aspect of structural engineering. It is the manifestation of the creative capability of designers and demonstrates their imagination, innovation, and exploration [1,2]. The first question designers have to answer is what kind of structural marvel bridge design are they going to create?

The importance of conceptual analysis in bridge-designing problems cannot be emphasized strongly enough. The designer must first visualize and imagine the bridge in order to determine its fundamental function and performance.

Without question, the factors of safety and economy shape the bridge designer's thought in a very significant way. The values of technical and economic analysis are indisputable, but they do not cover the whole design process.

Bridge design is a complex engineering problem. The design process includes consideration of other important factors, such as choice of bridge system, materials, dimensions, foundations, aesthetics, and local landscape and environment. To investigate these issues and arrive at the best solution, the method of preliminary design is the subject of the discussion in this chapter.

1.2 Preliminary Design

1.2.1 Introduction

What is preliminary design? Basically, the design process of bridges consists of two major parts: (1) the preliminary design phase and (2) the final design phase. The first design phase is discussed in this section and the final design phase is discussed in Section 1.3 in more detail.

The preliminary design stage (see Tables 1.1 and 1.2)consists of a comprehensive search of current practical and analytical applications of old and new methods in structural bridge engineering. The final design stage consists of a complete treatment of a new project in all its aspects. This includes any material, steel, or concrete problems. The important argument is that with this approach a significant savings in design effort can be easily achieved, particularly in the final stage.

In order to plan and design a bridge, it is necessary first to visualize it. The fundamental creativity lies in the imagination. This is largely reflected by the designer's creativity and the designer's past experience and knowledge. Also, the designer's concept may be based on knowledge gained from comparisons of different bridge schemes.

Generally, the designer approaches the problem successively, in two steps. In preliminary design, the first and the most important part is the creation of bridge schemes. The second step is to check schemes and sketch them in a drawing. It will then be possible to determine other design needs. An examination process is then carried out for other design requirements (e.g., local conditions, span systems, construction height, profile, etc.). From an economics point of view, choice of span structure, configuration, etc. is very essential. From the cost and aesthetics prospective, the view against the local environment is important. Completing these two steps yields the desired bridge scheme that satisfies the project proposal [3].

In the preliminary design stage it is also required to find a rational scientific analysis scheme for the conceived design. Thus, an essential part of preliminary design is to select and refine various schemes in order to select the most appropriate one. This is not an easy task since there are no existing formulas and solution. It is based mainly on the designer's experience and the requirements dictated by the project.

The final stage requires a detailed study and analysis of structural behavior and stability. Economy and safety are also important aspects in bridge design, but considerable attention must be given to detailed study for the analysis, which involves the final choices of the structural system, dimensions, material, system of spans, location of foundations, wind factor, and many others.

However, the difference in preliminary schemes if all analysis is done accurately should not be substantial. Therefore, it is very important to have, from the first step, the design calculation exact and complete. The designer workload can be dramatically reduced through use of auxiliary coefficients. These coefficients can be used if the chosen scheme needs to be modified.

Design calculation is done on the basis of structural mechanics. Usually the analysis starts with the deck, stringers, and transverse beams which determine the weight of the deck. Final analysis includes a check of the main load-carrying members, determination of various loads and their effects, total weight, and analysis of bearings. Parallel to the analysis, correction of the initial construction scheme is normally carried out.

However, at the preliminary design stage it is only necessary to explain the characteristics of the alternatives. The comparison is normally based upon the weight and cost of the structure. It should also be highlighted that at this stage the weight of the structure cannot be determined with absolute precision. It is normally estimated on the basis of experimental coefficients.

As mentioned earlier, the aim of preliminary design is to compare various design schemes. This can be achieved efficiently by using computers. The designer can create a number of rational schemes and alternatives in a short period of time. A critical comparison between the various schemes should then be made. However, this is not an easy process and it is necessary to go to the next step. Various components of each scheme, such as the deck, the spans, supports, etc. should be compared with each other. It is important at this stage that the designer be able to visualize each component in the scheme, sketch it, and check its rationality, applicability, and economy. Following this, the analysis and drawings can be adjusted and corrected.

Finally, the chosen scheme should undergo a detailed design in order to establish the structure of the bridge. The analysis is applied to each component of the bridge and to the whole structure. Each part should be visualized first by the designer, sketched, analyzed, and checked for feasibility. Then it should be modified if necessary. In each case, the most beneficial alternative should be chosen. It is a very sensitive task because it is not easy to find immediate answers and the required solutions. The problem of making final choices could only be solved on the basis of general considerations and designer's particular point of view, which is undoubtedly based on personal experience and knowledge as well as professional intuition.

The sequence of analysis in detailed final design remains the same as for preliminary design except that it is more complete. The bridge structure at this stage has a physical meaning since each part has been formed and detailed on paper. Finally, the weight is estimated considering the actual volume of the bridge elements and is documented in a special form referred to as "specifications" or a list of weights. The specifications generally should be drafted at the end of the project. This sequence leads to the final stage of the project, but the process is still incomplete. The project will reach its final form only at the construction stage. For this reason, it is worth mentioning that the designer should from the beginning give serious consideration to construction problems and provide, in certain cases, complete instructions as well as methods for construction.

1.2.2 General Considerations for the Design of Bridge Schemes

Factually, the structural design scheme of the bridge presents a complex problem for the structural designer despite the presence of modern technology and advanced computer facilities. The scope of such a problem encompasses the determination of general dimensions of the structure, the span system (i.e., number and length of spans), the choice of a rational type of substructure. Also, within this scope, there is a demand to find the most advantageous solution to the problem in order to determine the maximum safety with minimum cost that is compatible with structural engineering principles. Fulfilling these demands will provide the proper solution to the technical and economic parameters, such as structure behavior, cost, safety, convenience, and external view.

Also, during the design of a bridge, crossing the river should take into consideration the cross section under the bridge that provides the required discharge of water. The opening of the bridge is measured from the level of high water as obtained at cross sections between piers, considering the configuration of the river channel, the coefficient of stream compression, and the permissible erosion of the riverbed. By changing the erosion coefficient and the cross-sectional area within the limits permitted by the standards, it is possible to obtain different acceptable dimensions of openings for the same bridge crossing. During the choice of the most expedient alternative, it is necessary also to consider that reducing the bridge opening is connected with increased cost of foundation as a result of the large depth of erosion and the need to apply more-complicated and expensive structures for stream flow. During the design of such structures as viaducts and overpasses, their total length is usually given, which may be determined by the general plan or by the landscape of the location and the relation of the cost of an embankment of great height and the bridge structure.

