SHORT SPAN HIGHWAY BRIDGES.

by

Albert Claude Hobart, B. S.

Thesis

for

Degree of Civil Engineer

in the

University of Illinois.

1898.
INTRODUCTION.

Within the last decade the engineers of the world, but more especially of the United States, have witnessed such an uplift and continued steady growth of the steel industry as would almost justify them in adding a "Steel Age" to the grand historic divisions of the world's life. That this growth is but an indication of the things to come can be readily foreseen from the almost daily increase in the quality and availability of the raw product and the natural widening of its scope of usefulness.

Among the minor fields where this valuable and cheapening product has come and is still coming into usefulness under the direction of the engineer, is in the construction of short span highway bridges. By this is meant not only the short span truss bridge which was constructed of iron even before steel came into competition, but also those short spans where formerly the use of any other material than timber was undreamed of.

Under the circumstances the use of timber was the only material to be considered, but with the lapse of time the changing conditions both as to materials and the efficiency demanded of the bridges has lead to new demands and new ideals as to those small but important structures. The settlement of the public lands and the growth of the country highway traffic with the steady improvement of the farm lands has gradually lead to the betterment; first, of the corduroy crossing then of the planked and rickety platform, and now of the well known wooden beam or truss bridges
with which we are all familiar.

As in all changes, economy is a prime and sometimes the only motive. The farmer [and it will be understood the farmer's is the great demand for such short structures] is notoriously provident as to money matters, and innovations to at all appeal to him must be on the side of economy. That under such conditions steel should replace wood is only, as was before stated, another sign of the great economic changes now going on in the country's development.

Although this change as regards short span highway bridges is a well recognized one, the change is still so recent and so in the process of development, as to have attracted little thought from the majority of engineers. Perhaps the small scope of the individual problems too, has not endowed the subject with the degree of importance which it deserves. But whatever the cause, the subject has received little attention except in the bridge offices, and the ordinary engineer has vented his ambition and care on more pretentious, though in the aggregate no more important, structures.

In this monograph it will be endeavored through the study of standard plans of representative bridge companies, to make clear the present tendencies toward type forms of short span bridges, together with a comparison of their relative merits and defects. Necessarily such a treatment will be of more value to the undergraduate student than to the practical bridge engineer. It is hoped, however, that the presentation of the standard plans together with various tables, etc.
may make the thesis of value even in this latter direction. Addressed more to the former class will be the general discussions as to the genesis of highway bridges and the questions affecting location, number of spans, kind of span, abutments, etc.

CHAPTER 1.

The Genesis of a Highway Bridge.

Controlled by state laws which vary with every state, the method of procedure in the letting of a highway bridge contract is not susceptible of very definite or abstracted description. The method of procedure may even vary in different parts of the same state, according to the county organization or the importance of the letting. In general however, the letting on the part of the county is in the hands of the county commissioners, or supervisors as they are called in this state. These commissioners advertise for bids, let the contracts according to local methods of procedure, and see that the bridge is put up according to contract. The commissioners may or may not have the advice and assistance of an engineer during the letting and the subsequent construction of the bridge. This latitude allowed the commissioners as to the services of an engineer, as in all cases where public servants are given control of matters of which they have no intimate knowledge, is the cause of very flagrant abuses which are liable to continue until
the engineering part of the matter is the subject of legislative enactment. In some cases the counties have by dear experience found the value of an engineer's advice and assistance, and by his employment as consulting engineer have solved most of the difficulties surrounding a bridge letting.

A description of an ordinary bridge letting will clearly show the objections to which the system is subject and how well the bridge companies are aware and have taken advantage of them.

Some time before the letting occurs, an advertisement is put in a local paper or posted in the township stating that at such a time and place bids will be received for one or more bridges of the following description. This description probably includes the length of span and width of roadway but as to the rest of the necessary data is lamentably deficient. With this advertisement and inadequate description come in the first great mistakes of the letting. In order to obtain the greatest benefit from an advertisement one must place that advertisement where persons interested in the matter advertised are most liable to see and read it. From motives of false economy the bridge letting in the majority of cases is advertised in one or two county papers whose whole list of subscribers may not include a single contractor or engineer. In consequence the letting is attended by a few bidders only who have probably through shrewdness, inside influence or information, or "luck", heard of the letting. In consequence again, the commissioners do not receive representative bids and prices, and the county loses an hundred times
the cost of more intelligent advertising. Such lettings should be advertised in representative periodicals and the small increased cost of the letting will be more than repaid in the character of the bids received. Public business should be managed as intelligently as private and the matter of judicious advertising has come to mean success or failure in any enterprise. To be a judicious advertisement it is a first principle that the statement of the letting should contain information sufficient for a clear understanding of the matter involved. To submit a desirable bid the contractor must know exactly for what he is bidding, and it is just as short sighted a policy to advertise a letting with insufficient information in regard to the conditions involved as it is not to advertise at all. To secure the best results advertise just what is to be contracted for where the attention of the desired contractors will most likely be secured.

On the day of the letting as many "traveling men", or "bridge drummers" as have been reached by the advertisement of the letting, assemble to put in bids for their various companies. Understanding perfectly the ignorance of the county officials as to the merits or cost of a bridge design, this assemblage is more often for the purpose of mutual aid in "doing" the county than the submission of fair and intelligent bids for the work contemplated. If at a secret meeting the bridge men can decide on how much the county will pay for a bridge, what the cheapest acceptable bridge will cost, and who is to have the contract on an acceptable division of the profits, the letting is likely to become a decided farce and the county pays the maximum price for minimum material, the very antithesis of the result a public letting is supposed to accomplish. If, how-
ever, the “pooling” bridge representatives cannot come to an agreement on these points the result is still more disastrous. The letting degenerates to a “fight”, the contract is made at a price forbidding honest material, and the county has a bridge on its hands which may stand up for a time but is certain to fail under its first heavy loading.

The profits to be made from such “pooled” bridge lettings have encouraged the formation of many “paper companies” and bridge scalpers. These parasites have no intention of building the structure bid upon, but are in the business to compel a disgorgie and further division of part of the “pooled” profits. If by chance they obtain the contract for the construction of a bridge [and you may be sure the contract price is ample] they buy the bridge from a regular company and erect it as their own, the differences in prices forming a very considerable profit.

This whole matter of compelling the attendance of representatives of the bridge companies at bridge lettings is the third great objection to the ordinary method of procedure in such cases. “Pooling” is the natural outcome of it. At first pooling simply to assure themselves against loss of traveling expenses, the system has degenerated into a money making scheme which on the part of the “paper companies” and scalpers is little less than blackmail. In the first case the pool was legitimate; in the second it has become an unmitigated evil and by its magnitude is gradually opening the eyes of county commissioners to the extent of their losses and the desirability of a more efficient system. In this respect the evil is not without its good effect and it is
likely that before long legislative action may complete the reorganization of the methods of bridge lettings to the very material advantage of the engineer, the bridge companies, and the general public.

Not content in many cases with the profits arising from a successful "pool", the merit and safety of the bridge to be erected is still further reduced by the bridge company by a criminal reduction in area of the sections. Knowing that adequate inspection, on account of the expense, is not likely to be performed, the proceeding is comparatively safe from detection and is only likely to be revealed at the investigation set on foot some time in the future when the bridge has failed and the loss of life has perhaps attracted public attention. Even where the bridge design has been prepared by some competent bridge engineer this difficulty in the way of thorough inspection allows the company to use thinner sections than those specified, with little chance of detection. The only way to prevent this skimping of section in the absence of adequate mill inspection is to use in the design the thinnest sections rolled. Here the sections could not be skimped without the reduction of some of the main dimensions of the shapes and these reductions are easily detected by the most casual inspection. Where the bridge is considered, even by the commissioners, to be worthy the attention of a competent bridge engineer, the matter of the thorough inspection of the finished structure should not be neglected. As stated above, the skimming of sections is a common evil to be detected only by a careful use of calipers and rule. In the case of important structures [that is structures involving the cost of considerable money] this
inspection is most likely to be given, but is no less needed in any bridge worthy the name. The great majority of bridge accidents chronicled throughout the year are of highway bridges of small span. While separately these accidents do not attain a great degree of public attention and the matter is often hushed up by reference to tornadoes, washouts, etc. as causes, the aggregate loss in material, injuries, and life is very considerable and more than warrants close inspection in all cases. This matter of inspection should be under legislative control if necessary.

In furtherance of this idea of forcing the bridge companies to at all times erect safe and adequate bridges there have been many schemes proposed by engineers interested in this branch of their profession. Such schemes, however, on account of the public indifference to the subject and the ignorance of the officials having the construction of such structures in charge, have never gone further than the presentation of resolutions to various legislatures or the adoption of still more innocuous resolutions by engineering societies. The well known lassitude of the great majority of the American people to all measures of reform which are not supported and whose extreme need some most appalling abuse or catastrophe has drawn more than local attention, is sadly to be commented upon. It is to be hoped that the present movements for civic and political reforms of all kinds will extend to other branches of the body politic and especially to more consistent methods of highway bridge erection.

