proved its effectiveness in directing or controlling traffic as desired. All signs should be considered as experimental and subject to change or adjustment until observations of traffic flow prove that they function as intended.

TIMBER HIGHWAY BRIDGES IN OREGON

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SYNOPSIS

In normal times there is an economic balance between steel, concrete, and timber as materials for highway bridge construction. During the war emergency due to the nonavailability of certain construction materials there has been a great increase in the use of lumber.

The most generally used type of timber bridge and the type in which timber finds its most suitable use is the timber trestle. Pile trestles should be preferred because of the stability and economy of the substructure. A timber-deck type has been developed in Oregon which uses 4 in. by 12 in. plank for the subdeck and 2 in by 2 in. cedar or treated fir strips, laid longitudinally, for a wearing surface. The wearing surface is laid in hot asphalt. Due to waterproofness of the combination, exceptionally long service life has resulted. Where highways are on reasonably permanent location, the use of a preservative treatment is advisable

Oregon has developed a composite timber and concrete trestle which is intermediate in cost between the timber trestle and the concrete viaduct. A combination of treated timber substructure and stringers with a concrete deck is used. This type of structure has many advantages, such as a waterproof deck which protects the substructure, added stiffeners due to the T beam action of the deck and stringers, and low first cost. Economy is particularly apparent at sites where the character of the foundation material is such as to make pile support necessary for any structural type

Because of war conditions many timber trusses have been used at sites where spans longer than practicable with trestle construction have been required Pony or low type truss design is suitable for spans up to 80 ft. From this length up to 200 ft high trusses are used due to the necessity for adequate lateral bracing Timber trusses above 200 ft. in span require an excessive amount of material. Roadway widths are restricted by the size of floor beams required to a maximum of 24 ft unless a truss-type floor beam or a steel beam is used. Deck type trusses with the floor beams overhanging the top chord permit wider roadways. Split ring connectors effect a considerable saving in material and give more durable splices. Housing of untreated timber trusses may be expected to double the service life, but materially increase the first cost.

Treated timber culverts are practical even under normal conditions. Small sizes of lumber are used resulting in low first cost and more uniform impregnation by the preservative Untreated timber culverts are not advisable because of short life and high replacement cost For very temporary use, untreated log culverts have been used

Selection of bridge types should be made on comparative total annual cost. These costs can be divided into (a) capital costs, (b) maintenance costs, and (c) operating costs Based on Oregon experience, for maximum economy untreated timber trestles should be renewed at intervals ranging from 15 to 20 years, and

housed timber trusses at from 25 to 30 years Composite construction and steel and concrete spans can theoretically be carried in service indefinitely with economy when adequately maintained. Their life is probably limited by obsolescence.

Because of the urgent need, during the present emergency, for the maximum utilization of nonstrategic materials, the employment of timber in the design of highway bridges is receiving an increasing degree of attention

In the design of highway bridges during normal periods, there is a distinct field of utility for all of the ordinary materials of construction. Bridges of steel, bridges of concrete, and bridges of plain and treated timber each find a place, the problem of type selection being largely one of engineering economics as hereinafter discussed. During the war emergency, however, the economic picture will be warped because of the nonavailability of certain construction materials. The immediate result of this distortion, in so far as it pertains to highway bridges, is to increase the field of utility for timber.

Because of these conditions, it is inevitable that, during the present emergency, the utilization of timber in highway bridge construction will be pushed far beyond the point of its normal economic balance. For work of military necessity such as the construction of access roads or betterment projects whose purpose is to remove so-called "bottlenecks" on strategic military highways, there is no alternate, but, in all cases where such a procedure is possible, careful consideration should be given to temporary emergency construction, repairs, or reinforcements, postponing all permanent improvement projects until the return of normal conditions renders it possible to apply the principles of an unfettered economic policy.

In the succeeding paragraphs, the writers have attempted to describe the essential features of the timber bridge designs normally employed in Oregon, with a concluding section dealing briefly with the economics of timber bridge types.

UNTREATED TIMBER TRESTLES

The most generally used type of timber bridge, and the type for which timber is the most suitable, is the short-span timber trestle. The substructure may be of either pile or frame construction, depending on foundation conditions. Pile substructures are preferred and are used when the nature of the foundation material is such that piles can be driven. A pile bent, with adequate penetration, is much more stable under the impact of drift, and stream bed erosion is less apt to result in serious damage than in the case of frame bents on pedestals or sills, and, for this reason, pile substructures should be given preference over frame construction wherever possible. The emphasis placed on timber construction by the wartime shortage of both reinforcing and structural steel has forced the use of short-span timber trestles where longer span construction would normally be used.

Figure 1 shows a typical trestle design as used in Oregon. Under normal conditions, span lengths have been limited to 29 ft by the difficulty in obtaining large-size stringers. During the present emergency, structures with spans as long as 35 ft. have been used. For this span length, using structural grade Douglas fir, 8 by 24-in. stringers are required. Requirements of the war agencies have made structural grade lumber difficult to obtain, and common grade lumber has been substituted in many cases. This increases the required size for the above span length to 10 by 26 in, which approaches the practicable size limit for quantity production.