The design of the bridge usually starts with the development of a series of possible alternatives. By comparing alternatives, considering technical and economic parameters, we try to find the most expedient solution for the local site conditions. At the present time, the development and comparison of alternatives is the only way to find the most expedient solution. Factors influencing the choice of bridge scheme are various and their number is so great that obtaining a direct answer to what bridge scheme is most rational at a given local condition is a challenge. It is necessary to develop a few alternatives based on local conditions (geologic, hydrologic, shipping, construction, etc.) and apply the creative initiative of the designer to the choice of a structural solution. Providing structural schemes of bridge alternatives is a creative act., computers can be used to determine the

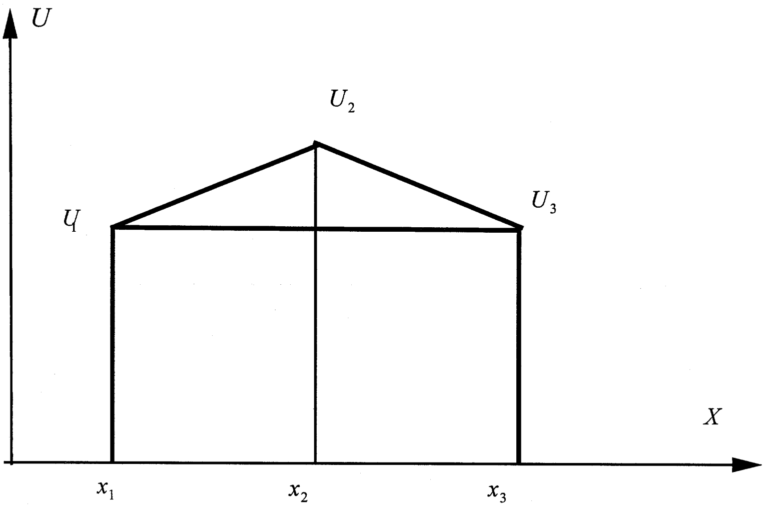

FIGURE 1.1 Quality index of the structure.

most advantageous span length and span system, to find the number of girders on the bridge having a top deck or the number of panels in the truss, and to choose the substructure. However, using computers to make a choice of rational alternatives, considering a comparison of all technical and economic parameters, is impossible. Finding an optimum alternative using different points of view often leads to different conclusions. For example, the alternative may be the most advantageous by cost, but may require great expenditure on metal or require special erection equipment, which cannot be obtained. Some alternatives may not satisfy an architectural requirement, when considering city bridges. When using computers it is still impossible to refute the conventional design method, considering all problems of specific local condition, which are practically impossible to write into a computer program.

1.2.3 Theoretical Basic Method of Preliminary Design

Methods of design cannot be invented on the basis of certain arbitrary principles. They are developed from practice. In a given theoretical study, there are enough proofs that methods of design are changing depending upon the bridge-building practice and its basic problems. Therefore, today's applied method of preliminary design is mainly determined by empirical methods.

To achieve improvement, this method is based on consistency in its exact application and explanation of its logical basis. This advanced method of preliminary design makes it possible to develop a perfect final solution for the project. It is worth mentioning at this point the importance of calculation parameters in the considered design approach.

Using mathematical models, it is possible to express (see Figure 1.1) the quality indexes U of the structure as a function of its parameters; $x, y, z,$ i.e.,

$$U = u\ (x, y, z, \dots) \tag{1.1}$$

Preliminary design provides means to determine the exact values of parameters and their quality indexes. The problem is similar to finding the limit of a function, as in calculus of variation. This analogy may be used to determine a logical basis for the method of preliminary design. It is clear that the problem of preliminary design cannot be solved in pure mathematics. The quality indexes cannot be expressed by algebraic functions. Note that the majority of parameters from one alternative to another change their size rapidly. Alternatives are shown only for consideration and to show the investigation process in order to prove the correctness of the accepted alternative.

Only in particular cases can a mathematical method be applied to find the limit. For instance, it is known that by this method it is possible to find exact dimensions of span lengths of simple-span trusses or exact heights of steel trusses those with parallel chords because of their behavior of minimal total weight of the structure.

To find the limit of the function U, it is possible to find the corresponding values of parameters x, y, z from the following equation:

$$\frac{\partial U}{\partial x} = 0, \quad \frac{\partial U}{\partial y} = 0, \quad \frac{\partial U}{\partial z} = 0 \tag{1.2}$$

These equations provide the tool to investigate the influence of each parameter as it changes the quality indexes of the structure. Leaving all other parameters constant, $\pm\Delta x$ is imposed to study the change of the value U. We can then find the value of the parameter for which ΔU changes its sign. This corresponds to the minimum of the function U.

Note that the separate parameters are interrelated. If one parameter is changed, it is necessary to modify the others. By exceeding certain limits, the span of the reinforced concrete bridge must change from a beam system to an arched system. Applying this method of preliminary design to bridges, the comparison of Eq. (1.2) leads to composition of alternatives. For each equation in Eq. (1.2), it is necessary to use a minimum of three alternatives. The first equation is formed from certain values of parameters x_1, y_1, z_1, etc. Leaving parameters y_1 and z_1 constant gives a new value of x, which is x_2 to compose a second alternative. Comparing this with the first, we establish the change of quality indexes of the bridge. If they have improved, it is necessary to change again the parameter x in the same direction, raising it to the new value x_3 to form a third alternative. Then, we compare this with the first two alternatives to determine the change of the quality indexes for the designed bridge. If, for example, they become worse, then their maximum value corresponds to x_2 (see Figure 1.1). If they improve, it is necessary to repeat the investigation for the second equation $\partial U/\partial y = 0$, and so on. All these equations must be solved simultaneously. In preliminary design, this means it is necessary to prepare many alternatives and compare them simultaneously. This process is difficult and tedious. The difficulty is increased because, unlike the purely mathematical method where the function U is given, in preliminary design the type of function is not known and should be determined.

Because of the above-mentioned difficulties, there is enough ground to assume that the first stage of the design process is based on creativity and invention.

How to build a bridge over a certain river? There are number of different answers to this question. The type of bridge can be steel or reinforced concrete, and for each case there are a number of applicable alternatives. If, for the given problem, there are several *known* solutions, there could be just as many or more undeveloped. This shows that building a bridge and creating a design are not easy tasks. Many undetermined problems face the designer. However, engineering science has proved that these difficulties could be solved in a systematic sequence, as illustrated below.