As indicating what may be done in this line, an abstract perhaps of the more important individual movements in the direction of these reforms may not be uninteresting. These have been
spoken of in greater detail by J. A. L. Waddell in his "General Specifications for Highway Bridges, but as these specifications are now out of print the abstract may be permitted as interesting and more available to the younger engineers.

The first of these movements was instituted by Prof. Geo. L. Vose, an eminent Massachusetts engineer, who in the early '80's issued a pamphlet entitled "Bridge Disasters in America: The Cause and Remedy". His remedy consisted in the appointment of state engineers whose duty should be to examine, before erection, the stress diagrams and sections of all bridges within their jurisdiction and to inspect all existing bridges at least twice a year. This system is at once simple, inexpensive, and effective if well carried out, was, through the indifference of the public, never carried to trial. Such a state inspector to be efficient must be appointed nominally by the Governor but in reality by a standing committee of some high and reputable engineering society, such as is the American Society of Civil Engineers. An inspector appointed in this way and given full power to condemn and prohibit traffic on any highway bridge as well as to control the bridges to be built, would fulfill its functions to the satisfaction of all concerned. The people generally however are averse to having government officers appointed, preferring election. But election would be fatal to the scheme since the people know little of the technical ability of the candidates and no engineer of high standing would be willing to submit himself to the power of the popular vote. A department of bridge supervision with head appointed by the Governor or elected by popular vote and with assistant inspectors appointed through civil service rules might be efficient
and practicable but is not soon to be hoped for.

Mr. J. A. L. Waddell, seeing the political difficulties in the way of the preceding scheme, endeavored to bring about the needed reform through the other parties to the question. The bridge companies themselves realize the disadvantages and loss subsequent on the present method of highway bridge building and Mr. Waddell's idea was to bring the manufacturers into such an association as would by its authority and strength control both the design and construction of all bridges. This association or trust was to emit a set of general specifications limiting the weakness of bridges and the style and character of the structures to be erected in the future. Deposits by the various companies represented and subject to fines on infraction of the rules of the general agreement would tend to hold the association together and give it working form. The general character of the specifications would not limit improvement in bridge design but would stimulate such design as a factor in the inter-association competition. The high standard of such an association and the effect an enunciation of its objects would have on the public interested in the attainment of the ideals of its formation would drive unscrupulous bidders out of the market and make it morally necessary for bridge commissioners to listen to its suggestions as to bridge design. Various minor details necessary to the practical working of the association were suggested by Mr. Waddell.

As with the scheme proposed by Prof. Vose, no definite result seems to have been brought about by Mr. Waddell's suggestions. While his pamphlet was widely discussed among engineers and
the benefits to be derived from the working of the proposed association generally admitted, the jealousies and rivalries among the bridge companies themselves precluded the actual formation of an association such as he had sketched out even if they had had any such thoughts in mind. As stated above, resolutions to various state legislatures were sent by different engineering societies but with little result. Except in cases to be presently described, bridge "pools" and "fights" are still the order of the day and the promoters of cheap "patent" bridges find many victims.

Through sad experience and sad experience only, I am sorry to say, numerous county commissioners have been obliged to protect themselves in the construction of new bridges by a method which while perhaps not so efficient or economical in the long run, or of so general application of good, as the schemes described, is yet more practical and certainly assures the county a safe and economical structure. After several expensive bridge failures such counties have been forced to see that final economy demands the assistance of a competent bridge engineer in the construction of new bridges. An engineer in this capacity [consulting engineer to the commissioners] should determine exactly what is wanted under the local conditions in question and make specifications covering such conditions. He should advertise well and through proper channels for proposals, the bridge companies or contractors being plainly informed that all plans and computations are to be submitted to his approval, that all material and workmanship is to be submitted to his inspectors and that the acceptance of the whole structure will depend on his approval. If such conditions are
well understood, responsible companies will have confidence in sending in proposals by mail and the county may be assured of responsible and intelligent bids lower than usual by the amount of traveling expenses saved and the profits perhaps lost on previous "fights". When the engineer has selected a bid the contract should be written understandably and the plans and specifications attached. Competent inspectors should be employed as the work goes on and the result will be a bridge as safe, economical, and as well suited to the local conditions as the best engineering skill can produce.

In the letting of the contract for the class of bridges here in mind, the matter of traveling expenses to a bidding, and which of course must be ultimately paid by the purchaser of a bridge, may make a very appreciable difference in the price unless several such structures are bid together. The employment of an engineer and method of procedure such as above described is so infrequent that mailed proposals are very seldom made except in cases where it is impossible for the bridge company to have a man in the field. The common method of having men ignorant of the matter in hand, select a bridge design on the representations of the interested parties, is fatal to the success of mailed bids. Mailed bids are not eloquent enough. Even in cases where an engineer has been employed, the force of precedent is so strong that mailed bids are in the minority and are not expected to be granted a fair consideration. Until this idea has been done away with, in cases where an engineer has been retained, by a most studious consideration of the bids on their merits alone, the best results from public bidding can not be expected.
The commissioners may choose still another alternative in order to eliminate the danger from irresponsible bidders. This is to follow the example of many large corporations and invite bids from firms only of known honesty and capacity in their line of work. This method is likely to be of greater success however in the case of corporations than with the highway commissioners. The selection of the list of bidding firms may be a prolific source of scandal and sometimes degenerate into an evil beside which "pooling" is comparatively harmless. The very idea too of such a selection is away from the fundamental principles of our form of government and on this question alone would be justly open to serious criticism.

Taking everything into consideration there is little difficulty in reaching a conclusion that until the public sentiment has been strongly aroused to the importance of safe highway bridges there can be little improvement as to their safety and economical construction. As De Velsen Wood remarks; "The evils of a community or of society are not removed by merely changing a system, and much less by shifting an organization. Any particular evil may be greatly modified and substantially removed by either of these methods, but new evils are liable to spring up which may be more burdensome and more difficult to remove than the former". Highway bridge evils can be done away with only by the intelligent direction and supervision instituted by an interested public sentiment; and until this sentiment arises, American highway bridge lettings are liable to be no more than half way efficient makeshifts, their efficiency varying with the local conditions. Every good bridge engineer should consider himself an apostle of the cause, ever preaching
the good desired, and lending his whole weight as an engineer and as a citizen to bring about the desired result.
CHAPTER 2.

GENERAL QUESTIONS AFFECTING THE DESIGN OF SHORT SPAN HIGHWAY BRIDGES.

In the selection of a bridge design [short span as well as long] there are certain general questions due to local peculiarities which must always be taken into consideration. The more important of these questions relate to: [1] the importance of the crossing; [2] the location of the crossing; [3] the character of the stream to be bridged; [4] the number of spans necessary; [5] the character of the abutment best suited to the local conditions and; [6] the character of the bridge approaches necessary.

[1]. The Importance of the Crossing.

In any consideration of the local conditions as affecting the character of the bridge to be constructed, the importance of the crossing is of the greatest weight. By “Importance of the crossing” it will be understood here as taken in its relation to the following matters: - [a]. the character of the traffic carried; [b]. the amount of traffic carried; [c]. the importance of the crossing as an available passageway.

[a]. Except where dominated by condition [b] the character of the traffic will in the majority of cases have most to do with the design of such short span bridges as are here under consideration. In isolated instances, as will be shown later, the amount of traffic instead of its character may fix the major dimensions of the bridge. Ordinarily however, the country bridge is
not subjected to great concentration of traffic activity but is required only to pass safely the daily routine of teams and cattle. The loads likely to be imposed by these elements fix the character of the specifications under which the bridge is to be designed. There is one important exception to this.

Probably the greatest load concentration coming upon a bridge is that imposed by the passage of a road roller. In the case of longer highway bridges the considerable increase of metal necessary to provide for such a load forms a very appreciable percentage of the total weight of the bridge. The infrequency with which this load is likely to be imposed makes the metal so used extremely uneconomical as compared with that taking the rest of the loads, so much so, that many engineers disregard this factor entirely, requiring that road rollers, etc. shall be taken apart before crossing the bridge.

In short span bridges these loads may be so easily provided for and the extra metal is of so small amount in the aggregate that it is not good practice to leave it out. In fact it is questionable practice with almost any span, not to provide for all concentrated loads likely to come upon it by legitimate traffic. As the years go on the road roller will come to be more and more a feature of the good roads movement and so an especially legitimate species of road traffic.

[b]. The amount of traffic naturally carried by a bridge is generally taken as the only necessary index to its importance and usefulness. While this may be entirely true, it has little to
do with the design of the structure except in a secondary manner. While the amount of traffic does not impose the conditions of loading necessary to be provided for in the design, it does designate the amount of capital which can economically be expended upon the structure and its maintenance. This may control features of design as important as those affected by the loadings expected. In the future, aesthetic design of all engineering structures will be looked for and expected, and although short span highway bridges are not susceptible of a great variety of treatment in this regard, they can certainly be improved in architectural appearance. Thus the amount of money available for bridge purposes as controlled by the amount of traffic may advantageously and properly be expended in an improvement of both the structural appearance and the surroundings of the bridge. Even now railroads appreciate this matter of aesthetic treatment and as far as possible beautify the prosaic structures of yard and track. If the public appreciates such treatment of property by individuals, and shows its regard by increase of patronage, why is not the same motive as potent in the affairs of the county or state and as closely to be looked after.