A timber deck type has been developed in Oregon which is a marked improvement over most of the types in general use. This design consists of a 4 by 12-in. plank subdeck placed transverse to the center line in combination with a longitudinal upper deck or wearing surface of 2 by 2-in. strips. The underdeck plank are spaced with a ½-in. clearance to allow circulation of air around three faces of the plank. The top surface is given a coat of hot asphalt, and the 2 by 2-in. top deck is laid before the asphalt cools. Asphalt of 150–200 penetration (SC-6 road oil) is best suited to this purpose. In fastening the 2 by 2-in strips, a combination of toenailing into the subdeck and horizontal nailing into the adjacent strip is used. No nail heads show in the deck surface, and, consequently, the nails cannot work loose. The Oregon practice is to use either Port Orford or Western Red cedar for the longitudinal decking because of its resistance to decay. A few structures have been built using creosote-treated Douglas fir strips. These deck surfaces are quite slippery and should be covered immediately with an asphaltic mat having a nonskid surface. This construction is practically watertight and is very rot resistant.

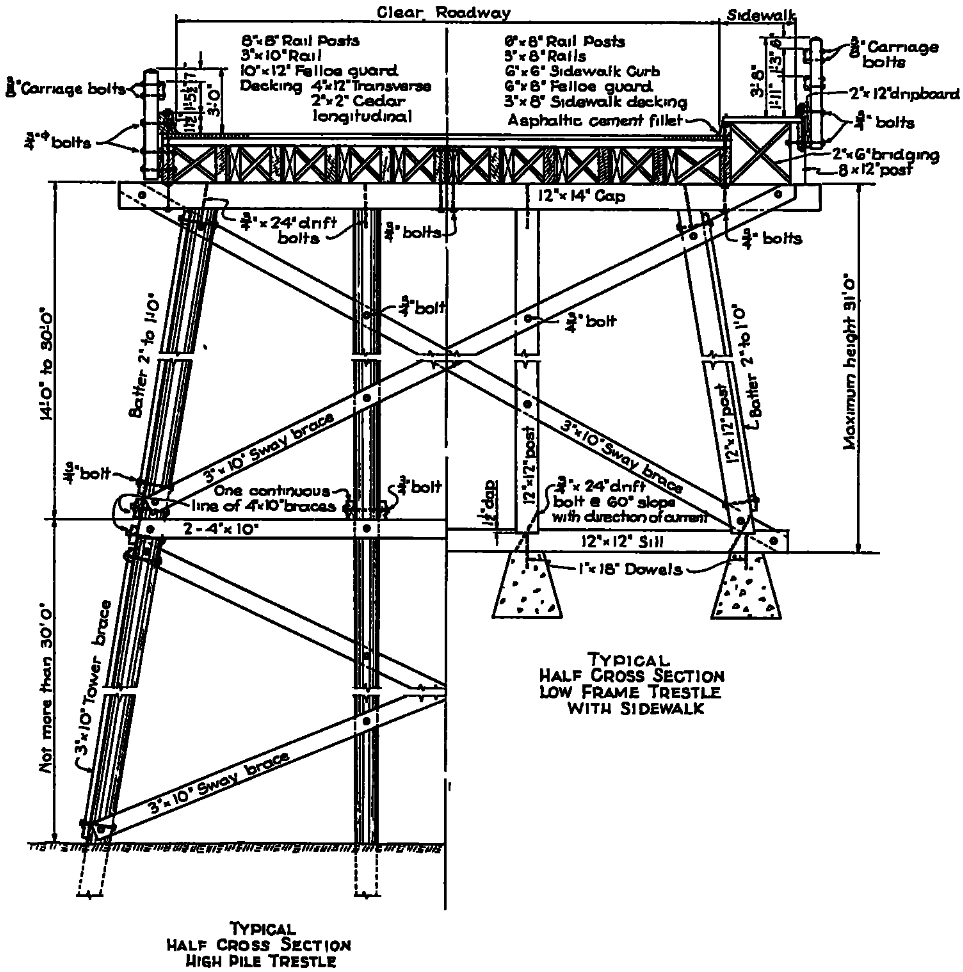


Figure 1. Timber Trestles

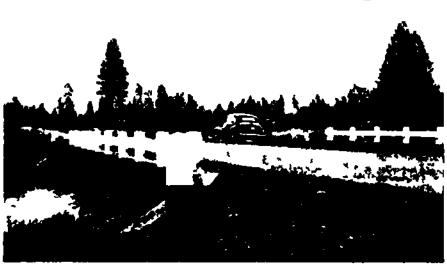


Figure 1a. Typical Timber Trestle with Low Type Handrail

Structures with this type of deck were first built in Oregon 12 years ago and are still in service with little or no apparent decay.

The increase in heavy truck traffic during the past few years has led to the development of a low-type handrail with a heavy felloeguard. This rail is used on structures where no sidewalks are provided. Details of this rail are shown in Figure 1. It has proven more suitable than the higher one.

Where highways are on their permanent

location, the longer service life makes the use of a preservative treatment advisable. Handrails should be painted; and, if preservative treatment is used, some form of metallic salts treatment is preferred, as painting over creosote treatment is rather difficult.

Where longer spans than are practicable with ordinary trestle construction are needed, log spans have been used Figure 2 indicates the essential details of a 60-ft. log span Such construction is possible only where large logs are available locally, as is the case in the heart of the timber belt in Oregon