1. Equation (1.2) should be applied to the problem of structural design and solved by a method of successive approximations which follow preliminary design. This method is considered to be technically reliable and has been used in engineering successfully. In order to improve and accelerate this method (of successive approximation), it is of major importance to choose absolute precision. Experience, in a significant way, helps in making such a decision.
2. Preliminary design is generally the first approximation in the creation of a bridge project. It solves the equation for the most important parameters which have great influence on the quality indexes of the structure. Details of the structure may be investigated at a later stage.

Many solutions have been developed in practice for detailed structure. It is worth mentioning that when working with parameters, there are not many basic ones.

3. Some parameters are given and remain constant during design. Others take a limited number of values and this shortens the number of alternatives. Relations among the parameters, their correction, and the importance for the quality indexes of the bridge make it easier to carry out the methods of investigation of alternatives.

If it were possible to solve the problem by pure mathematics, then the solution would be simply to solve the equations. But we should remember that these equations (except those of the first degree) have several roots and arbitrary constants. In application to bridge design, this means, if a few equally valid alternatives are obtained, the investigation should be refined further.

The method of successive approximations should be accepted as the methodological principle because, as the process results in several alternatives for one project, we should consider only the best scientific solution. We may stop at an approximate solution, but only after we have been convinced that, in comparison with other solutions, it is the best scientific approach. This is the best way to generate designer success. The same method is applied for choosing a bridge system, as well as making a final choice for the material of bridge design, and so on.

1.2.4 Choice of Final Alternative for Reinforced-Concrete Bridges

The designer may, for instance, decide that, for a given material (say, reinforced concrete), a third alternative is chosen. Using this reasoning, the following imperfection arises: in the mathematical analogy, it was necessary to solve Eq. (1.2) simultaneously, but here each is solved separately. After determining a certain parameter, it will be kept constant and the choice for the others will follow.

There is an element of sensitivity within this method. The values of parameters are not chosen arbitrarily. The initial values are determined empirically so that their values are as exact as the real ones. The order of invention of individual parameters is also important. First, the parameters that affect the quality indexes of the structure most significantly are investigated. Then, investigation for the less important parameters follows.

Remember, the span structure implies length of span but also requires determination of the type of span structure, its form, its shape, its system, the varied types which could be uniform or unequal span structures, or the number of spans.

Within this method, the chosen alternative determines the system of span structure with minimum weight and maximum economy and safety. Now, a legitimate question may arise. Does it mean that the chosen alternative with varied type of span design (including span length, shape, form, and type) can be considered the *best* choice for the bridge project with maximum economy and safety? Although the answer may sound controversial and theocratically inconsistent, it is not. The answer is factually yes! There is a reason for that. Certain types of bridge projects require structures of various type of spans which represent economically and safely the least choice for bridge design. For refining, continue investigation by the method of successive approximation.

Note, when laying out spans for frame-beam bridges, an equal span system is often used because it provides maximum standardization of elements. However, the application of unequal span construction is also possible and in certain cases more favorable.

In following the above discussion, if an economically feasible span alternative is not satisfactory, say, does not meet the requirements of shipping regulations, or if the bridge length does not permit equal spans, then it is necessary by the method of successive approximation to find more sensitive alternative schemes with a system of spans unequal in shape, form, length, etc.

In conclusion, by changing the span system, the number of spans, or their form or shape or their combination or dimensions, it is possible to obtain a number of alternatives that will satisfy the best given local conditions at minimum cost.

For instance, changing the span system, say, by reducing the number of spans, results into a reexamination of the whole bridge design, and consequently a new bridge scheme should be drafted.

TABLE 1.1 Preliminary Design — Example 1

Design Stages	Beam System
First alternative	System of span structure, deck-type beam; bridge having three spans; construction of span structure from reinforced concrete having four main beams; supports are massive
Second alternative	Same, only two spans
Third alternative	Same, only four spans
Comparison of alternatives	The best alternative is four spans (third alternative); the first and second alternatives are canceled
Subalternatives of third alternative	1. Four-span alternative with two main beams and supports from third alternative two columns 2. Same, with prestressed concrete 3. With application of welded reinforcing frame
Comparison of alternatives	The third alternative is chosen; four-span bridges with two main reinforced concrete beams
Fourth alternative	Arch-type, three spans with four separate arches and columns above arches; supports are massive
Fifth alternative	Same, two spans
Sixth alternative	Same, four spans
Comparison of alternatives	Fourth alternative is chosen: three-span bridge with four separate arches
Subalternatives of fourth alternative	1. With two narrow arches and walls above arches 2. With box-type arches
Comparison of alternatives	Fourth alternative is chosen: three-span bridges with four separate arches

If the weight of the span structure is relieved, the span system should be modified either by decreasing the span length or span shape or form or other aspects of span structure.

It worth mentioning at this point that the significance of choosing the right alternative for the span system should not be underestimated. This is because the choice of material type for the bridge structure (e.g., monolith or prefabricated, conventional or prestressed, or reinforced concrete) is of lesser importance in cost value than the total span system, which consists of length, shape, form, number of spans, etc. Due to the relative simplicity of reinforced concrete shapes of spans and supports, calculating their volume is not a difficult process if their dimensions are given or determined from preliminary calculations.

The greatest advantage of applying theoretical methods is that the process of design is not abstract and is based on scientific analysis and quantifiable information. Therefore, during the process of choosing the best alternatives for solution, there are opportunities for eliminating imperfections for each scheme. Typical for this method is searching for the best solution through detailed investigation for each material, superstructure, bridge system, etc.

The number of alternatives obtained could be large. In the scheme of variation given in Table 1.2 it was decided to compose these alternatives with subalternatives. It takes extensive investigation, which is not always necessary. In some cases, shorter methods may be applied. In the example shown in Table 1.2, it is possible to choose the bridge material first, thus composing one alternative for steel and one for reinforced concrete systems. It is advisable to consider information from experience using an empirical approach for bridge schemes.

Example 1.1: Preliminary Design of Highway Bridge

Given

Clearance, design loads, location, bridge span, type of foundation (wells), and the material is reinforced concrete and steel.