In isolated instances the amount of traffic may influence directly the design of such short span bridges. In any location the bridge must not be an obstruction in any sense to the free movement of traffic. Now under certain conditions this movement may be of such magnitude at certain times and through special causes as to require special treatment in design to provide for it. As the amount of traffic increases the importance of an adequate crossing increases at a still greater ratio until at a certain point the demand becomes so great as to displace the ordi-
nary types of highway bridges and require more expensive and capable structures brought into existence by the new and higher conditions. Such instances are especially liable to occur under city conditions where in any case the short span structure is out of its natural limits.

[c]. In certain cases the importance of the crossing as a crossing, i.e., whether other crossings are or are not available, will have great weight in the selection of a type or design for a highway span. If the traffic is large and insistent, the waterway narrow and unfordable, and the available points of crossing infrequent, greater care than usual must be taken to select such a structure as will be as free as may be from the liability of accident of any kind. Here the stopping of traffic by a washout means a loss of both money, time and patience; in the former respect out of all proportion to the immediate cost of the bridge renewal. Under such conditions true economy in the design should insist on an outlay which while unnecessary under ordinary circumstances, will make the crossing unusually safe and available at all times. The good engineering adage that a bridge or culvert must be washed out once in twenty years to prove its economic design does not hold here. The crossing is the main desideratum and every other condition should be made subservient to it.

[2]. Location of the Crossing.

Since in the greater part of the United States the highways are generally defined by other considerations than the topography of the country through which they pass, the location of the
highway bridge crossing is seldom within the province of the engineer. This matter too is not so important with the short span bridges as with the larger structures. The economy of material to be considered with the larger structures is a small point with so small spans as are here treated. This small matter though is not to be neglected and when local conditions allow, the choice of a bridge crossing may mean a considerable saving, especially so in the case of those types where the abutments are of metal and constitute an integral part of the bridge proper. This choice may make necessary a consideration of the banks of the stream, the character of the banks and bed, their height, parallelism, etc. In all cases it is to be expected that the crossing is to be of as small span as is possible with a regard for the foregoing conditions.

[3]. Character of the Stream.

Clearly second in importance to traffic considerations only, the selection of a type style of short span bridge for any particular locality depends greatly on the character of the channel or stream to be bridged. This is particularly so where the bed of the stream is of such a character as to exclude from consideration one or more of the type styles, and so at once to narrow the selection to but few possible types. In many cases the character of the stream bed make necessary nice discrimination between the relative economy of abutment bridges and spans whose abutments are an integral part of the bridge itself, and here in all cases a study of the local conditions is the only possible solution of the various questions which are bound to come up. The gradient of the stream, extent and character of the flood, whether the floods bring down an ap-
preciable amount of drift, should all go into the questions as to the selection of type of span and the style of bridge to be used in any locality. It has been the neglect of these considerations which has brought bridge builders into such bad repute among highway bridge users. If bids are to be solicited and intelligent designs expected, all these matters must be brought to the attention of the designing engineer if a worthy structure is to be prepared.

[4]. Number of Spans Necessary.

The questions potent in the selection of type styles for short spans will have much to do also with the question of the multiplication of spans where this is necessary. In many cases while the total waterway is of considerable width, the character of the stream is such that a simple bridge of many short spans on bents is the economical solution of the crossing involved. At the same time there are many crossings where the reverse of this is true, and central bents or piers are out of the question. As before stated, all such questions are matters of local decision, and cannot be tied to hard and fast rules of any kind.

The solution of the question of the economical length of span, where long bridges are made necessary by the character of the channel, will not be attempted here. With the case of short span bridges, entirely different elements enter into a solution and admit of the formation of certain general rules, which, however, it must not be expected will apply or should be applied in all cases.
Ordinarily all crossings where it is admissible to use a number of short spans of the usual highway type rather than one longer span are wide, shallow, of little flood rise, and with a bottom allowing the use of the more simple bridge entirely practicable and safe. This consideration now will become a great element in the number of spans and bents to be used. If the bents may be located at almost any place in the crossing [and if they cannot, the question immediately reverts to long spans] the desirable length of span with the type desired will become a function of the cost of the bents and the cost per foot of the bridge itself. Since the cost of the bridge is itself a function of the length of span, considerable approximation will be necessary to obtain the final results. Experience in the actual construction of such structures will suggest the most economical length, this length depending in many cases on the standard length already designed in the shop for single spans and the saving of time and work thus made rather than the actual economy of metal which a slightly different span might offer.

[5]. Character of the Abutments.

Here again, almost the only rules which the engineer must consider are entirely controlled by local conditions and may not be specifically stated. In the study of the local conditions however, there are certain general conditions which must be taken account of.

If stone is available and cheap, it is without doubt the best material to be selected. While even with a comparatively low cost as regards masonry, the first cost of stone abutments
may be high, the increased life and the satisfactory service of the stone abutments must be taken into consideration in the final selection of material. Consistency in engineering, as in everything else, should be a first consideration, and flimsy abutments carrying a substantial bridge is a most glaring inconsistency.

In deciding upon the abutment construction, the length of haul from the railroad station has much to do with the availability of material. Railroad haulage is low, and within limits, is little bar to the use of a desirable material. Teaming and hauling are expensive, and often add enough to the first cost to bring the contract price above the allowable limit.

In many cases where stone itself is unavailable, gravel concrete may offer a substitute at once cheaper and easier to handle, while at the same time equally as good. It is only within a few years that the availability of concrete for a small part of its many uses has been discovered and appreciated. Forms for concrete bridge abutments are easily, cheaply and quickly constructed and the entire building up of the pier itself requires no skilled labor. Common laborers with a carpenter or two are amply able to put up a pier which will be at once efficient, stable, and sightly.

After stone or concrete, brick will probably form the only other material successfully used in abutments. As with concrete, brick is not a common abutment material, owing more perhaps to the force of engineering precedents than to any other reason. Generally easily and cheaply available in all those parts of the states where stone is out of reach, brick should be more generall
and freely used. Abutments of this material should have ample area, with the work well bonded and honestly done. With all material, the mortar should be good cement mortar, Portland if possible.

It will be understood in the above, that the abutments considered are entirely distinct from a species of metal abutments shown in all types of leg bridges. Here the legs are the main part of the abutments, but as a very essential adjunct of the legs is the leg backing or filling as the case may be. The legs form the supporting part of the abutment, the backing the protection keeping the roadway embankment safe from erosion. Generally this backing is of wood, and more rarely of tile, concrete, stone, or sheet iron. The first named is the worst as well as the most common, being an inconsistent part of any good bridge design. Even when well creosoted [which is hardly ever the case] the plank are liable to rot out and need renewal long before the bridge repairs should be necessary. This renewal is quite difficult, expensive and a hindrance to the bridge traffic. Tile are liable to get broken and so render the abutment as liable to repair as in the case of wood. Tile, however, is comparatively little used and very justly so. Concrete, masonry and sheet iron are all good and efficient.

[6]. Character of the Bridge Approaches Necessary.

Where the local conditions are such that the bridge grade must be elevated considerably above the general level, the character of the bridge approaches will be a subject for serious considera-
tion before the final selection of the bridge type. These approaches necessitate a considerable fill, which is always expensive, or spans supplementing the main spans of the crossing. If the approaches to the main span are of sufficient magnitude to warrant the latter treatment, the influence of the approaches on the type of main span will be especially marked. In this case the crossing partakes to some degree of the nature of a viaduct with the bents as towers, and in this case the selection of the general type of span with the style of the supporting bents is worthy careful study of the resources of the neighborhood and the possibilities of the crossing.
CHAPTER 3.
Short Span Highway Bridges.

In this study of the numerous styles of short span highway bridges, the subject will be divided for convenience into two general divisions; [1] beam bridges, and [2] truss bridges. This is a perfectly natural classification made on the lines of the actual type construction, and in this respect a much more simple division of the subject matter than could be attempted along the lines of length of span or any other such arbitrary ruling. It will be understood the first division includes both plate and lattice girders. The second division will include all those forms of bridges where the truss is built of different members, these members being proportioned for a definite stress which in each case may be definitely determined.

[1]. Beam Bridges.

Short span beam bridges may be subdivided into two general types according to the substructure used, as follows:- [a] beams on masonry, [b] beams with legs. Plate and lattice girders as evolved and higher types of beam bridges make a third type [c]. Each of these types have a great variation in the style of designs and might be perhaps further subdivided along these lines. Such variation takes place in the details of the designs rather than in any important type principle, however, so that such subdivision would be apt to create confusion as to the type relations and for this reason will not be attempted here.
Beams on masonry.

In short span highway bridges of this type the roadway is supported on a set of I beams resting on masonry abutments of the usual type. The two outside beams are usually channels instead of I beams. These bridges are probably the most common and acceptable of any of the highway types for the proper spans and should be used wherever the local conditions will permit of the masonry abutments. Consisting as they do of simple I beams resting on abutments there is very little shop work necessary in the superstructure and the bridge is simple, cheap, and as easy of erection as may be. The metal is used in the manner for which its section has been especially designed and hence the span will be rigid and economical. Simple, rigid, cheap, and easy of erection and maintainance, beam spans form an ideal highway bridge. Properly designed, the stone abutments and beams may be made an harmonious whole in an architecturally good looking structure.