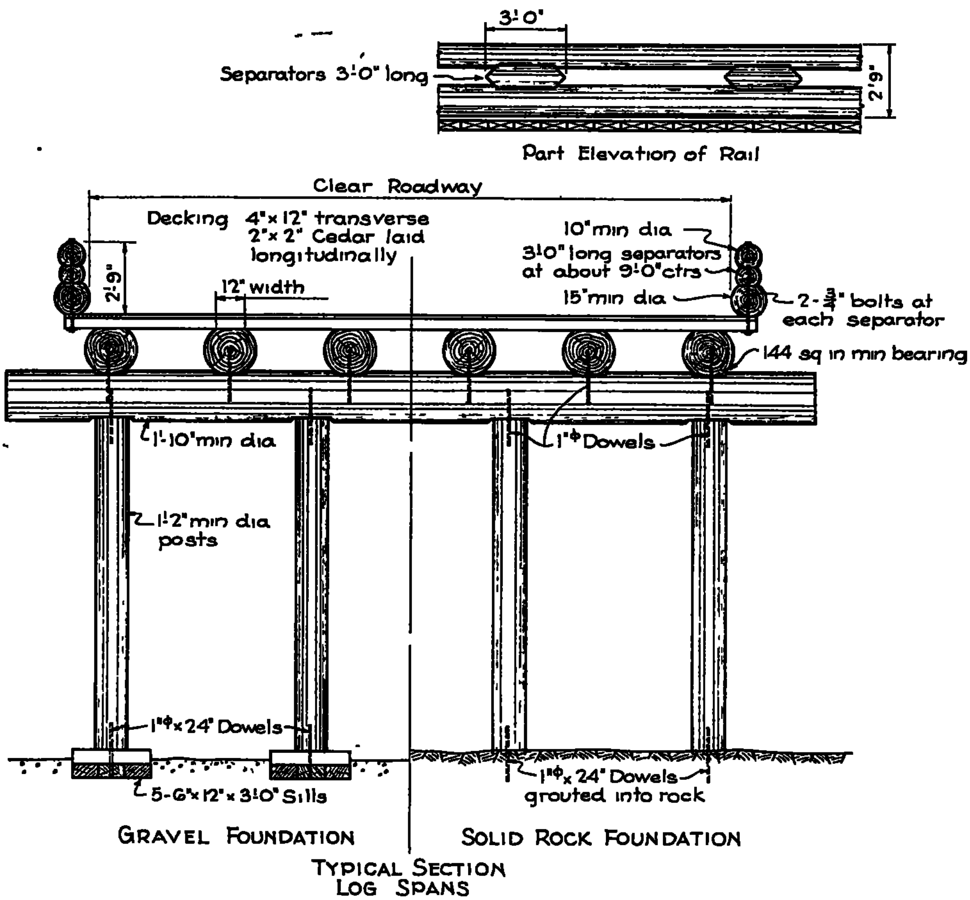


Figure 2. Details of 60-ft. Log Span

COMPOSITE (TIMBER AND CONCRETE) TRESTLES

In Oregon, a need has developed for a type of structure intermediate in cost between the timber trestle and the concrete viaduct. This occurs most often on highways where the alignment is relatively permanent and at sites where the longer spans (possible in the case of the concrete viaduct) are not a controlling consideration. To meet this need, a composite trestle superstructure consisting of treated timber beams or stringers and a reinforced concrete deck was developed. Figure 3 shows the details of this type. The deck is anchored to the stringers by means of shear connections at the junction plane so that a composite T beam action is obtained. A comprehensive series of full-sized tests was made in connection with the development of this design, and it was found that a combination of daps and spikes driven half way into the tops of the stringers gave the most practical method of attachment. Approximately

180 structures of this type have been built in Oregon in the last 10 years using both pile and frame substructures. They are particularly advantageous at sites where the distance between grade line and ground line does not exceed 30 ft and for crossings of swamps or overflow channels where the nature of the foundation material would have necessitated deep foundations on pile supports had concrete or steel viaduct construction been used.

The composite trestle has many advantages among which the following may be mentioned. (1) The overhanging concrete roadway acts as a waterproof and fire-resistant covering, thus lessening both the fire hazard and the chance of decay (2) The composite action adds stiffness to the stringer system, preventing excessive deflections under load and thus reducing the chance of cracks forming in the deck. (3) Each stringer acts as a T beam, and the neutral axis is near the top of the stringer. This reduces the shear at the center of the stringer where the natural tendency to season checking is greatest. (4) The restraining action of the timber stringer against thermal change makes longer spacing of expansion joints possible, resulting in better riding qualities. (5) First costs, while higher than for the conventional timber trestle, are lower than for the more permanent types, especially in locations where full advantage can be taken of all of its potential economies.