Solution

The detailed design process is shown in Table 1.2. It can be observed that the shortened method is achieved to reduce investigation and the number of alternative projects and to increase the use of

TABLE 1.2 Preliminary Design — Example 2

Design Stages	Beam System
First alternative	Reinforced-concrete beam, three-span bridge of deck system, with four main beams; supports are massive
Second alternative	Steel beams two spans
Comparison of alternatives	The first alternative is chosen: reinforced-concrete bridge
Third alternative	Reinforced-concrete arch, two spans having four separate arches
Comparison of alternatives	After comparison of the first and third alternatives, the first alternative is chosen: beam bridge
Fourth alternative	Two spans, reinforced-concrete beam bridge
Fifth alternative	Four spans, reinforced-concrete beam bridge
Comparison of alternatives	After comparison of the first, fourth, and fifth alternatives, the fifth alternative is chosen: four-span bridge
Subalternatives of fifth alternative	1. With two main beams, monolith 2. Same, with four beams, prestressed concrete prefabricated 3. Same, with welded reinforcing frame
Comparison of alternatives	By comparison of the fifth basic and additional alternatives, fifth subalternative 2 is chosen

existing available data in practice. Thus, new investigations are unnecessary and this results in significant savings in design analysis and endeavor.

1.3 Final Design

1.3.1 Basic Trends in the Design of Bridges

In many aspects, the design of bridges is based on exact analysis and for this reason it is analogous to the solution of mathematical problems, where the results are obtained by examining the problem data and utilizing mathematical methods to arrive at a solution. This approach works well for technical and economic analyses which present very important aspects of bridge design, but it leaves out a significant part of the project.

This is because, first of all, many problems cannot be solved numerically. Second, the analysis may not correspond exactly to the actual situation. Technical analysis is valid for providing information for construction, but not significant for the solution of basic problems: choice of bridge system, choice of material, general dimensions, foundation problems, etc. These problems are solved on the basis of general considerations and the designer's judgment.

For the same problems in technical analysis or basic problems, for a bridge project there could be as many proposals as the number of the participating designers involved in engineering disputes [6]. The final choice of alternative depends to some extent on the attending participants who defend their view and support their arguments technically. It is necessary to analyze the different reasoning and determine which proposal is the most consistent with prevailing and accepted standards in the present circumstances.

The assistance of different methodological trends in bridge design is inevitable considering centuries of steady improvement and progress in bridge engineering. Progress in techniques of bridge construction depends on scientific and technological developments at each historical moment in the creation of a bridge; traditions are preserved and present views are formed.

An investigation of the history of bridges demonstrates that bridge construction has passed through several industrial stages [7]. We can separate these stages into primitive, industrial, architectural, and engineering phases. These can be subdivided still further into simpler forms and characteristics.

The influence of previous centuries on bridge design indicates that, to best understand the present trends, one must study the evolution of bridge engineering. Note that it reflects involvement of materials, the spiritual culture of the society, and the transfer of heritage. Concerning technological advances universities have had a large influence. The future engineers take from their professors the basic knowledge and new trends in design.

1.3.2 Creative Trends

In the 20th century, bridge design has undergone considerable change. With increasing demand for reinforced-concrete bridges, the need for and the creation of a new system was inevitable. The old methods had many limitations and will not be discussed here. They actually presented many obstacles for further developments in bridge engineering. It was necessary to create new specifications for reinforced-concrete structures.

The construction of highway bridges and the application of reinforced concrete presented designers with a basic problem regarding the choice of the bridge system. This created strong demand for preliminary design. This new concept required developing new methods and has put pressure on designers to look at the bridge not as a condensation of essential parts but rather as a monolithic compound unit with interrelated parts.

Because of the growing demand for reinforced-concrete and suspension bridges, the designer had large choice of materials and means to develop new bridge systems and the idea of cable-stayed bridges followed. The new century created strong demand for an analytical approach and necessitated a growing need for preliminary design with more schemes.

The acceptance that for each case there is no *one* solution but, rather, that there are several from which it is possible to choose the one most consistent with prevailing, accepted standards and most effective for the actual project leads to the basic characteristic of the second significant trend in bridge design, which will be called “creative.”

Therefore, the design of each bridge is a process of finding a solution to a new problem. If there is no solution available, it must be sought. Considering the role of personal creation, this second trend may provide original new projects. Supporters of such a trend believe that creation of a bridge depends upon personal predisposition, capability, and vision. Design is considered to be a creative process that consists of a combination of structural expressions based on required knowledge and professional intuition.

1.3.3 Practical Trends

Practicability is the main consideration in this trend. The word *practical* goes hand in hand with scientific investigation using modern technology. Designers use both scientific principles and creativity for their designs only in order to solve the actual problem. In this trend, the bridge is considered as part of the highway or railway and its basic purpose is to satisfy the requirements of transportation.

The bridge should satisfy the basic requirements of safety and economic factors. The construction of the bridge should also follow the pattern of successful industrial methods.

Supporters of the creative trend considered highways and railways as areas to apply their creative capabilities and for testing their new inventions. Followers of scientific analysis investigation considered highways as large laboratories for their investigations. Adherents of practical design have borrowed their concepts from both trends, insisting that bridges must be first safe and permitted experimental structures only on secondary highways. Practical designers suggested that the structure should be standardized for industrial preparation because it could lead to faster ways of reconstruction or rehabilitation. Also, practical designers insist on use of construction techniques that require minimum maintenance and do not affect the traffic flow.

1.3.4 Basic Assumptions of Design

Methodological rules compatible with technical and applicable requirements in bridge engineering play a major role in modern progressive methods for designing bridges.

Nowadays, time is an important factor, especially in bridge construction. Progressive methods must satisfy technical swift performance as well as requirements of astute engineering economy. Such majestic structures must function effectively and, in addition, be aesthetically appealing. Bridges play the major role in the transportation system crossing rivers or other obstructions.