Beams on masonry offer an unobstructed waterway section for any height of stream up to the bottom of the beams. Where the flood rise of the stream is accompanied by drift in considerable quantity this will be found to be a point of some value in preventing clogging of the waterway, washing away of the superstructure or flooding the highway. All western streams are habitually high in the spring rises and bring down considerable quantities of drift in the shape of brush, dead wood, and dry grass. Piers or bridge braces in the waterway section catch this drift and an accumulation generally results in the stopping of traffic for a time. It is these same floods
which in the other forms of abutments wash out the backing and leave the bridge superstructure in a precarious condition through lack of its lateral support. Several recurrences of such accidents will go far to scale down the difference in first cost between masonry and other abutment constructions.

It will not be attempted here to discuss the various forms of bridge abutments most suited to structures of the highway type. The same principles apply here as in all cases where abutments are necessary and the usual standard forms will be efficient and good.

The question of the economical length of beam bridges is more dependent on local matters than would be the case with larger structures. The total weight of metal is so small that this economical length of span is not altogether decided by the weight of metal but has to do more with the minor matters of the shop, field, or erecting gang. Additional expenses in any or all of these places, while so small as to be hardly considered in heavier spans will here be potent factors in deciding as to limiting economical spans. Under these circumstances only general limits for for the length of beam spans may be stated, the ever important local considerations applying in specific cases to determine the matter more definitely. An inspection of the standard short span plans of several bridge companies shows that provision is made for beam spans of from six feet to forty feet. Thirty feet however is the limit for such spans in several cases. These plans have been prepared under conditions which have to do with the production of the cheapest possible structure for the given span. While the maximum limit stated is not the maximum practicable span.
for such types by any means, it will be understood as the limit beyond which it is not at all economical to go at the present state of highway bridge work. Beyond this limit other types will be cheaper though no more efficient. As the requirements for highway bridges advance so as to make economy not the great or the greatest consideration, these conditions will be materially changed. Under such circumstances the limiting spans for beam bridges will advance and there will have to be a readjustment of relative type values all along the line.

Table 1 gives the usual practice in the proportioning of beam bridges. One hundred pounds per sq. ft. live load is the present usual specification in this regard in good practice and the twenty two pounds dead load per sq. ft. of floor surface is about right for all ordinary cases. In isolated instances where the beam bridge supports a pavement, the provision for dead load must be materially changed. Such constructions are so infrequent however in this class of work as not to pay for tabular data applying to them. Ordinarily Table 1 will be amply sufficient for the proportioning of beam bridges.
Table 1.

Maximum Panel Lengths for which Steel Joists can be used for a Carrying Capacity of 100 Pounds Live Load and 22 Pounds Dead Load per Square Foot of Floor Surface, with a Maximum Fibre Stress of 15 000 Pounds per Square Inch. The Joists will also Carry a 12 000 Pound Traction Engine except the 5 Inch Joists in Panels Longer than 11 feet and Spaced over 2 Feet 6 Inches Center to Center. The Outer Joist on each Side is a Channel, Spaced Four and One Half Inches from the Edge of the Roadway; all Intermediate Joists are Beams.

<table>
<thead>
<tr>
<th>Size of Bims &amp; Channel</th>
<th>12' Roadway</th>
<th>14' Roadway</th>
<th>16' Roadway</th>
<th>18' Roadway</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Lines</td>
<td>5 6 7</td>
<td>6 7 8</td>
<td>7 8 9</td>
<td>8 9 10</td>
</tr>
<tr>
<td>Spacing, c.f.o.</td>
<td>2'9½' 2'3' 110½&quot;</td>
<td>2'8&quot; 2'2½' 110½&quot;</td>
<td>2'6½&quot; 2'2&quot; 1'11&quot;</td>
<td>2'5½&quot; 2'2&quot; 1'11&quot;</td>
</tr>
<tr>
<td>5' 9½&quot; 6½&quot;</td>
<td>11'7&quot; 13½&quot; 14&quot;</td>
<td>12'0&quot; 13½&quot; 14½&quot;</td>
<td>12'6&quot; 13½&quot; 14½&quot;</td>
<td>12'6&quot; 13½&quot; 14½&quot;</td>
</tr>
<tr>
<td>6' 12½&quot; 8&quot;</td>
<td>14'6&quot; 16½&quot; 17½&quot;</td>
<td>15'0&quot; 16½&quot; 17½&quot;</td>
<td>15'3&quot; 16½&quot; 17½&quot;</td>
<td>15'3&quot; 16½&quot; 17½&quot;</td>
</tr>
<tr>
<td>7' 15&quot; 9½&quot;</td>
<td>17'3&quot; 19½&quot; 21&quot;</td>
<td>17'9&quot; 19½&quot; 21&quot;</td>
<td>18'3&quot; 19½&quot; 21&quot;</td>
<td>18'3&quot; 19½&quot; 21&quot;</td>
</tr>
<tr>
<td>8' 18½&quot; 11½&quot;</td>
<td>20'3&quot; 22½&quot; 24&quot;</td>
<td>21'0&quot; 22½&quot; 24½&quot;</td>
<td>21'3&quot; 23½&quot; 24½&quot;</td>
<td>21'6&quot; 23½&quot; 24½&quot;</td>
</tr>
<tr>
<td>9' 21½&quot; 13½&quot;</td>
<td>23'6&quot; 26½&quot; 28½&quot;</td>
<td>24'0&quot; 26½&quot; 28½&quot;</td>
<td>24'6&quot; 26½&quot; 28½&quot;</td>
<td>24'9&quot; 26½&quot; 28½&quot;</td>
</tr>
<tr>
<td>10' 25½&quot; 15½&quot;</td>
<td>26'9&quot; 29½&quot; 32½&quot;</td>
<td>27'6&quot; 29½&quot; 32½&quot;</td>
<td>27'9&quot; 30½&quot; 32½&quot;</td>
<td>28'0&quot; 30½&quot; 32½&quot;</td>
</tr>
<tr>
<td>12' 31½&quot; 20½&quot;</td>
<td>32'6&quot; 36½&quot; 38½&quot;</td>
<td>33'3&quot; 36½&quot; 38½&quot;</td>
<td>33'9&quot; 36½&quot; 38½&quot;</td>
<td>34'0&quot; 36½&quot; 38½&quot;</td>
</tr>
</tbody>
</table>
Beam bridges are so simple in the major part of their construction that there is little room for any great differences in design. Originality in design must therefore be expended upon the details of the structure and in fact it is here that we find about the only differences in the standard plans of the different companies. The details upon which thought and care may be most successfully expended include the fence, the floor construction, and the seating of the beams upon the masonry.

Fence. In almost all styles of short span bridges, and perhaps particularly so in beam spans, the fence is a weak part of the design. Bridge fences or railings to fulfill their functions with the greatest degree of success should be stiff and strong, sufficiently so not to give way under the shock of a heavy wheel hub jammed into it by the sudden twists of a frightened horse. In the majority of cases the fence seems to be designed on the principle that it is to be used simply as a hand rail. Even in those cases where some pretense seems to have been made at staying it, the stays are so flimsy as hardly to warrant the name.

An inspection of Plates 9, 9, and 10 of the standard plans will show the popularity of the gas pipe fence. In the shorter spans these gas pipe fences have no other stay than the screws or nails at the bottom of the posts. It seems to be assumed that on the short spans there is little necessity for the braces which are put in on the longer ones. This is a mistake liable to lead to grave accidents. Through frightening of the horse or reckless driving a wheel hub is as
likely to be thrown against the fence on one of these short spans as on the longer structure and in such cases the need of protection is fully as great. In any case the shock of wheel against fence should be withstood by the latter with as little damage as may be to both bridge and vehicle. Plates 8, 9, and 10 shows the insufficient character of the bracing wherever this is put on. The angles and channel projecting laterally and forming the support for the stiffening rods are quite sufficient to take all the stress likely to come upon them through wheel shock against the fence. The small round rods however are the inconsistent points of the design and would buckle and bend at the slightest provocation. The use of angle iron instead of round rods would materially improve the design. The stiffening rods too should have their upper ends attached to the posts instead of to the upper pipe rail at the middle of the fence panel. Regard for this point might necessitate an added brace for the sake of symmetry, but such an addition would do little harm and involve little extra expense.

A close second to the gas pipe in popularity is the lattice fence. If this is constructed in the substantial manner as shown in Plates 2, 3, 4, 5, 6, and 7 there can be little fault found with it on the score of weakness. The double angle iron construction of the top chord, with the angle braces makes a very efficient fence.