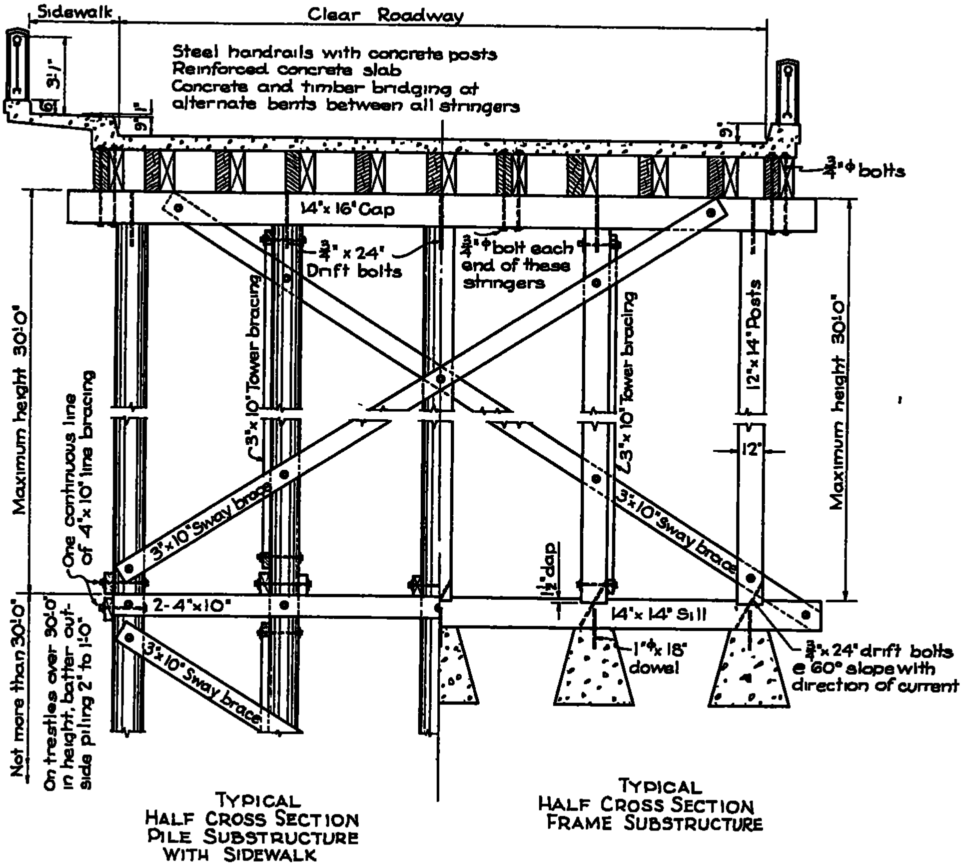


Fig. 3. Composite Trestles

This type of structure requires reinforcing steel in the deck only and thus gives an opportunity for semipermanent construction under wartime conditions For a 26-ft. roadway, the deck requires approximately 110 lb. of reinforcing steel per linear foot.

TIMBER TRUSSES

Timber trusses fall naturally into three groups: (1) pony or low truss spans, including A-frame trusses; (2) through truss spans, and (3) deck trusses. All of these types have been used extensively in Oregon.

For longer spans, the floor beam and stringer sizes required make it advisable to use three or more panels Typical designs are shown in Figures 4 and 5.

For span lengths of 90 to 200 ft, the high truss is used, either as a through or as a deck

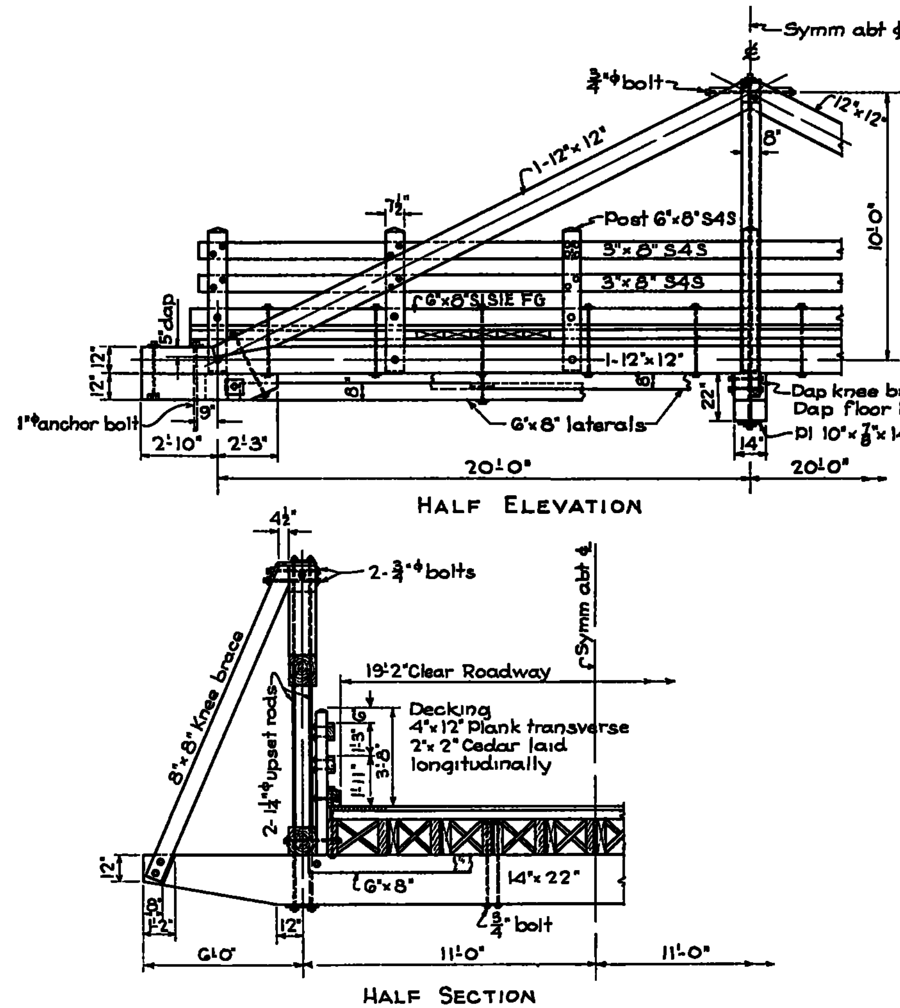
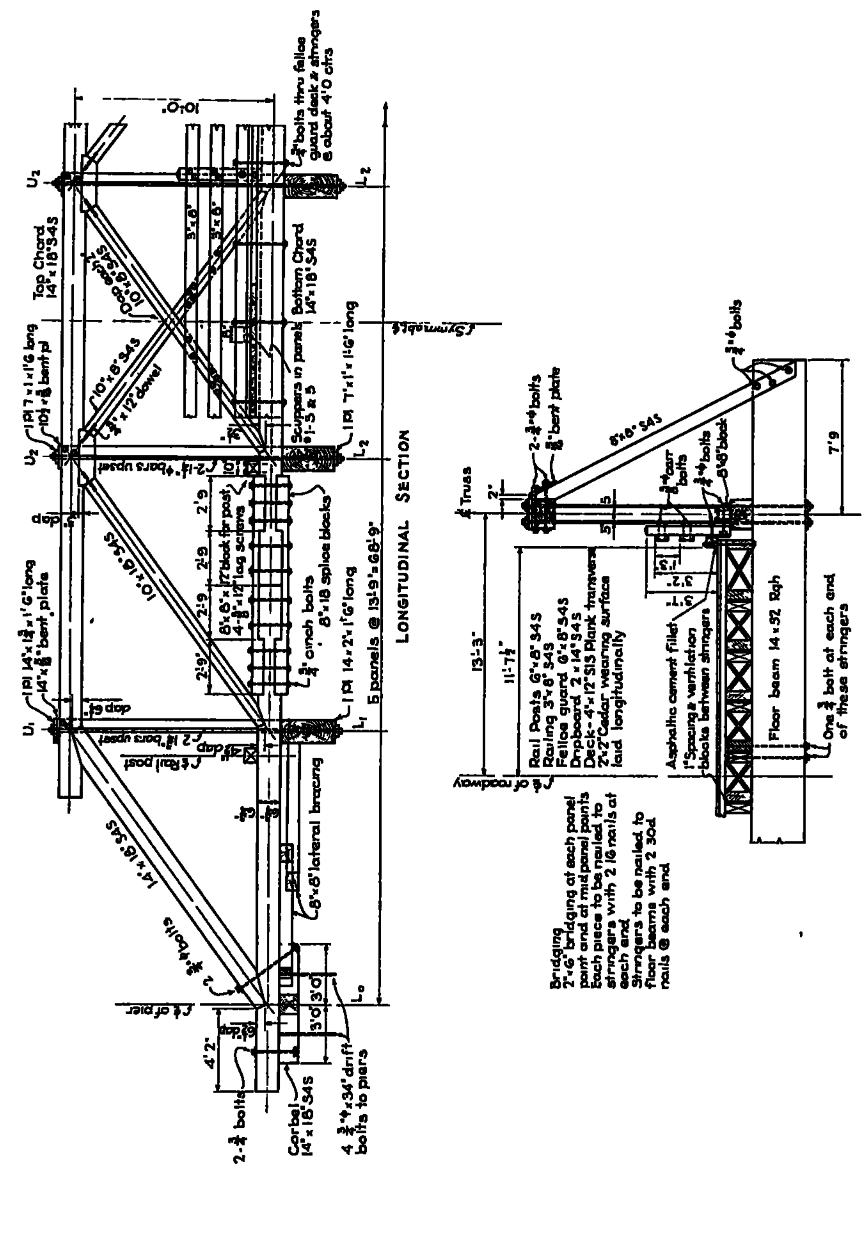