At different times, bridges were built for more than one purpose. The following are examples:

1. Roman bridges and those built in the Middle Ages served not only for transportation or for chariots, but also for joyful, exuberant activities for the population. These traditions were continued at later times.
2. Another trend that appeared in the Middle Ages is the construction of bridges for fortresses, castles, and towers as a protective measure against attacks by enemies. An example is the bridge at Avignon, France; also "London Tower Bridge," which was built with towers for aesthetic purposes only.
3. Another trend in the same era was to build chapels on bridges and to collect tolls to maintain them, the same old problem of upkeep (e.g., Italy, Spain, Germany).
4. During the Middle Ages and later, bridges were built to serve as dams for water mills, which were important parts of the economy in those days (e.g., Holland).
5. During the 16th and 17th centuries bridges were built as wide structures for shops and convenience in general. Good examples are London Bridge, England and Ponte Vecchio, Florence, Italy. Construction of these types of bridges was terminated toward the beginning of the 19th century.
6. In Western civilizations, bridges are sometimes built as majestic monuments to commemorate outstanding events or achievements of national importance for an important person or national hero. Examples are the monument to George Washington, the George Washington Bridge, New York City; the monument to Princess Margaret of Great Britain, The Princess Margaret Bridge, Fredericton, New Brunswick, Canada (this bridge was designed by M. S. Troitsky); the monument to the victory at the Battle of Waterloo, The Waterloo Bridge, London, England; the monument to Russian Tzar Alexander the Third, The Alexander IIIrd Bridge, Paris, France (one of the most beautiful cast-iron bridges of imperial style); the monument of the Sarajevo Association, The Gavrilo Princip Bridge, Sarajevo, Yugoslavia; the monument to Napoleon Bonaparte's victory at the battle of Austerlitz, Austerlitz Bridge, Austria.

The 19th century was characterized by industrial growth, and the use of bridges was confined to transportation as a result of the boom in building railways. Later, with Ford promoting "auto-vehicles," the building of bridges for highways became in great demand. This new trend in transport requirements put on pressure to improve safety factors as well. As a result, it is very important in modern bridge engineering to determine the carrying capacity of the bridge or the maximum value of the temporary vertical load that the bridge can bear.

Also, to avoid interruption in traffic flow, the calculations should consider the maximum number of vehicles passing in a given time. For bridges crossing navigable rivers, passing clearance must be considered. Also, similar consideration should be given to underpasses. The carrying capacity of a bridge is defined by the number of lanes, their width, and the accepted lateral clear distances of shoulders and medians required for safety considerations.

To avoid interrupted traffic flow, it is necessary for the width of the bridge to be greater than that required by the calculated carrying capacity. For example, in long bridges, it is necessary to provide an extra parking space for possible emergency cases in order to prevent a traffic jam. As a rule, the width of the roadway on the bridge is equal to the width of the highway. However, there may be deviations from this rule. For instance, although the highway may accommodate three lanes for traffic, the number of lanes on the bridge could be reduced. Also, there are examples of the reversed situation.

The condition of maximum traffic suitability and convenience is not a requirement but is preferred and attention should be paid to this issue during planning the project. Also, this issue could be considered as one of the criteria for the appraisal of the project, provided that the cost is not prohibively excessive.

The most efficient functional bridge structure is considered to be the one that embodies the most requirements of transport, with top safety factors, carrying capacity, that contains extra convenience facilities, that is most effective in labor and material, and that can be completed in a reasonable time. Since Henry Ford's time, extra pressure has been put on the transportation system, primarily on highways and railways, which has directly affected innovation in bridges. Modern-day transport is increasing in number and weight. This means bridges must be designed so that their carrying and passing capacities can accommodate heavier vehicles and larger numbers of vehicles. Designers must be resourceful and have means to overcome difficult situations effectively and to cope with the growing demands of faster and larger moving transport with the greater reserves for future growth, the longer the bridge stands without needing repair or reinforcement.

Note that by increasing the reserves for passing and carrying capacities, the cost of the bridge will increase. Determining the necessary reserve is a problem that needs to be resolved by engineering economy. The Romans did not visualize the fast development of transport and means for transportation, but concentrated their conceptual design on timelessness of the bridge structure and, for this purpose, provided great reserves for passing and carrying capacities.

The property of material is not necessarily the basic factor that defines the service time and safety of the bridge. More often, bridges are reconstructed for other reasons: too small passing and carrying capacity, insufficient clearance under the bridge, straightening of lanes or reduction of the grade.

1.3.5 Basic Requirement of the Bridge under Design

Choosing the right location is crucial for designing and planning a bridge. But above all, safety considerations that govern the technical, functional, economic, efficiencies, expeditiousness, and aesthetic requirements are very important. It is necessary for the bridge and each of its components to be safe, durable, reliable, and stable. This is usually checked by analysis using current specifications. But not all questions of durability, reliability, and stability may be answered by analysis. Therefore, in some cases it is necessary to provide special measures such as testing the performance of the structure and examining its behavior under maximum loading on the construction site.

Specifications and technical requirements should be satisfied because they guarantee the carrying capacity of the structure. From the safety point of view, all bridges designed according to the technical requirements are equal. But practically speaking, different aspects of technical requirements may be satisfied with different margins of safety.

Regarding the various bridge components, it is necessary to know that for engineering structures, the best solution should provide the appropriate material and carrying capacity.

During comparison of projects, the technical requirements should be considered. Because technical requirements may be accomplished using alternatives, consideration should always be given to additional guarantees for safety. Never compromise the safety of the passengers. Essential requirements naturally should have great importance, but they are basically satisfied by accepted clearance. Also, additional consideration must be given to issues other than elementary demands in order to make traffic flow efficiently. Note that the height of the bridge and the elevation of the roadway must be determined at an early stage, because they have influence on the traffic flow. Also, greater or smaller grades of the approaches should be designed earlier in the project. Maximum grades are defined by specifications, but for practical purposes minimum grades are the most convenient. Further, it is important to define the number of joints in the roadway that correlate to the division of the structure in separate sections.

Conditions of minimum wear of the parts of carrying construction under the influence of moving vehicles are also important to consider. Regarding the maintenance of the roadway and the bridge, it is possible to consider this as a general expense and therefore relate it to economic considerations.

Essential requirements indicate that the total cost of the bridge at all conditions should be economically rational. The overall cost of construction and bridge erection is determined in significant part by the quantity of material and the unit price. Yet, the tendency to reduce the quantity of material in order to achieve lower cost does not always lead to minimum overall cost. There are other factors that should be taken into consideration. Take, for example, steel structures: consideration should be given to quantity of steel and on top of that special attention must be given to modern industrial practices in production which in its turn may lead to conveniences in erection resulting from heavy construction with lower cost.

During comparisons of various projects, analysis of their economic criteria may reveal principles of expedience that can be applied to the project under consideration. Construction requirements are connected to economic constraints because, when the amount of material is small, the work is simple and the time required is shorter. Also, the unit price is considered as part of the economic criteria, which implies the cost of preparation and erection. All these factors affect the overall cost.