In many cases it is probable that the careful design of the fence has been made with a very different idea in mind than that of having a strong fence. Some bridge men fly into a violent rage if such a construction is called a fence and say that it is a lattice girder taking a con-
siderable part of the bridge load. If the roadway beams are designed on this assumption it will be well for the engineer to throw out the bid submitted for such a design. In the case of Plates 3, 4, 5, 6, and 7 the fence is actually to some degree a lattice girder, taking the stress which would ordinarily come on the outside channels. This is as far as its supporting power can be regarded as efficient or desirable, the assertions of the bridge men to the contrary notwithstanding. Plates 6 and 7 show an especially elaborate effort on the part of the designer to make the fence a girder. Here it will be noticed that at each end of the lattice one of the flat bars is replaced by an angle, the idea being, I suppose, to have it perform the duties of an inclined end post. If these constructions can not be regarded as girders taking very much of the bridge load, this style of fence is too elaborate and expensive for the good to be derived from it. The replacing of the outside channel (and in some cases the fence is put on with the channel) with the substitution of a simple fence is a much better and more consistent construction.

A third style of fence and one that is hoped has been little used, consists of three angle irons as rails supported by angle posts and without a sign of bracing. Such a fence would be almost blown over by a good wind. With sufficient bracing however, modifications of such a construction could be made efficient and good.

A very successful fence designed by Prof. Ira O. Baker is shown on Plate 1. Here the fence is composed entirely of channels, is strong, simple (and so inexpensive), and entirely consistent with the rest of the design. The detail of the attachment of the posts to the outside channel
of the bridge floor insures a very stiff fence without any bracing. The channels sharp corners [on the fence rails] are chipped and ground off so as to prevent gouging deeply any vehicle which may come in contact with them or the wounding of cattle which may be pressed into the fence during the rush of a drove crossing the bridge. Every detail in this bridge has been the result of careful consideration of the needs of such a part of the bridge and of study of tentative construction in actual service. The only objection which can be urged against the fence is its positive ugliness. This feature, however, in the present state of affairs as regards country highway bridge construction, is a very small matter and would only be considered where some thought must be taken as to its architectural fitness.

In the construction and design of a bridge fence all braces must be placed on the outside. While the observance of this detail may entail a little more care in the design of the strut at the foot of the brace [and to which it is attached] to make the brace effective, it will do away with all chance of injury to the brace through contact with wheels, loads, or clubs of mischievous boys. A design where any part of the brace comes inside the felloe guard is especially to be avoided. Such inside braces will be seen on inspection of Plates 14 and 15.

Floor details. While the floor is quite generally constructed of two or two and one half inch oak plank, there is an almost endless variety of methods of holding it down to the beams. Inspection of the various standard drawings will show this very plainly. The extremes vary from a nailing piece on every beam to a single wooden strip held to the side of a central beam. In the
one case no nailing strips at all are used, the plank being held down by nails driven each side of every beam and bent under the projecting edges of the I. [See Plates 4 and 5] In all cases the nailing of a bridge floor is simply for the purpose of holding it in place under the pounding of the traffic. If the nailing is well done and in the proper place very little will be required. The use of a nailing strip on every beam is time and money thrown away, besides being in many instances a positive detriment to the bridge. Every line of nails in that part of the bridge floor under wear soon becomes a projecting ridge of short, sharp points, a nuisance and a danger to animals and bicycle traffic. The nailing strips should be near the ends of the planks out of the roadway. Here they will not only be out of the way and harmless but will at the same time be more efficient because not disturbed by the wear and tear of this same traffic. A nailing piece bolted to each of the outside channels as in Plate 1 will be sufficient and efficient. There is no great advantage in lifting the planks entirely off the beams by pieces on top of each of the latter.

To the ends of the planking as in all highway bridge floor constructions, it is customary to bolt a four by four or a four by six felloe guard. This is general practice as to size, the only variation coming in in the manner of bolting it down. There is little choice in these methods, all being efficient if enough bolts are put in. The great desideratum is simplicity and economy. That method most quickly and cheaply to be applied, with good holding power after being applied, is the one to be selected. The various methods in most common use may be seen by inspection of the stan-
Bean seats. The province of the various methods of seating the beams upon the abutment tops is to give a firm, even bearing for the transmission of the bridge load to the masonry. This would be a comparatively simple matter were it not that the engineer has endeavored to unite two necessary functions in one, i.e., in seating the beams and stiffening them against overturning at the same time. An inspection of Plates 6, 7, and 8 will show how this is commonly accomplished. In the case of the smaller spans a single inverted channel does very nicely. With the larger spans two channels riveted together are used, this giving much more of a bearing on the masonry than in the case of the single channel. Some companies however plane off slightly the sharp edge of the legs of a wide channel thus getting a sufficient bearing with less work and metal than where two are used. To secure the beams against lateral motion or overturning they are riveted or bolted to these channels. In some designs the beams are not punched for these bolts or rivets but are held in place by bending the rivet or bolt body over the projecting edges of the I. Short bolts through the punched I beams will probably be found most efficient and satisfactory. A few engineers fit a couple of lines of channels in between the beams, riveting them to the beams with short angle connections. (See Plate 11). In this case the beam seats may be simple flat bars laid along the abutment coping.
[b]. Beam Leg Bridges.

Beam leg bridges consist essentially of an ordinary beam floor support resting upon metal posts instead of the common masonry abutments. This construction came into use in the effort to solve the question of adequate abutments for a steel beam superstructure where the first cost of masonry abutments would have prohibited the erection of the bridge. While of course the masonry abutments are much superior to the leg construction, the latter under proper treatment in design is capable of very efficient service, entirely good enough for the small unimportant spans for which they are primarily intended. The great objection to them is that they are not capable of being kept in a condition necessary to the long life of metal constructions and are liable to fail long before the bridge superstructure proper. If the legs could be covered with an efficient coating such as is given water pipe for example, and could rest on sills which would at all times be under water, this question of the length of life of the legs need cause very little worry. It is the rotting and rusting of backing, legs, and sills which causes the final failure of this type of bridge. There is a question, however, as to whether the saving in first cost over masonry, and interest on capital invested, by the use of metal legs is not sufficient after ordinary service to pay for the new structure required.

As in the case of the beams on masonry the general practice in the proportioning of the floor beams is quite uniform, the great differences in the type designs coming in in the construction of the legs and leg details. Plates 9 and 10 of the standard designs illustrate probably as
simple leg bridge construction as is commonly designed. Here the floor beams rest upon I beam posts which in turn are supported at the bottom by a mud sill of oak. This is the typical leg bridge design in the principles involved but as before stated the great variations in design come in with the details of connections, leg sections, leg bracing, leg backing, fence, etc. and for this reason it will probably be best in a consideration of the designs to divide the subject along these lines.

Leg Sections. For the short spans involved in this class of work it is quite general practice to have the legs of I beams. These may be easily varied in section and weight to suit necessary changes in length of leg or span and admit of simple connections with floor beams, bracing, and mud sill. In some cases [See Plate 12] in order to make special connections with the outside channels to give extra stiffness to the fence, the end posts are made of two channels instead of an I beam. This is not usual however as an inspection of the various standard designs will show.

In the selection of the section required for a given length of leg and span there seems to be no general rule followed other than the experience of actual practice. This varies with the designing engineer or the bridge company but is almost always within limits which are certain to give a satisfactory factor of safety as far as can be observed. Since in the design of the leg section we must take into consideration the earth pressure due to the backing and since the precise determination of this pressure under all conditions is out of the question, it can be readily unde
stood how judgement and engineering common sense have more to do with the design than a precise mathematical determination.

Where the beam bridge has through evolution been expanded to the plate or lattice girder type, the conditions for the leg bridge have materially changed and hence allows and really necessitates a different leg section. The plate or lattice girder will have but two principal supporting posts at each end instead of the six or seven of the ordinary beam bridge. The load to be carried by the posts in such a case is quite large and independently of the earth pressure requires a section of considerable area and radius of gyration. Here it is usual to employ a couple of channels latticed or perhaps three channels riveted together in a rough I section. Ordinarily, the first method will be the better practice. Between these two principal supporting legs in the case of the plate or lattice girder may be the usual I beam legs for the support of the end joist.

Since in this style of abutment the major part of the load on the mud sill is concentrated near the ends there is a tendency to bend the sill ends down, letting the post slip or tear off. In some designs this tendency is done away with by reserving the mud sill for the joist posts only, treating the main posts as metal piles and driving them to solid bearing. In such a case two I beams are generally used, with a cast iron point to assist penetration.

Leg Connections. By leg connections is meant the method by which the legs are joined to the floor beams at the upper ends or to the mud sill at the bottom. At the bottom there is prac-
tically but one connection in common use. Short angles are riveted to each side the posts and lag bolted or spiked to the sill. Common bolts are seldom used although this is the better practice. The ordinary method of using one lag bolt or boat spike in an angle riveted to the posts by two or three rivets is hardly consistent. A better detail in this regard would be to set the posts in a channel resting flat side down on the mud sill and then bolting or spiking the posts to the channel and the channel to the sill. The common connection with the floor beams consists of short angles riveted through the web of the posts and flanges of the floor beams. Instead of this one company [See Plate 9] used a patented connection consisting of a splice plate so shaped as to fit over the projecting flange of the I of the floor beam and rivet to the web. While this connection if well made is undoubtedly efficient, it is doubtful if the result attained warrants the extra expense over the other method. In either case it is common practice to strengthen the joint by an angle riveted to both legs and floor beams at the inner side of the junctions of posts and beams.