Figure 4. Typical A-Frame Truss H 10 Loading

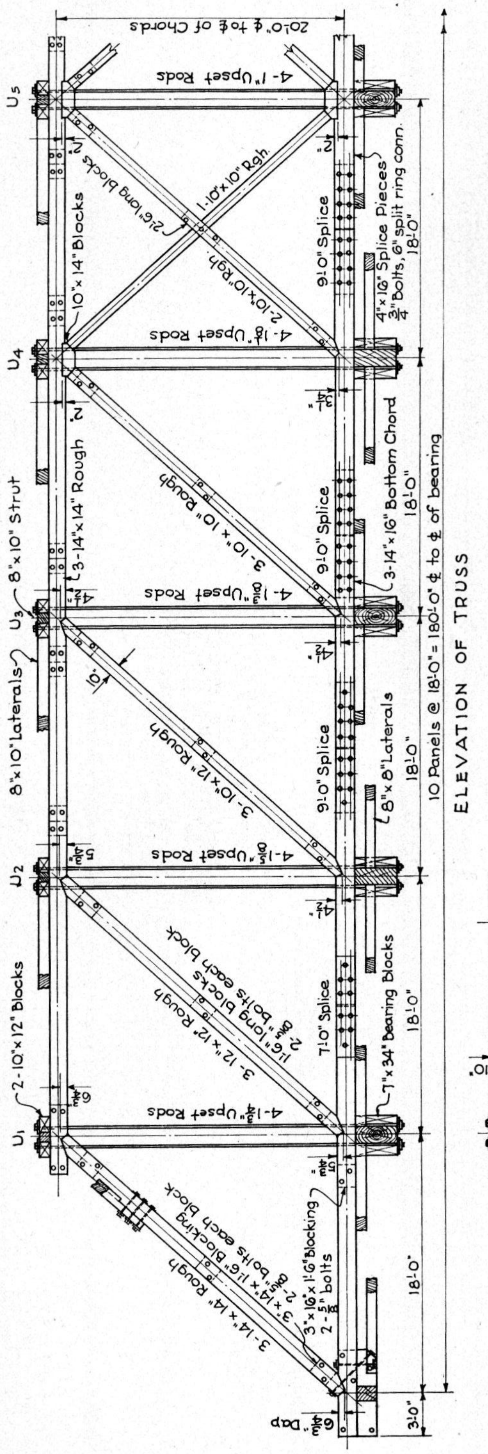
The pony or low truss design is suitable for span lengths of from 40 to 80 ft. Beyond this length, the truss heights required are such that overhead bracing is advisable. For spans of 40 to 50 ft., the A-frame type, with a single floor beam at the center, is more economical than the parallel chord truss.

structure Timber trusses, 200 ft. in length, require an excessive amount of material, and it is probable that this is about the maximum practical length for this type of construction. Roadway widths are limited by the size of floor beams required. A roadway width of 24 ft. has been found to be about the maximum