For conventional bridges to be built from a certain material, construction is carried out by established methods. Therefore, during comparison of alternatives, construction criteria are not so important. In special cases of complicated erection of bridges having large spans, or for urgent work, construction requirements are very important and may influence the choice of the bridge system and material. In these cases, it may be necessary to use a great quantity of materials, thus increasing the cost of construction and ignoring other requirements. For example, during the initial period of application, assembled reinforced-concrete constructions were more expensive than monolithic ones. However, with increased use of these constructions, the application of assembled structures is more rational and economical.

1.3.6 Aesthetic Requirements

Apart from the basic requirements of the bridge design, there are often additional demands. The first is the problem of aesthetics. Beauty should be achieved as a result of good proportions of the whole bridge and its separate parts. In spite of the tendency to build economical structures, we should not forget beauty. The importance of the architecture of the bridge should not be ignored because of economic and technical requirements. In fact, the most famous bridges are remembered by their architectural standards and magnificent structures (examples, Brooklyn Bridge, Verrazano Narrows Bridge, Golden Gate Bridge, Tower Bridge, Alexander IIIrd Bridge, Ponte Vecchio Bridge, Revelstoke Bridge, British Columbia (designed by M.S. Troitsky), Skyway Bridge, Ontario (designed by M.S. Troitsky), etc.).

There are different views regarding aesthetic practices in bridge engineering. Supporters of the rational analytical trend feel that aesthetic demands are not important and not necessary for bridges outside cities. On the other hand, designers of the creative trend consider these aesthetic values to be more important than the economic ones and equivalent to the requirements of strength and longevity.

Because of the conflicting views, this problem requires special consideration. All designers inevitably want their structure to be the most beautiful. This wish is natural and shows love and interest of the work and is necessary in order to make the designed structure head toward perfection.

During the process of design, the engineer is occupied with detailed calculations. The engineer also may be occupied with particularities and may lose sight of the complete structure. By checking the creation from an aesthetic point of view, the engineer gives attention to the wide scope and shape of the structure and has the opportunity to design details and correct if necessary. If the designer is aesthetically unsatisfied with the creation, the designer will improve it and try to find workable solutions. But the designer should always be aware of technical, economic, and safety values of the structure. Note, the architecture of bridges should not contradict either as a whole or in details the purpose of the structure. The designer's ideas should be compatible with the technical concept, surrounding conditions and environment (for example, London Tower Bridge).

It is necessary to be technically literate. Moreover, it is not enough just to design the external view of the bridge. Bridges satisfying demands and requirements of modern engineering requests and properly designed will achieve recognition and will deserve worldwide acknowledgment and credit. If designers are guided by fanciful tastes of their own, regardless of the technical concepts, they will not achieve this goal. A beautiful shape alone cannot be invested and applied to the bridge. The design should consider both the technical concepts and the structural shape.

The critical rules of proportion and the use of purely geometric shapes had, in their time, not so much an aesthetic but a technical basis. Designers based their theories on the principle of initiations and relations that they observed in nature. Historical investigation indicates that many aesthetic rules were preserved from previous centuries when they had a different basis. Even today, a bridge is considered beautiful when it has an even number of supports because it is classic and not easy to achieve with tough natural conditions. According to Palladio [7] it is clear that this rule is accepted because all birds and animals have an even number of extremities which give them better stability. Freeing themselves from prejudice and carrying out independent investigations to find the shape corresponding to the contents should lead designers toward the development of the theory of true aesthetics in bridge engineering. History has shown how the shapes of bridges were changed depending upon the general development of the cultural and economic life of a nation. For this reason, the problem of aesthetics in bridge engineering should be viewed in a historical perspective. A designer should be able to judge the bridge by considering its external view and scheme of construction.

Followers of the historic direction renounced such investigations and by this changed their principles and were more attracted to the design of bridges. However, a joint venture by engineers and architects is not always useful for solving a problem of bridge design. Nowadays, architects specialize in the construction of buildings which is reflected in their aesthetic taste. Although architectural rules and views may be correct for buildings, they may not be applicable to bridges. For example, when designing a building, architects usually use steel construction as a frame for the building which requires certain covering. For the bridge designer, steel construction is a force polygon that clearly demonstrates the transfer of forces. For an attractive external view for the bridge, detailed design and proper accomplishment of the construction are important. The external view may be spoiled by careless work. The technical concepts of structure and the architectural shape should not be separate, but should satisfy the local conditions and cover a wide scope of requirements. By understanding the validity of recognizing special aesthetic criteria a proper alternative can be selected. The final choice of alternative is the solution of some technical problem in correspondence with the basic purpose of the bridge as part of the roadway.

If the bridge is not considered a monument commemorating an outstanding event or an outstanding historic figure or a significant happening in the world, but serves only for traffic for a certain period of time, then it is not necessary to design this bridge as a highly aesthetic creation. We may be satisfied by more modest wishes with regard to its external view. Practice indicates that designers may create, and actually have created, attractive bridges even when they were governed only by the technical and economic requirements during the design process.

A bridge that is properly designed from the technical and economic point of view cannot contradict the basic rules of architecture. The general basis of architecture consists of the idea that masses of material should be distributed expediently. The properties of the material should be used correspondingly, and the whole structure should correspond to its purpose.

Generally, economic considerations of bridge design are the same as those stated above. An economic design is achieved by (1) the expedient distribution of material, choice of the most economical system, cross sections of the members, and considering working conditions; and (2) the use of proper material (members in tension use steel, members in compression use concrete).

Therefore, economic expediency and architectural conception are determined by the same criteria. From this, it is impossible to contrast aesthetic criteria with technical and economic aspects.

For example, it is advisable to reject a beam bridge for an arch in the case when the first by all other properties is better, or to prefer a single-span bridge to the more expedient two spans. Also, it is possible to say that the choice of alternative, considering technical and economic criteria, should not deviate from the proper way to achieve the aesthetic aims.

Finally, the bridge will only be perfect in an aesthetic sense, when its system as a whole and its separate members are chosen not on the basis of personal taste of the designer, but considering technical and economic expedience.

All other proofs that are often applied by the authors of separate projects to defend unsuccessful technical and economic alternatives should be rejected. All these proofs are based on the unstable and changeable bases of personal opinion. Such proofs are only declarations of personal impressions and tend not to prove anything but only to convince people by the use of feeble verbal arguments.

Many definitions are expressed using varied terminology synonymous in meaning, but with drastically different shades in the positive and negative sense. For example, regarding the structure of the bridge, when the deck is at the bottom chord the defender may say that this structure is "expressive," "easily seen," or "stands out with a beautiful shape on the sky." The opponent, however, may object and say that this structure "obstructs view," "hangs on the observer," etc. By the skillful use of such terminology, it is possible to convince the inexperienced that a beautifully presented perspective is not as worthy of praise as a less successful project.