In many cases the floor beams instead of resting directly on the supporting legs as in Plate 9 or 10 [the design having as many legs as there are floor beams], rest on a cross beam which is supported by the legs. [See Plates 11 and 12]. This cross beam is riveted to simple angle connections with the legs and the floor beams make similar connections with it.

In the majority of cases these connections furnish all the floor beam stiffening or bridging used and it is probably sufficient. A few designs provide for the ordinary channel bridging
spoken of on page 35 and shown in Plate 11.

**Leg Bracing.** To be perfectly stiff in all directions a leg bridge perhaps needs to be braced in both the direction of the axis of the bridge and transversely thereto. This latter is a simple matter, but in the consideration of the former, bridge engineers have wandered from the subject in hand and tried (generally unsuccessfully) to combine both stiffening and strengthening at the same time.

A common practice in bracing or tying the legs together is to rivet an angle or two angles diagonally across the leg faces. Diagonal rods are often used for the same purpose and as efficiently. The one method requires field riveting to quite an extent and the other necessitates either boring of holes in the leg webs to allow the passage of the diagonal rods, or providing rod attachment so that the rods may pass outside of the abutment face. Where bracing to the floor beams is put in the above leg stiffening is omitted in many cases. There is no reason why it should not be just as necessary in the one case as in the other, and in the better designs both are so provided.

Girder braces, as the braces to the floor beams are called, are generally made up of two angles riveted back to back and connected to legs and floor beam as shown in Plates 14 and 15. Where these braces are put in the outside channels commonly provided are replaced by I beams so as to allow for a better connection with the braces. These I beams are made of much smaller section than the rest of the floor under the assumption that the braces will carry part of the load to
the legs. Besides the two outside braces there is usually one provided to the middle floor beam and this is treated in the same way as to its section. Where the angles are of considerable area and length of legs this strut action required of them is undoubtedly well performed and the bridge gets along very well. Where, however, such an arrangement as is shown in Plate 15 is in to distribute the loads over all the floor beams it is an entirely different matter to be considered. It will be much easier to state that such an arrangement does distribute the loads over braced and unbraced beams than it will be to prove absolutely that it does or does not. If the unbraced floor beams of a design are lightened in section on the assumption that it does, the engineer in charge of the letting where the design is submitted would probably be on the safe and better side by throwing out the bid. Primarily these struts are to stiffen the structure and not to take part of the floor load. Taking everything into consideration it is questionable whether these braces are really necessary. If the earth backing on either side is equally firm, this will give all the necessary stiffening without the use of any such elaborate arrangements as are often provided. Short and simple braces as shown in Plate 12 will take care of any action due to slipping or unequal pressure of fresh filling while the bridge is new, and be an inexpensive arrangement amply sufficient for its only probable temporary need at such time. The elaborate struts shown in Plates 14 and 15 are impressive as indicating increased strength only to the non-technical bridge commissioner and were probably provided for no other purpose.

As stated in the consideration of beams on masonry, the bridge braces may become a positive
nuisance where the flood rise of the stream is great and brings down considerable drift. Aside from the added danger to the bridge in such a case during the flood, the drift left tangled in the braces on the subsidence of the water is neither ornamental nor useful. In one instance coming to my notice the masses of brush and dried grass held against the bridge floor were ignited by careless campers camped under the structure and caused the total destruction of the bridge.

Leg Backing and Filling. While the metal legs of a leg bridge are the weight supporting part of this abutment substitute, it is necessary that they be backed by some means so as to provide for the earth holding and erosion preventing part of a true abutment. This backing is commonly of plank which should be tarred or creosoted but is generally not. This is the weak point in the leg bridge design, for the backing soon rots out and is an expensive source of repairs if the bridge is to be kept in good condition. To remedy this evil at a small cost is to vastly improve a leg bridge design although this is not often attempted. In Plate 16 is shown a backing of tile, but this is expensive in itself besides being difficult and expensive to put on. The tile too would probably become much broken under the hard usage and vicissitudes of the average highway bridge.

There is really little need of the paucity of designs with good backing. With the present low price of cement, the space between the legs could be easily and cheaply filled with gravel concrete, forming an abutment backing of the first quality, besides greatly strengthening the legs and improving the quality of the abutment as a whole. With a little care such a construction
could be expanded and improved so as to be in every way as good as masonry at half the cost. The substitution of a concrete mud sill for the wooden beam would naturally follow and do away with the majority of the objections to the leg type of bridge. With the added strength to be derived from the concrete filling, the post sections might be reduced to a certain extent and even the number of posts cut down. A rough rubble of cement mortar and field stone would be a better backing than the present universally used plank. In a few designs sheet iron has been shown as backing. This is efficient in a sense but to secure the necessary stiffness requires a thickness of metal which adds considerably to the first cost.

In certain localities a backing of rough stone slabs has been used with quite general success. These stone slabs are roughly shaped so as to fit in between the I beam legs as closely as may be without too much care. An inverted channel cap is then put on over the legs and top slabs. The slabs fitting in between the legs and cap are held in place with the expenditure of little extra trouble on the part of the bridge men. The slabs are roughly dressed with the pick, and fitted together at the joints so as to hold the earth from coming through in too great quantity. If a little earth falls through at first not much harm is done, and the packing of rain and traffic soon stops even that. As a backing the stone slabs are quite efficient and good. However such a construction is only likely to be followed where local conditions are especially favorable. The bridge must be near a quarry where thin-bedded stone supplies a quantity of slabs.
which may be easily and cheaply obtained for the use of the bridge. At best this backing will be higher in price than timber and to secure its adoption in a bridge design the commissioners must see the inconsistency of the use of timber as a backing and be willing to advance the extra money needed for the stone. In the majority of cases the commissioners if economically inclined will favor timber backing; if in favor of better construction they will build masonry abutments. In very few cases, and never except under the favorable conditions noted above, will the middle course of the adoption of a more durable material than timber be followed.

Fencing. The question of proper fencing has been discussed under beams on masonry and all that has been said there applies with equal force to the leg bridge. The designs shown in the standard plans are very similar as they naturally would be. One plan however, (See Plate 11) has a considerable variation from the ordinary practice and is unusually novel and meritorious. Here the outside legs are extended above the flooring as fence posts, latticing being filled in between a top rail consisting of a special T iron and the outside floor channels. This provides a fence at once strong, comparatively simple, and neat and adds considerably to the whole appearance of the bridge. This whole design in fact is an unusually efficient one.

This same fence idea could well be carried out in other structurer where a poor fence is a deterioration factor in an otherwise good bridge design. This is notably the case in Plate 12. Here
the general design is well and ably carried out with the exception of the weak and unbraced fence. The extension of the legs would give stiff end posts for the fence and make a thoroughly consistent design.

[c]. Plate and Lattice Girders.

Plate and lattice girders, while as yet little used for highway spans, are really constructions evolved and expanded from the familiar beam structures so much in evidence in this work, and so deserve consideration with them.

Plate Girders: Of the standard designs of short span highway bridges obtained from some half dozen representative bridge companies, but two were of the plate girder type. One of these designs was not a true plate girder but could perhaps be classed under that heading. This scarcity of plate girder designs will show quite clearly that the plate girder as a type has not been successful as a highway bridge structure to any great extent. As has been before stated this is due to the generally light character of the highway spans and the cheaper constructions of the truss types which may be more advantageously used for this reason. To attain its maximum efficiency the plate girder span should be entirely shop constructed. This necessitates a heavy and bulky piece of metal most difficult and expensive to handle on the majority of country roads and with the appliances at hand in such cases. Plate girders are most economical of metal where the loads are heavy and concentrated. This makes them much more useful and available for railroad work.
where a stiff structure is especially needed and where the facilities for handling heavy freight of all descriptions is such as to make a plate girder’s bulk and weight no especial drawback.

That the plate girder type is not at present a success as a highway bridge does not mean that future conditions may not make it so. Just as the increasing weight of railroad engines and loads has been increasing the economical length of span for railroad plate girders, so will the improvement of the roads and the increased load concentrations brought into being by such conditions, finally lead to the general adoption of plate girder highway spans. The plate girder is a beam bridge just a little farther along in the process of development than the rolled beam structure. At present the conditions for the economical use of beam bridges is within the limit of the rolled beam. The plate girder comes with future conditions.

Plate 17 shows a plate girder design for highway uses. Since the web is not shown spliced at all it must be understood of very small span. More likely it is a general design where such details are to be considered later. Since the plate girder is a future rather than a present construction, not much can or need be said on the matter. The principles of design and the specifications applicable to railroad structures of the same type will, with necessary modifications, apply equally as well for highway conditions.

Before leaving the subject entirely it may be interesting to study Plate 18. Here it is difficult to exactly classify the structure. Of the plate girder type as to superstructure, the addition of legs gives a hybrid type classed by the designing company as a leg bridge but which is
more properly perhaps a leg plate girder. A general inspection of the design will show its undesirability. To the objections of the ordinary plate girder has been added the increased depth of girder at the legs instead of at the center where it is most needed, with a corresponding waste of metal. If this increased depth at this point has been put in to brace the legs, the design for this purpose is most uneconomical and unnecessary. In all points the structure is a kind of engineering monstrosity and should never be used.