HALF CROSS SECTION

Figure 5. Typical Pony Truss



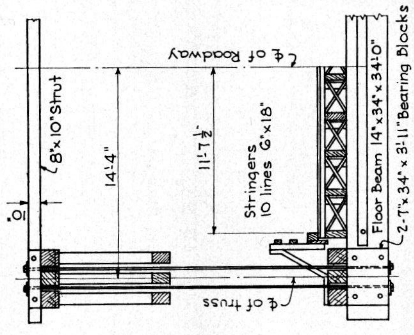


Figure 6. 180-ft. Howe Truss

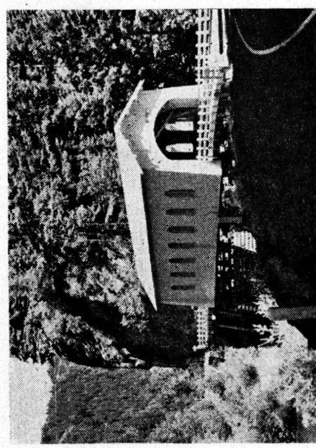


Figure 6a. Typical Housed Timber Truss

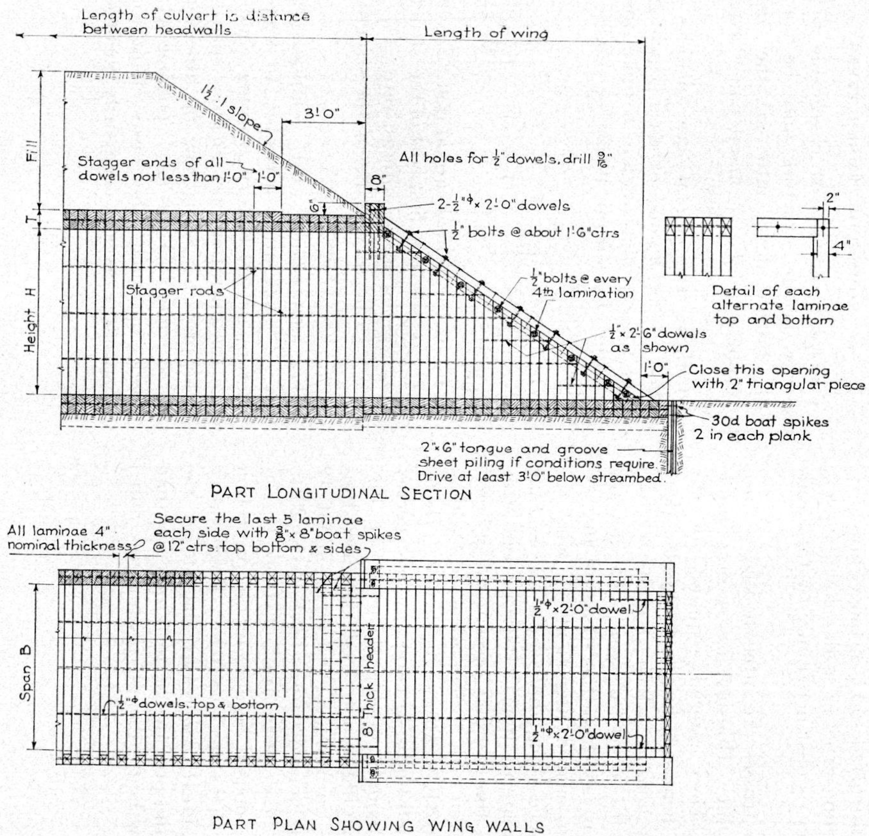


Figure 7. Treated Timber Culvert

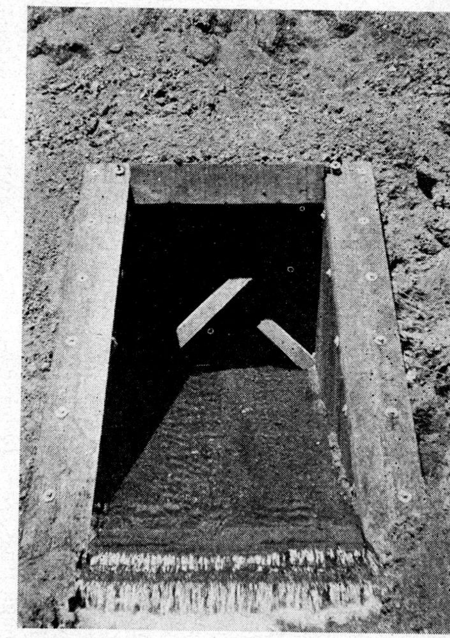


Figure 7a. Typical Treated Timber Culvert

practical width with timber floor beams. For an H-15 loading, this width requires 16 by 36-in. floor beams. These members are difficult to locate even in the largest mills. This limitation can be partially overcome by the use of structural steel girders for floor beams. A distinct improvement in tension splices is now available in the split-ring connectors which have recently come on the market. A considerable saving, both in labor and lumber, can be made by their use, and the splices are less likely to split along the shear tables. Figure 6 shows the design of a long span through truss for H-15 loading

Where the grade line is high enough to permit its use, the deck truss should be employed. With this type, the trusses need not be spaced so widely apart, and a considerable saving can be effected in the piers. The floor beams need not be supported at their ends, and much smaller members can be used for the same roadway width. The waterproof deck acts as a roof over the trusses, thus minimizing the chance of decay and prolonging the service life. Another point in favor of the deck type is the unobstructed sight distance provided The supporting structure is all below the deck, and the view is obstructed only by the handrails

Through trusses are often housed to prolong their life Housing has several disadvantages The material required for the trusses is increased due to the added dead load of the housing, which amounts to from 500 to 550 lb per foot of span The housing restricts the view from the structure and, especially on curved alignment, impairs the sight distance along the road The housing cost is a material item. With present wartime prices, this cost may exceed $20 per linear foot and, even with normal prices, will seldom be less than $12 to $15 per linear foot. Housing untreated timber trusses may be expected to approximately double their service life. The average life of untreated, unhoused timber trusses in Western Oregon is about 12 years, while housed trusses have lasted 20 to 25 years under heavy traffic. Deck trusses are seldom housed because of the protection afforded by the deck system. Preservative treatment greatly increases the life of the structure and provides better protection than housing without the disadvantages noted above.