1.3.7 Requirement for Scientific Research

The second additional requirement sometimes asked of bridges under design is called the scientific research or "innovation." This requires that the bridge contain a new achievement due to scientific research or a new invention.

The design of a bridge always contains something new. Even if the project is worked using old examples and applying typical projects, the designer uses new contributions along with the known. Therefore, there is always a certain degree of novelty. A good designer or engineer should not only be familiar with previous designs but should also be updated with modern scientific research and benefit from that by using advanced technical sciences in the design as the project changes.

It is natural for the designer to search for novelty; yet new solutions should be born only from the tendency to reach the best solution by starting from the existing conditions at the project. Therefore, the "novelty" requirement cannot run contrary; they should complement each other.

The history of the evolution of bridge engineering is the progression from simple to more complex, and it was achieved gradually and unevenly. Some periods were distinguished by invention and the appearance of new shapes, systems, and types of bridges; other periods were characterized by mastering and perfecting existing systems and the development of scientific research work. For example, at the end of the 19th century, a great step forward was made in the area of stone bridges. Perhaps the most significant achievement in the modern era was the appearance of the cast-iron arch and iron-suspension systems with different members of trusses and large spans. All these novelties resulted from the impact of growing industry and transportation.

The first 40 or 50 years of the 19th century were spent creating the iron beam bridges, and the second part of the century was devoted to developing expedient systems and improving the construction. Significant periods in later history were devoted to the development of reinforced-concrete bridges. The initial period of trials and creation of the construction was 1880 to 1890, and the period of mastery was 1900 to 1910. However, it is necessary to note that with the general development of science and technology, the role of scientific research is increasingly racing together with novelty, rationalization, and invention. It is obvious that the necessity for novelty results from the general economic conditions and sociocultural requirements.

The attitude toward novelty in bridge engineering has been modified. Adherents of the rational, analytical direction preferred to hold on to some classical models, considering that the search for new shapes should be related only to scientific research work of creative direction, however, tending toward the new and original by ignoring any old pattern. A realistic approach to a new idea should be based on understanding that novelty is not an aim in itself and that the new idea should be a solid ground for improvement.

It is necessary to consider the criterion of novelty because it sometimes appears as an independent factor during appraisal of projects and choice of alternatives. Because novelty is not an aim in itself, it should not be a special criterion, forcing a preference for new construction irrespective of its quality. When by basic conditions the new idea is better and there is no doubt regarding its quality, then it should be adopted and should replace the old. In the opposite case, it should be refused.

Not every novelty leads to progress in bridge engineering. If the novelty is sound, it may be developed to such a degree that it would lead to a new method, but if it is not better than the old method or not yet developed, its development at a later stage may be helped by abstaining from early application. Early application leads to lowering the quality of bridges and may compromise new ideas before they reach full appreciation and are fully evaluated.

The criterion of novelty may be considered independent only in separate cases when economy requires the introduction of a new type of construction. An example is the introduction of prefabricated reinforced-concrete construction. At the present time it is expedient to use prefabricated reinforced-concrete construction, but initially it was more expensive than conventional construction. The criterion of novelty then was contrary to other criteria. It had to be solved for each case, especially when the novelty was not an aim in itself, but was required for economic and commercial demands.

One reason for introducing new construction techniques is related to the necessity of experimental and practical checking of the scientific research work, which is certainly necessary.

Regarding bridges on main highways, however, it is not advisable to subject them to experiment, because their basic designation is to serve transportation. Only separate experimental structures and special controls are permitted. However, in each case, the problems of special scientific research and structural experimentation should be performed at a scientific institution.

1.3.8 Basic Parameters of the Bridge

The quality of the structure is evaluated considering different criteria: technical, functional, economic, construction, and, in addition, the material of the system and the geometric dimensions of the bridge. All these criteria are temporary parameters defining the quality of the structure.

The problem of design generally consists of the way to find the values of these parameters that will correspond to a better quality of the structure. It is necessary to consider first, in detail, basic factors influencing the quality of the structure. All the parameters interact, but their influence on the quality of the structure is different. Their influence on each other is different: one may depend little on another; another may greatly influence the other. For example, basic parameters for material may not influence basic parameters of foundation and so on.

During preliminary design, the determination of basic parameters interacts and has major influence in making decisions about the location of the bridge, the span, the material, the type of foundation, the system of the bridge, the length of separate spans, the type of superstructure, and the type of supports.

The location of the bridge usually does not much depend on other parameters, but does have an impact on them. For small bridges, the location is defined by the intersection of the highway with the river, ravine, etc. For medium to large bridges, it is possible to compare a number of alternatives, such as the basic value of the highway and the cost of approaches and highway installations. The cost of the bridge itself plays a deciding role because its span at all alternatives is usually an unchangeable constant. For this reason, during selection of bridge location it is possible to propose an often-used bridge type without detailed study. However, there are two exceptions to this general rule. First, if the river is not used for shipping and has sandbanks, then at the location of largest curvature the span of the bridge obtained is smaller, but the depth of the water here is greater. Therefore, foundations are complicated and the installation of pile supports may be impossible. On the sandbanks where the span is increased, but the water depth is shallower, it is possible to build a simple viaduct-type bridge supported by the piles. If the bridge is proposed to be built from timber, its location should be chosen over sandbank. Therefore, during choice of crossing, it is necessary to consider both alternative types of bridges.

The second exception is the design of viaducts across mountain ravines. In this case, the change of the crossing has substantial impact on the choice of the span of the bridge and it is reflected in its cost. It is true that the type of the bridge for the first comparison may be left unchanged (e.g., reinforced concrete arch type, etc.), but it may be designed for all alternatives because the cost of the viaduct will have impact on the choice of location of the crossing.

The above exceptions do not occur often and should be considered separately; for this reason the location of the crossing may be chosen before preliminary design and must be made by the investigators with designers' efforts only in order to check the correctness of the choice. The size of the bridge opening is defined by hydraulic and hydroanalytic investigations and is assumed for the design. It some cases, however, during the design process it is possible to change the span. The size of opening, as shown above, depends on the crossing location. It also depends on the type and depth of the foundation. At greater depths, greater washout is permitted, with corresponding diminishing of the opening. At shallow foundations the reverse could occur.

