that of the I-Beams, since working stresses in timber may be doubled for loads of short duration, retaining the same safety factor as for static loads of the same amount Of course in many instances considerations of deflection would not permit the doubling of live load working stresses in timber, but a reasonable allowance should be made to secure any possible advantage from this characteristic of timber For example, with the usual working stresses a timber bridge designed for 15 tons actually has more live load capacity than a 20 ton bridge of other materials Hence in a comparison of alternate designs, proper allowance should be made for this fact

With the present tendency toward the construction of very long I-Beam spans it is believed substantial economy may be gained by an increased use of well designed timber floors, due of course to the reduction in dead load While it has been the strict purpose in this paper to avoid reference to any features concerning the design and construction of bridges, it is believed this suggestion, based on the firm conviction that timber floors *can* be designed and constructed to give adequate service, will be accepted in the spirit in which it is advanced—to the end that maximum economy be secured

LOW COST STEEL HIGHWAY BRIDGES

F H Frankland, *Director*

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SYNOPSIS

Examples of new designs in steel bridges that have resulted in greater economy through use of continuous girders and beams, and steel plate floors are cited The life of steel structures is placed at not less than 100 years if the steel is maintained by periodic painting Costs for painting are presented Important features of steel bridges are their movability and the ease with which they can be reinforced or enlarged

The essential characteristics of a bridge are adequate strength and capacity; maximum durability and minimum cost of maintenance, flexibility and movability and unlimited variety of beautiful line, form and color All these are inherent in the steel bridge

To determine the ultimate cost of a bridge it is necessary to consider its maintenance cost over an assumed period If steel is used it must be maintained by painting, but with proper painting it should last at least one hundred years

If a steel bridge is properly painted and prevented from rusting, and not overloaded beyond the stress limits for which it was designed there is no danger of its wearing out or going to pieces on account of use or lapse of time within any known period of years There is nothing either in experience or theory pertaining to metallurgy that indicates deterioration in steel as the result of use provided the limits of stress are kept within the so-called endurance limit, which is about one-third of the maximum strength of the metal.

Impact tests and tests involving reversals of stress have been made by established authorities wherein the repetitions of stress ran to 100,000,000 cycles without showing evidence of damage to material Probably the most comprehensive series of tests covering this ground were those made a few years ago by the University of Illinois under the sponsorship of the Engineering Foundation and the National Research Council The material used in these tests was submitted to the standard pull tests to determine whether there had been any deterioration in ultimate strength, and it was conclusively proved that in no case was any deterioration shown

By proper maintenance a steel bridge may be made to defy the elements indefinitely, but for the purpose of considering the economics of small highway bridges it may be accepted that changes in traffic conditions make such a structure obsolete long before the end of the one hundred year period The practice of the leading railroads is to repaint their steel bridges about every seven years A well-known consulting bridge engineer states that he assumes a cost of $1 00 per ton per year to keep bridge steel properly maintained, and this statement checks very closely with the experience of our representative railroads It is the paint that depreciates from exposure and not the steel, and if the paint is properly renewed the structural integrity and strength of the bridge is unvarying and everlasting No exposed structure of any kind of material can escape the necessity for maintenance, which is less expensive for steel structures than for those of any other material except possibly vitrified clay, granite, and some other stones

Experience in this country and Europe during recent years with copper-bearing bridge steels has shown considerable savings in maintenance costs, as the paint coat adheres better and rusting underneath the paint is of rare occurrence with this type of steel The extra cost of copper-bearing steel is but two to three dollars per ton and it is readily available from those mills rolling structural shapes In the author's opinion it is therefore well worth while giving consideration to the use of copper-bearing steel when economic studies are made in connection with bridge designs

The toll bridge over the Susquehanna River at Harrisburg, Pa, was built in 1889 The floor system was strengthened in 1894 to carry 30-ton trolley cars The underside is painted every five or six years and the upper part every eight or nine years A complete painting (total length of bridge 2,846 feet) costs $9,000, which reduced to an annual cost amounts to 46 cents per lineal foot The structure is in perfect condition today

There are many steel bridges throughout the country which have been in continuous service—in some cases they have been subjected to heavy overloads for years—since about 1880, the early days of steel manufacture.