TIMBER CULVERTS

Treated timber box culverts are practical even under normal conditions and are especially so under wartime restrictions and prices. Figure 7 shows the type of timber culvert used in Oregon. The wing wall details shown have proven very satisfactory and have eliminated trouble previously experienced at the point of attachment to the barrel. The small dimensions of the lumber used make it easy to obtain, and a greater percentage of the wood is actually impregnated with the preservative.

When treated lumber has been unobtainable, culverts have been built of logs. These generally consist of a floor of small logs, side walls of logs flattened on two sides and laid one on top of the other, and a deck of small logs laid transversely. Untreated fir logs have a relatively short life under these conditions, and their use is only justified as a temporary expedient Culverts built of cedar logs have a much longer life, some built more than 20 years ago being still in service.

ECONOMICS OF TIMBER TYPES

The total annual cost chargeable to any highway bridge structure may be conveniently broken down into: (a) the cost of providing capital, (b) maintenance expense, and (c) operation costs

Of these, the capital cost includes that portion of the annual expense which grows out of the use of provision of funds for the structure. In general, it can be represented by the formula.

$$C_{ac} = C\left[r + \frac{r}{(1 + r)^n - 1}\right] \qquad (1)$$

where:

C_{ac} = the annual capital cost.
C = the total first cost of the structure.
r = the annual interest rate
n = the service life of the structure in years.

The maintenance cost comprises those items of expenditure necessary to keep the structure in satisfactory working condition, while the operation cost includes such items as the provision of lighting facilities, operation of movable bridges, policing, traffic control, and such other costs chargeable to the structure as are necessarily incurred in the operation of the transportation plant proper (exclusive of maintenance)

For the purpose of type comparison and selection, the item for operation generally cancels out (except in the case where the annual cost of a movable bridge is to be compared with a corresponding high level structure) For the present purpose, therefore, we may express the total annual cost as follows.

$$C_a = C_{ac} + C_{am} \qquad (2)$$

where:

C_a = the total annual cost.

$C_{ac} = C\left[r + \frac{r}{(1+r)^n - 1}\right]$ = the annual capital cost.

C_{am} = the annual maintenance cost.

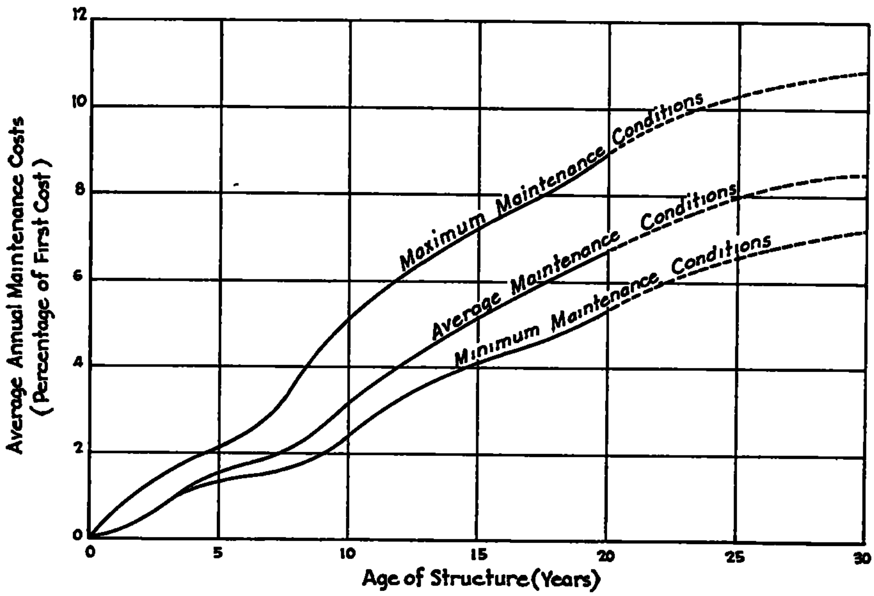


Figure 8. Graph Showing Average Annual Maintenance Costs—Untreated Timber Trestles

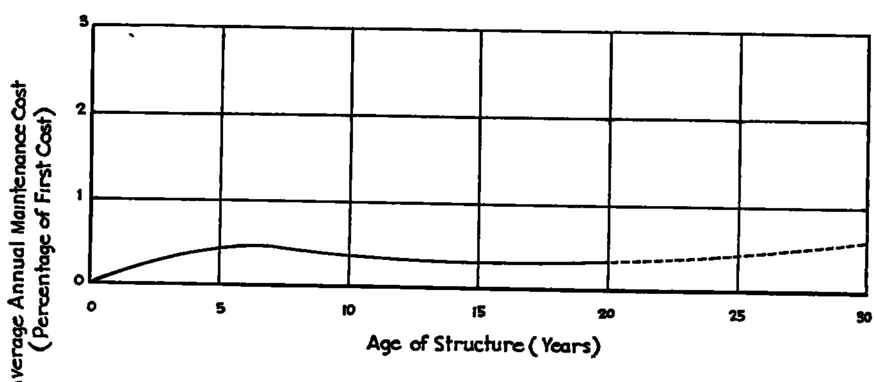


Figure 9. Graph Showing Average Annual Maintenance Costs—Composite (Concrete and Treated Timber) Trestles