In principle, two opposite solutions may exist:

1. Build bridge supports as safe against washing, squeeze the river by flow-directed dikes, and obtain a minimum opening.
2. Not squeeze the river, cross the whole river during flood, and thus the concern that the supports will wash out will no longer be a problem.

The first solution is used as a rule for rivers on the plain and can be justified economically and technically. Only for a timber bridge is it expedient to cover the whole flood area by the approach viaducts. Here the size of the opening depends upon the bridge material. The second solution may often be expedient for mountain rivers in which the main channel is often changing and threatens to wash out the flood embankment.

Generally, the size of the opening may change a little depending on the type of foundation. If the type of foundation as a whole is determined by the local conditions (e.g., by using caissons or wells), then the size of the opening for all alternatives remains unchanged. Choice of material is the most substantial problem during preliminary design and depends not only on the designer's point of view but also on other conditions that must be considered before preparing the project. Each material has its own area of application and the problem of material choice arises when these areas intersect.

Timber bridges are usually used as temporary structures. Spans greater than 160 ft often present difficulties. For permanent bridges, the choice is usually between reinforced concrete and steel structures. The following are some recommendations concerning the material selection for the bridge:

1. For spans ranging between 65 to 100 ft reinforced-concrete beam-type bridges are mainly used and steel is considered for overpasses and underpasses.
2. For spans ranging between 330 and 500 ft, steel bridges are often preferred.
3. For spans ranging between 650 and 800 ft, it is expedient to use steel bridges.

Therefore, the choice between reinforced concrete and steel bridges is generally for spans ranging between 65 and 330 ft.

The type of foundation for the bridge is determined mainly by the geologic investigation of ground in the riverbanks and in the main channel, and also by the depth and behavior of the water.

Relatively, the type of foundation influences the superstructure, size of separate spans, and type of supports. Foundations built at the present time may be divided into two basic groups:

1. Piler foundation in which timber pilers are used for shallow foundations and reinforced concrete and steel piles are used for deep foundations.
2. Massive, shallow foundation (between others or piles) and deep foundations (caissons and wells). It is obvious that for large spans it is necessary to use a massive foundation.

Shallow pile foundations are possible for viaduct bridges having small spans. Regarding the bridge system, it should be emphasized that pile foundations almost define the beam system and arches. Suspension bridges require a massive foundation and supports, but there might be other alternatives. During design, the following parameters remain constant or are slightly modified for the bridge system:

1. Size of spans (unequal or uniform);
2. Span system;
3. Type of supports.

1.3.9 Bridge System

The bridge system (i.e., beam, arch, suspension) is integrally related to the chosen material. Beam systems are mostly used for small and medium spans. An arch system is mainly used for large spans and a suspension system is used for long spans.

When using reinforced-concrete bridges, the following should be taken into consideration:

1. For spans up to 130 ft, a beam system is recommended.
2. For spans ranging between 130 and 200 ft, either a beam or arch system can be used.
3. For longer spans, an arch system is recommended.

For steel bridges, beam systems are mainly used. The arch system is expedient to use for spans longer than 160 ft. All the above span lengths are approximate and can be used as preliminary guidance in the early stage of the investigation in order to determine the appropriate system to use. The bridge system depends also on other parameters. It is impossible to investigate all other parameters without assuming the material type for the structure and the bridge system in the early stage of the investigation.

1.3.10 Size of Separate System

The size of the separate system greatly influences the cost of bridges. Determination of the span system involves a number of basic problems that need to be solved during the preliminary design.

For beam bridges having steel trusses, a known rule exists. The cost of the main truss with bracing per span should equal the cost of one pier with foundation. For all other cases, the length of span depends upon the type of foundation and pier.

Similarly, the system of the span construction has influence on the system of the span. With arch bridges, the cost of support is generally greater than that of beam type. For this reason (all things being equal), the span of the arch bridge should be greater than a beam bridge. The exceptions are high viaducts having rising high arches which are more economical. The limits of changes to span length are governed by clearances for ships and typical uses of span structures. The clearances for ships regulate the minimum size of the span. Usually the span is greater than the most economical length. For this reason, during crossings of navigable rivers the size of the span at the main channel in most cases is predetermined. It is necessary to change only side and approach spans. When choosing approach spans, it is necessary to consider typical projects because the use of typical construction is more rational and useful.

From this it follows that the length of spans is not arbitrary. They are chosen from defined conditions. The span length is closely connected with the system of span structure. Therefore, it is necessary at the early stage of the project to assume the proper system of span structure, noting that the choice of the system significantly determines the bridge system.

1.3.11 Type of Span Construction

The type of span construction is closely related to the bridge system. After assuming a bridge system, the span structure should be determined. There might be some problems related to the type of structure (e.g., solid or truss type for steel, monolith or prefabricated for reinforced concrete), the number of main girders, the basic dimensions, etc. Detailed study for each case is needed. Many problems common to particular cases can be investigated earlier, during the preparation of typical projects.

The use of typical projects substantially helps the individual design. For example, in the majority of medium-span bridges typical projects may be used. The use of typical projects simplifies fabrication of the structure, reduces the time necessary for design and construction, and makes the structure more economical to execute. However, the immediate use of typical projects should not be considered as a rule. They should be considered as a first solution, which in many cases can be improved. Each project has different circumstances, and typical projects do not provide solutions to all possible design problems. In some projects there might be some local conditions that need to be dealt with and were not addressed in previous projects. This problem is especially recognized in the design and construction of long-span bridges. Examples of already built bridges may provide a rational starting point. Together with this experience in the design and building of bridges, it is possible to establish some useful relations such as the ratio of truss height to span to the number and length of panels, etc.

The design of bridge structures starts with the critical study and the use of existing bridges to prepare the first alternative of the structure and continues during the investigation to separate parameters to prepare the next alternatives.

1.3.12 Type of Support

Supports can be divided into two groups: columns and massive supports. The second group is used in the presence of large floating ice and arch-type span structures. Column-type supports are most expedient with small-beam structures.

1.4 Remarks and Conclusions

A proper design method should meet two basic criteria:

1. First, the design method should be based on scientific engineering research and analysis. From comprehensive research, design derives logical conclusions.
2. Design methods should be achieved by practice and previous experience in the design and construction of bridges. Also, modifications should always be performed to improve the design. This is largely reflected by the designer's creative capability, sense of invention, and innovation.

Therefore, the integrated part of preliminary design is a comprehensive search of scientific, practical findings and analysis.

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