Recently there has been increased attention given to the development of new design in steel bridges, and this has been marked in the smaller highway structures. The engineers of Tennessee State Highway Department have developed an economic design for a continuous deck girder bridge, and have built a three-span structure, continuous over four supports, using girders consisting of rolled sections, at a very marked saving in cost as compared to various alternative designs studied for the project. The details of splice connections for the

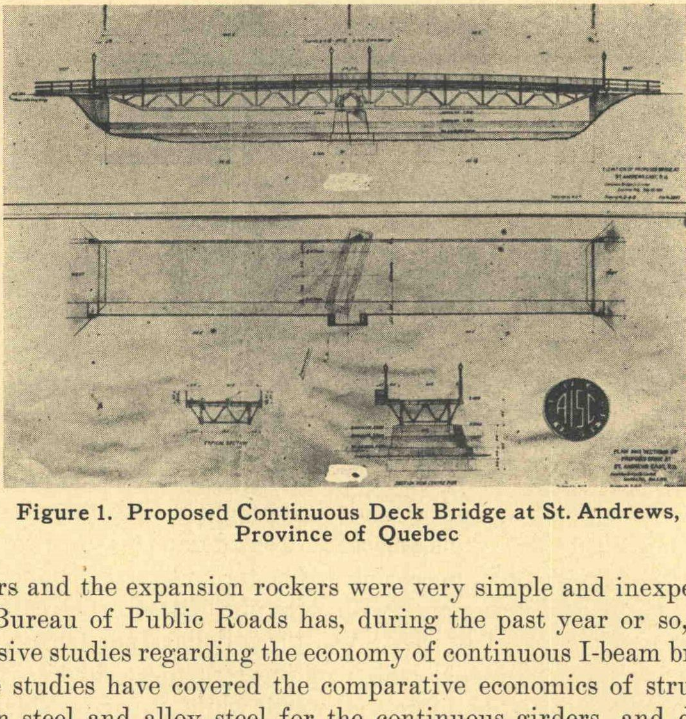

Figure 1. Proposed Continuous Deck Bridge at St. Andrews, Province of Quebec

girders and the expansion rockers were very simple and inexpensive. The Bureau of Public Roads has, during the past year or so, made extensive studies regarding the economy of continuous I-beam bridges. These studies have covered the comparative economics of structural carbon steel and alloy steel for the continuous girders, and demonstrate the great economy of continuous bridges where the foundation conditions are reasonably satisfactory. The Virgin River Bridge in Zion National Park, designed by the Bureau of Public Roads, consists of three continuous span beams, two of 48 feet 5¼ inches and one of 88 feet. Figure 1 illustrates a proposed continuous deck truss bridge at St. Andrews, Quebec. The two spans are of 100 feet 3 inches each, and the design is an economic solution of a difficult problem where the abutments are at right angles to the axis of the bridge but the center pier is on a skew to accommodate the river current.

The economics of design as relating to steel plate floors for highway bridges are now quite well known, due to the extensive use of this type of floor by the Department of Plant and Structures of the City of New York and development of design for various types of steel plate bridge floors. The Department of Water Supply of the City of New York has under its jurisdiction a number of steel arch,