Lattice Girders. Ordinarily the lattice girder is a step in advance [as to length of span where it is most economically used] of the plate girder, just as the plate girder is a step in advance of the rolled beam. Since the plate girder under present conditions has been shown to be a future rather than a present desirable and economical highway type, much more so will be the lattice girder. Of all the standard designs presented but one can be called a true lattice girder. This design is shown in Plate 19 and is called by the makers a cantilever bridge. Where the cantilever principle is brought into play is beyond comprehension although much may be expected of a "patent" bridge in the way of undiscovered merit. As in the case of several other designs the drawings were probably intended for the county commissioners rather than for an engineer. The same objection too as in the case of the plate girder of Plate 17 applies to this design. The increased depth of girder at the legs if put in for strength is in the wrong place, while if intended for leg bracing is uneconomical and unnecessary. In all cases such constructions are makeshift and experimental rather than established through satisfactory service under actual traffic.
Patent bridges of all kinds are to be treated with suspicion by the engineer until their merit has been proven.

In the above no consideration was taken of such designs as are shown in Plates 3, 4, 5, 6, and 7 where the lattice fence, while perhaps actually a girder to a certain extent, is light and does not, and is not intended, to act as a girder sustaining all or a great part of the bridge load. Under such conditions the consideration of lattice girders of the styles used in the above designs is out of the question.
[2]. Truss Bridges.

Any classification of truss bridges [especially of the short spans] on account of the great variety of truss shapes, sections of members, and member connections is at the best but an arbitrary one. To simplify the study of such bridges, however, it is absolutely necessary that some classification even though open to the above objection should be followed. As an attempt to simplify the subject matter, all truss bridges will be here understood as divided into two general divisions according to the method of connecting the members; i.e. as [a] pin-connected trusses, or [b] riveted trusses. A third division might be made of those trusses where both pin and riveted connections are made in the same truss but as such cases are few and at the best not designed according to good practice, they will be treated as variations of the other general types.

[a]. Pin-connected Trusses.

In a consideration of pin-connected trusses as applied to short span trusses it will be difficult to exactly define the limits meant by the term "short span". Since all peculiarities in the truss type occur with the shorter spans where pony trusses are universally used, only these styles will be considered as coming within the definition. The longer spans have been ably and voluminously treated by many bridge engineers, Waddell especially making an exhaustive discussion of this class of bridges. As with the beam bridges of short span, the short ponytrusses and bedstead bridges are of more recent general use and so comparatively little known. The almost insignificant sums paid for their construction, too, in comparison with the contract prices of
longer spans have probably had much to do with their being left to the comparative obscurity of the offices of the various bridge companies and bridge contractors.

It is extremely difficult to determine just where the length of span becomes sufficient for the economical construction of a truss bridge as against a beam bridge. Conditions affected by the companies bidding for the contract and who may have made specialties of one or the other types of construction will have much to do with the case; much more probably than any theoretical determination of the economics of the matter. In actual practice very few spans are built at crossings of less than 36 feet span. Thirty five feet will probably be safely within the limit at which they will ever be constructed. Future conditions will act to constantly though slowly increase this limit.

Still more difficult than the determination of the minimum span for highway pony trusses is the effort to define the limit for maximum span. Here a theoretical determination of the capabilities of the style would be impossible on account of the unknown efficiency of the upper chord for compression because of its practical non-support along it entire length. Study and comparison of the designs in actual service is the only criterion and so necessarily unsatisfactory. The longest truss of the representative designs is of 43 feet span, which is well towards the minimum limit and counts for nothing. Waddell gives 90 feet as the desirable limit for pony trusses and this is undoubtedly good practice. Waddell also specifies a limit of 12 feet depth for pony trusses with the floor beams riveted to the truss posts and a limit of 9 feet with suspended floor
beams. At the economical ratio of 1:7 for truss depth to length, this would give limits of span of 84 feet and 63 feet for the two forms respectively.

In the determination of the minimum span one condition other than economy of metal or manufacturers preferences plays a most important part. Beam bridges require an abutment or a modification of the abutment as a support for the beams. Where the approaches are supplementary spans instead of the usual fill it is difficult to provide beam supports corresponding to the abutments either in cheapness or efficiency. A pier or bent of metal posts is cheaper and more desirable and hence a determining factor in the selection of a truss span. These metal bents are simple and need little discussion. Generally constructed of sheet metal and filled and stiffened by piles embedded in concrete they are efficient and durable if well constructed and maintained. The posts of each pier or bent should be well tied together by diagonal rods and struts. Such a construction is shown in Plates 21 and 22. See also Plate 20.

This question of abutment support has lead to the design of a peculiar type of pony truss which almost constitutes a class by itself. Here the same desideratum which lead to the evolution of the leg bridge came into play and resulted in the extension of the end posts of the metal abutments to form the end posts of the supported truss, the simplification of the bearing between post and truss with the added lateral stiffening of the truss, more than compensating for the slight added increase of metal needed. In other respects the "bedstead truss" as the style is called, may be considered in the same manner and along the same lines as the ordinary types.
The compression members of short span trusses are of great variety of section and make up. Besides the ordinary styles of latticed channels, or channels with an upper plate, I beams are sometimes used in the smaller structures.

The best form of member is undoubtedly the latticed channels. Here the section is perfectly regular and admits of great simplicity in the laying out of the pin holes and the consequent prevention of extra stresses through eccentricity. However this best form is not the one most frequently used. A plate can be riveted on the channel at about the same expense for shop work as the lattice. This plate will then apparently contribute materially to the available area of the section and at a less proportionate cost than when the metal must be all supplied by the two channels.

The extra stresses due to eccentricity of the pin holes in compression members is not often considered in short span highway bridges although always of importance. The small size of the member does not admit of placing the pin hole very far out of the center of the channels on account of the crowding of the diagonals into or through the top plate. To avoid the bother of providing in the design for such a condition, the bridge company relies on the ignorance of the commissioners as to what extent this increases the stresses of the members, and places the pin hole where it is most convenient. In many cases sections dangerously near the safe limit at the best, are by this device brought considerably above the specified allowable limit. The use of the latticed channels without the top plate does away with all such difficulties and should be insisted upon where
the engineer can control the design.

The great difficulty in the use of I beams for compression members with pin-connections is in the design of a suitable detail at the pins. With a large beam and comparatively small pin not much trouble would be experienced and much of merit might be brought out. If care was taken in the boring of the hole, great bearing surface would be provided, doing away with all possible necessity for pin plates. The flanges of the beams would offer as suitable and convenient surfaces for the splice plate riveting as in the case of the channels. In any case however the selection of an I beam section wide enough in the flanges for the efficient design of the pin-connections and at the same time economical as to metal will be difficult and tedious. This in fact has much to do with the comparative scarcity of pin-connected I beam designs although in the riveted trusses and combination riveted and pin-connected trusses to be spoken of later, such sections are very common and popular among bridge contractors, if not among engineers.

Still another drawback to such a section militates against its successful use in all cases. The radius of gyration of a I beam is comparatively small and unless the member where it is to be used is very short, the safe ratio of least radius of gyration to length will probably not be within the limits. Of course I beam sections with a large enough least radius of gyration can be selected for almost any case likely to occur in short span highway practice, but such a section will not be at all economical of metal.

Closely related to the compression capacity of the top chord of pdny trusses is the capacity
of the chord taken as a whole and which was spoken of before on page 49. As there stated this chord unless extremely well braced is practically unsupported along it entire length, and hence has an unknown value with compression stresses. To minify this element, great care must be taken to see that the truss is well stayed and braced, but through efficient floor beam connections and outside supports. In too many cases designs are weak in both these respects, dependance being placed on the end bearing for all lateral stiffness. If the fence of a beam bridge needs lateral support for the safety of traffic, how much more so is this the case where the very existence of the superstructure itself depends on its resisting an outward thrust. Such a thrust of considerable magnitude may easily be conceived as liable to come from team accidents.

Pir-connected pony trusses are especially deficient in adequate lateral truss stiffening. Not only are the outside stays left off, but a most common floor beam connection is to simply hang them over the lower chord pins by a loop as is not very clearly shown in Plates 21 and 22. Here the floor and lower lateral system is simply hung from the pins and so constitutes a menace rather than a help to the stiffness of the truss. The top of the floor beams is drawn up tightly against the foot of the posts during construction and the threads beyond the holding nuts on the loop battered so as to prevent loosening. At first friction may hold the beam enough to allow the lower lateral system to fulfill its functions, but under the jar and vibrations of traffic the beams will never fail to work loose and become useless so far as the holding power for lateral or truss stiffness is concerned. The lower ends of the posts should always be extended beyond the pins and the
floor beams riveted or bolted to them. Field riveting in such small structures is not relished by contractors, and bolts, if lavishly furnished by the design and well tightened after the bridge has been in use long enough to get the stiffness out of it, will answer fully as well. There riveted floor beams also offer an opportunity for the placing of outside braces which are generally conspicuous by their absence. Angle braces to a cantilever support will double the stiffness of a truss depending on the floor beam connections alone for stiffness.

This matter of lateral stiffening is one of the good points of the beadstead type. Here the truss is an integral part of the abutments, and outside braces are unnecessary. The floor beam connections, however, should be riveted so as to provide for the efficient performance of the functions of the lower lateral bracing.