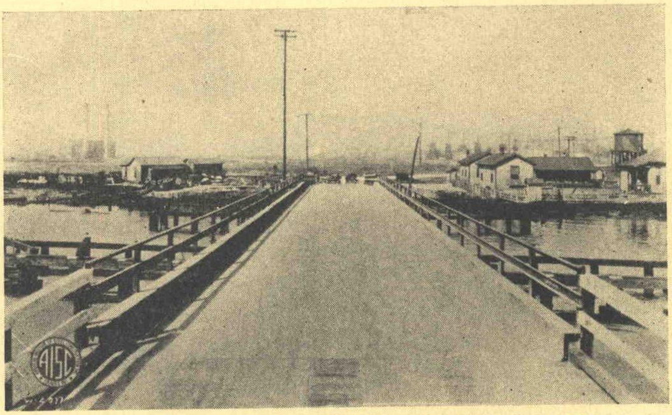

Figure 2. Taylor Bayou Bridge, Port Arthur, Texas

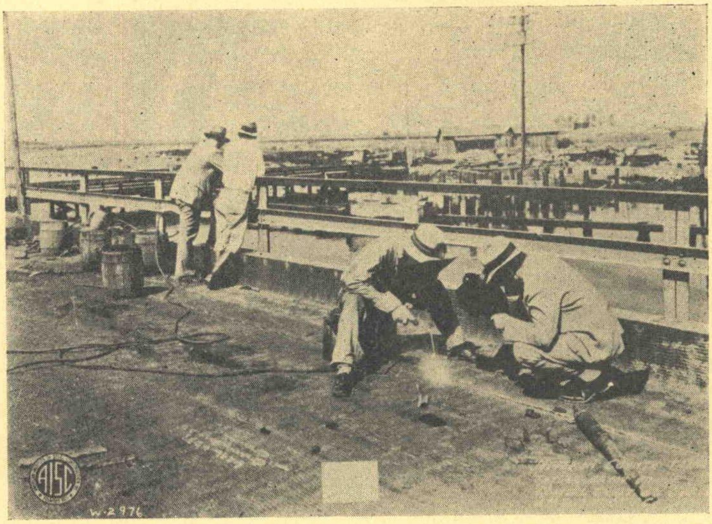

Figure 3. Taylor Bayou Bridge, Port Arthur, Texas

cantilever and truss highway bridges built in 1906 and 1907. The floors of these bridges were originally of laminated wood, but, due to considerations of maintenance, these floors have recently been replaced by the flat steel plate type, surfaced with wood block, bituminous concrete and asphalt plank. The so-called Battledeck floor was used for a highway swing bridge over Taylor Bayou, Port Arthur, Texas—Figures 2, and 3. This use of a steel plate floor saved much dead load and power required to operate the bridge, and reduced materially the cost of the structure as compared by estimate with the usual type of floor

The Robertson Keystone Steel Floor is radically new in conception and, from the results of comprehensive tests recently completed at the Bureau of Standards, the weight-strength ratio of this type construction very nearly approaches the possible maximum This type of floor makes use of the maximum possibilities in taking advantage of the favorable economics of shop versus field fabrication—the field labor being reduced to a minimum The Robertson floor is considerably lighter than any other floor for a given strength, yet no part is stressed to permissible design limits when subjected to any type of loading, and apart from the marked saving in dead load of the floor system important savings in fabrication and erection costs are claimed Another advantage claimed for this particular type of floor is its shallowness, thus indicating its special usefulness where shallow bridge floors are required, as in grade crossing eliminations

Although not coming within the scope of the structures dealt with in this article, the lift bridge recently completed over the Delaware River between Burlington, N J , and Bristol Pa , furnishes an illustration of the economies possible by the use of steel floors The main span of 534 feet is the longest movable span in existence, and incorporates a light-weight floor made up of shallow beams and checkered steel plates—as in the Taylor Bayou bridge. The floor was composed of $\frac{5}{8}$ inch steel plates supported on longitudinal stringers spaced on 13 inch centers Three main carrying stringers were provided, one at each curb and one along the center line of the 40 foot wide roadway Between these stringers are riveted transverse cross beams at 6 foot 2 inch centers on which are supported eight inch stringers carrying the floor A cross beam is used at each end of each panel in order to avoid riveting the top stringers into the floor beams The floor plates were made in widths slightly over three feet and came riveted to the stringers in panel lengths Ash-Howard-Needles and Tammen, the designing engineers, state " the steel plate on the lift span effected a $40,000 saving in the structure. Before adopting this steel plate floor, several other types were considered and given careful study " There was a short-span beam bridge built near Pittsfield, Massachusetts, about forty years ago with a steel plate floor. This bridge is standing today in splendid condition, having had the beams reinforced with hog rods to assist in carrying greater live loads than those for which it was designed

About twenty-five years ago there were a great many short-span highway bridges built in Iowa and Nebraska with steel piles of rolled sections The experience with these bridges has been so eminently satisfactory from every consideration that recently the great economy in cost and maintenance of this type of sub-structure has become well recognized, with the result that several steel beam bridges with steel H pile bents have been constructed, such as the one for the California State Highway Department at Lytle Creek in San Bernardino County.

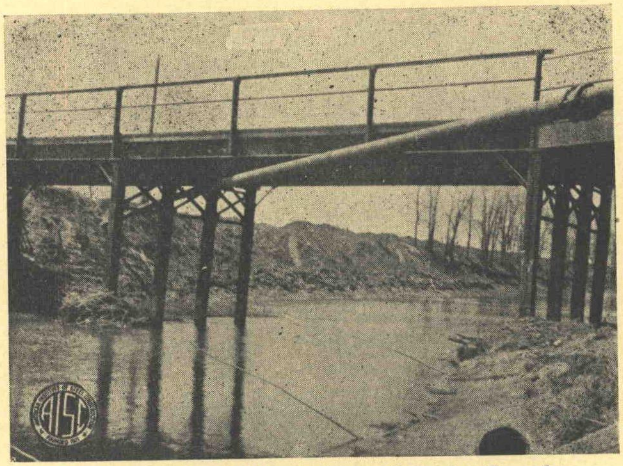

Figure 4. Steel Pile Bridge, Ontario, Canada

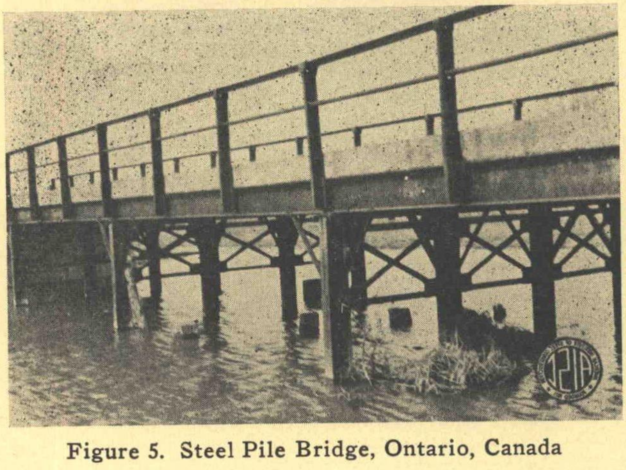

Figure 5. Steel Pile Bridge, Ontario, Canada

The Lytle Creek Bridge is similar in general design to many others recently built in California.

Thirty years ago there were four short-span bridges built in Ontario with steel bents. (See Figures 4, 5, 6, and 7.) The condition of these structures may be seen from the photographs which were taken thirty years after the bridges were first put into service. The low first cost and maintenance of steel pile bent bridges for those locations where such structures are suitable is of much importance in present-day economic studies for highway bridge construction. The fact has been established that, even without maintenance, steel H piles lose not more than one per cent of their cross section at the water level, the location of greatest corrosion, during a 25 year life.

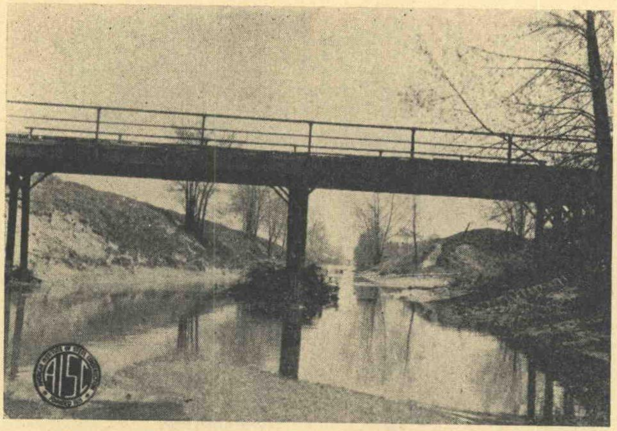

Figure 6. Steel Pile Bridge, Ontario, Canada

Figure 7. Steel Pile Bridge, Ontario, Canada

An important consideration in studying the economies of bridge design is what may be called the movability feature. Flexibility and movability are characteristics of steel bridges only, as because of their articulated construction they may be inexpensively reinforced for increased loads or moved to other sites when necessary. There are thousands of such cases throughout the country, and there have been cases where a steel bridge has been used at three or more sites during its thirty or forty years of service.

The Sherman's Creek Bridge, Perry County, Pa , consists of two 80 foot and one 55 foot spans of light steel trusses During the spring flood of 1927 these spans were washed off the piers, floated downstream and deposited upside down on the bank of the creek The trusses were re-erected on the piers the principal damage consisting of some broken connection angles

Mr H G Hunter, M Am Soc C E , says (Journal of the Western Society of Engineers, Vol XXXIII, No 5, May, 1928) "the facility with which the materials entering into a bridge structure lend themselves to reinforcement or to the accommodation of loads beyond their design-capacity deserves consideration The ability of a steel structure to carry overload without injury recommends it for use, particularly in cases where a possibility of greatly increased traffic requirements can be even remotely foreseen The ease with which a steel bridge can be reinforced, or even enlarged, in order to provide for additional traffic, deserves some thought"

Low cost and durable wearing surfaces on steel bridge floors are obtainable by the use of a variety of finishes In some cases a checker steel plate, such as used on the Taylor Bayou bridge, is economical When the traffic treads become worn smooth the steel may be surfaced with asphaltic concrete, the steel first being treated with a thin coat of asphalt mastic Another economical but durable wearing surface may be obtained by the use of 2 5 inches of concrete, reinforced with a light mesh, applied direct to the steel, with a wearing surface of one-half inch unicrete or some such similar mix of asphalt, cement and sand It is an established fact that such a properly designed asphaltic concrete, will withstand extremes of heat and cold and will not dissolve when wet with oil or gasoline

With the availability of deep wide-flanged rolled steel sections, radical economies may be obtained in steel beam bridge design, not so much by the saving in weight of steel but by the reduction of expensive fabrication Also in bridges with steel floors it is possible to design the floor system in such a way as to provide for a large part of the necessary fabrication being done in the shop, thus eliminating much expensive field erection As a matter of fact the fabrication of units in the shop should be limited only by their size and weight This ratio of shop and field cost in bridge work is becoming more and more an important item of study in the economics of bridge design as the ratio of cost per ton for field work increases and the cost per ton of shop work decreases This economic trend can obviously be taken advantage of by skillful design with that end in view