Where the truss is of the beadstead type the first panel of the lower chord should be a stiff member. The end post being simply an extension of the abutment legs is more than likely to have a considerable bending moment due to the pressure of the earth backing. This pressure must be taken up or the post will bend, buckling and distorting the truss.

Slight buckling of the trusses is also caused in many cases where they rest upon tubular piers. The holes in the cover plates of the metal piers to receive the holding down bolts of the end bearings are punched in the shop. When the pier is put in, the unavoidable twists coming in through the various vicissitudes of erection make the fitting of holes at this point a most pains-taking job of drifting. As stated, this drifting is liable to buckle the truss. In through
bridges of considerable span such buckling has been observed to bend the lower chord bars one or two inches out of line. When a load comes upon a structure so buckled, the bars and diagonals rattle and clatter as if everything in the bridge was loose and ready to fall to pieces. Foremen of construction gangs all state that they would prefer to do the necessary punching for this detail in the field, and there is no question as to its desirability from an engineering point of view.

Floor, beam, and joist details are much the same for trusses as for beam bridges, and all points noted in the discussion of the former type will apply equally as well not only for the pin-connected but for riveted and combination structures. In the case of the fence there is a considerable difference in the conditions. With the truss bridges the fence posts are supplied by the truss members and the ingenuity of the designing engineer must be expended upon the railing and its attachments to the posts. Lattice fences are more expensive than necessary; farmers complain that they rattle and that the whiffle-trees get caught in the meshes and frighten the horses before released. A simple channel or angle fence of two rails is all that is necessary. The fence shown in Plate 1 with the simple modifications fitting it to the truss is as efficient as when used on the beam bridges.

Where channels or angles are fitted as fence rails to truss members as shown in the above
diagramatic sketch, the screwing up of the holding bolts springs the rails unless care is taken to provide fillers between posts and rail. Such sprung rails make an exceedingly bad looking job - one that discredits the whole bridge. This difficulty occurs with several kinds of posts other than are shown in the sketch.

The wooden fences shown in Plates 21, 22, and 23 are never desirable. The rails are soon cut and hacked and broken and useless, making frequent renewal necessary if the bridge is to be kept in first class condition. The rails form a tempting place for the nailing of signs and the carving of initials and legends dear to the rustic youths heart and so make the whole structure an eyesore to the traveling public. A fence simple, neat, and consistent in its construction with the bridge design, is most to be desired.

[b]. Riveted Trusses.

Much that has been said in the foregoing as to pin-connected trusses applies with equal force to the riveted truss. Riveted designs have many points of merit however which are not possible in the other direction. At the present stage of metallic construction the pin-connected design for short spans is to my mind altogether out of place. Its great points of merit in clearly defining stresses and permitting great ease of erection have not so much force in such short span pony trusses as in the majority of cases constitute most of the highway spans. The stresses of such structures are not of such magnitude as to make their precise definition a matter of great economy of material. As to the ease of erection any bridge foreman would smile at the question.
In most cases were it not for the clumsiness of the completed truss they could be put together in the shop and easily erected complete in the field.

Riveted trusses are rigid, stiff, and [on the authority of a bridge builder] cheaper than the pin-connected structures, for the shorter spans. Riveted trusses too, admit of the economic employment of many more and different member sections than the pin-connected types. Angles may here be advantageously used with a great simplification of connection details. Such a plan is shown in Plate 24 and is in all respects an admirable design. The convenient support for outside bracing formed by the riveted floor beam connections has been noted before.

Where I beam sections are used with riveted connections, the design will be much more simple and efficient than in the case of pin-connections. Plate 23 shows a combination design with some of the good points of both riveted and pin-connections. It will be noticed here how simple and effective the connections can be made—especially in the case of the floor beams. Such a combination has its drawbacks however in an increased care necessary in the fitting of the tension rods and bars. The safe ratio of least radius of gyration to length must also be carefully inspected as this is always likely to be a weak point in such a design.

The design shown in Plate 25 is a queer combination where the I beam sections and partly riveted connections are used. On its face the design seems simple and effective, but actual use has brought out several weak points in its construction which make it practically worthless. The greatest fault is in the connection of the diagonal and chord rods with the floor beam. In con-
struction, when these rods are tightened with the ordinary initial tension, the bending moment on the floor beam at the connection, buckle the beam badly, so much so in many cases as to make it necessary to condemn the whole structure. In these bridges too the necessary stiff member between the legs and the first pane of the lower chord is omitted unless the floor channel riveted to the posts can be so called. Such a connection at the best is poor and inefficient.

This bridge is a patent structure and partakes of the usually worthless character of such designs. Here I want to again warn against new constructions which may appear efficient and cheap, but the proof of the value of which has never been verified by trial under actual conditions of service.

In conclusion I wish to speak a word for the value to the engineering student of the study of various designs representing common practice in regard to the structure in which he is interested. It is extremely difficult to dissect and analyse the various details of a structure in a style vivid enough to show at once just where they are lacking or are of merit. Given the essential points in a good design with warnings as to difficulties likely to occur with certain constructions and there will be little trouble in combining the good points of the many designs as proven by actual service, in a single design far better than any of the others. This may be said to be imitative rather than creative, but all work for that matter is imitative to at certain degree and if we profit by the failures of others we are just so far ahead in the struggle for the ideal.

Recognizing these principles I have endeavored in a general way to say a word as to the im-
portance and best practice in regard to the various points to be considered in the design of the present styles of short span highway bridges. Working with standard plans largely, there is no attempt made to solve concrete examples, and indeed there is little value in such a treatment where the mathematical problems of design are so simple as in the present case. There may be and probably are many interesting details which have been overlooked. It is hoped however that these are unimportant and non-essential to a clear idea of the requirements, limitations, and ideals of the various types of short span highway bridges and of the conditions which govern their construction.
CHANNEL FENCE.

Design by

Prof. Ira O. Baker.

Note:-
Legs of channels forming fence rails to be planed and ground off as shown.

4x4" x 1/2" L - 9/6".

8" L - 1 11/16" g.

5" L - 6 1/2" #

5" L - 6 1/2" #

10" L.

6" 3' 0" 3' 0" 6"
BEAMS on MASONRY.

King Bridge Co.,
Cleveland, Ohio.
BEAMS on MASONRY.

King Bridge Co.,
Cleveland, Ohio.
INDIANA BRIDGE COMPANY, MUNCIE, IND.

Span __________ ft __________ in. Extreme Length.
Roadway __________ ft __________ in. Extreme Width.
Capacity __________ per lineal foot Live Load.
Capacity __________ per lineal foot Dead Load.
Unit Stress 15000 lbs. per sq.in. in extreme fibers.
Plate 12.

STANDARD BEAM LEG BRIDGE

MILWAUKEE BRIDGE & IRON WORKS.
MILWAUKEE, WIS.
The J.G. WARNER CO., PROP.
Plate 13.

STALLINGS BROTHERS.

HIGHWAY BRIDGE of STEEL I BEAMS.

SPECIFICATIONS:

<table>
<thead>
<tr>
<th>Description</th>
<th>Measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of Span</td>
<td></td>
</tr>
<tr>
<td>Width of Roadway</td>
<td></td>
</tr>
<tr>
<td>Capacity per square foot</td>
<td></td>
</tr>
<tr>
<td>Floor Beams</td>
<td></td>
</tr>
<tr>
<td>Posts</td>
<td></td>
</tr>
<tr>
<td>Total Height</td>
<td></td>
</tr>
</tbody>
</table>

Remarks:
- Floor to be laid on welding strips.
- All metal to be painted.
INDIANA BRIDGE COMPANY, MUNCIE, INDIANA.

SPECIFICATIONS FOR IBEAM BRIDGES.

IN SPANS OF 10FT. TO 18FT.

Span □ ft. □ in. extreme.
Roadway □ ft. □ in. extreme width.
Height □ ft. □ in. top of floor to mudsill.
Capacity - Live load □ lbs. per lin. ft.
Dead load 400 lbs. per lin. ft.
□ Girders 5’ 9” I Beams.
Girder Braces 3” x 3” x 5/16 Tees.
Main Legs - 5’ 9” I Beams.
Intermediate Leg □ I Beams.
End Floor beams □ I Beams.
Joist □ lines □ I Beams beside guides.
Nailing strips 2” x 4” oak.

Railings - 2 lines 1” gas pipe.
Laterals - 5/8” Beam Hanger 9/16.
Flooring □
Backing □
Mud Sill □
Felloe Guards □

Plate 14.
Plate 17.

STANDARD STEEL PLATE GIRDER BRIDGE

THE J.G. WAGNER COMPANY
MILWAUKEE BRIDGE & IRON WORKS
MILWAUKEE, WIS.
Improved Patent Cantilever
Sub-structure bridge for
Spans from 35 to 70 feet.
Construction: All steel and stone.

Manufactured only by the
Indiana Bridge Company,
Muncie, Indiana.

Side Elevation.

End View.
STANDARD RIVETED TRUSS

MILWAUKEE BRIDGE & IRON WORKS,
J.G. WAGNER, Eq. Prop.
MILWAUKEE, WIS.