It is apparent from these formulas that in order to determine the annual cost of any structural type it is first necessary to assume or compute the average service life "*n*." Such service life is influenced by many factors, some of which are quite intangible, for which reason it is impossible to make any assumption or prediction which will hold under all conditions. Some aid in approaching the problem, however, may be obtained by plotting, for each structural type, the average annual maintenance expense to date against period of more than 20 years. The ordinates represent the average maintenance costs in terms of percentage of first cost, while the abscissae represent the age of the structure in years. Figure 8 is for untreated timber trestles, and three curves are indicated thereon. The upper curve represents structures

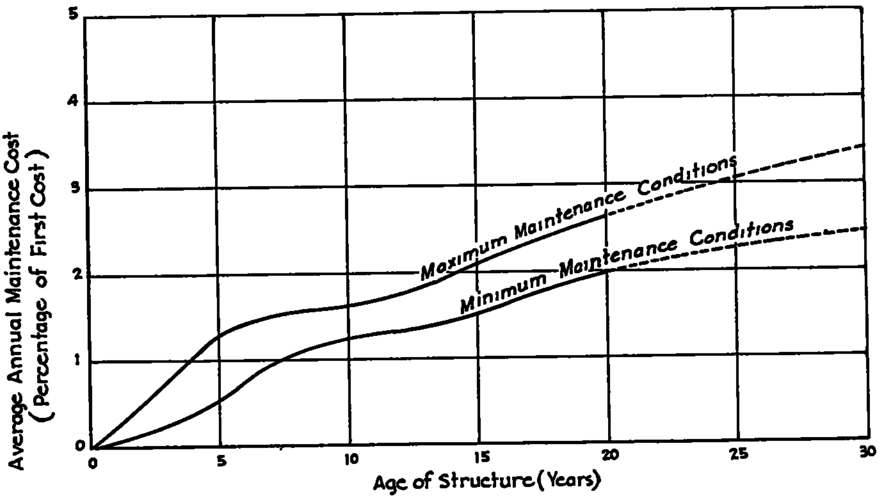


Figure 10. Graph Showing Average Annual Maintenance Costs—Housed Timber Trusses

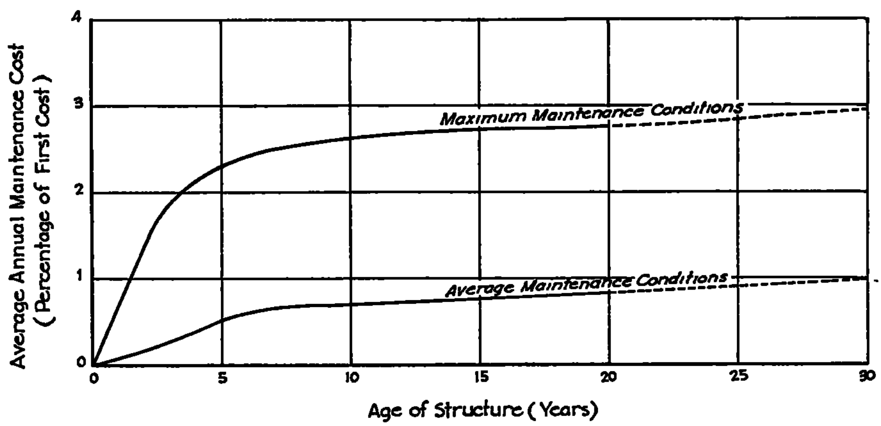


Figure 11. Graph Showing Average Annual Maintenance Costs—Steel Truss Bridges

the age of the structure in years and superimposing such graph upon the amortization curve calculated from Equation (1).

To illustrate this procedure, Figures 8 to 12 have been plotted from the maintenance records of the Oregon State Highway Department. These records include several hundred structures and extend back over a erected in the coast region where the tendency to decay is accentuated and maintenance expense correspondingly high, while the lower curve represents structures in the arid regions east of the Cascade range. The middle curve is for Willamette Valley structures where climatic conditions are midway between the other two. Figure 9 is for composite (concrete and timber) construction, Figure 10 for housed timber trusses, Figure 11 for steel structures, and Figure 12 for those of reinforced concrete.

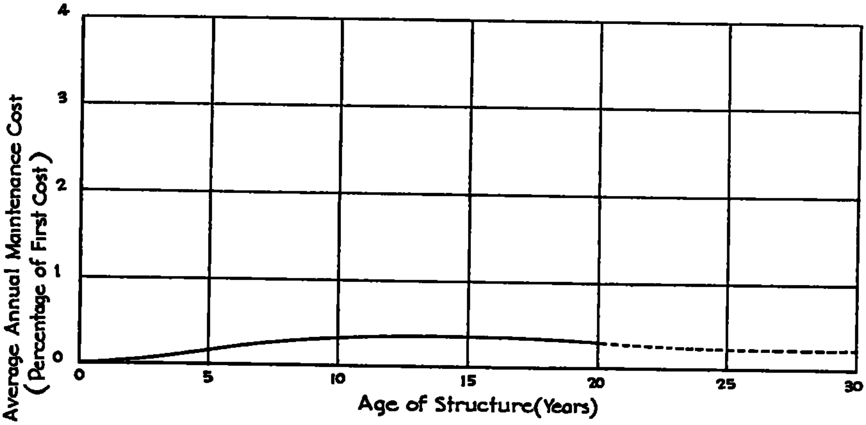
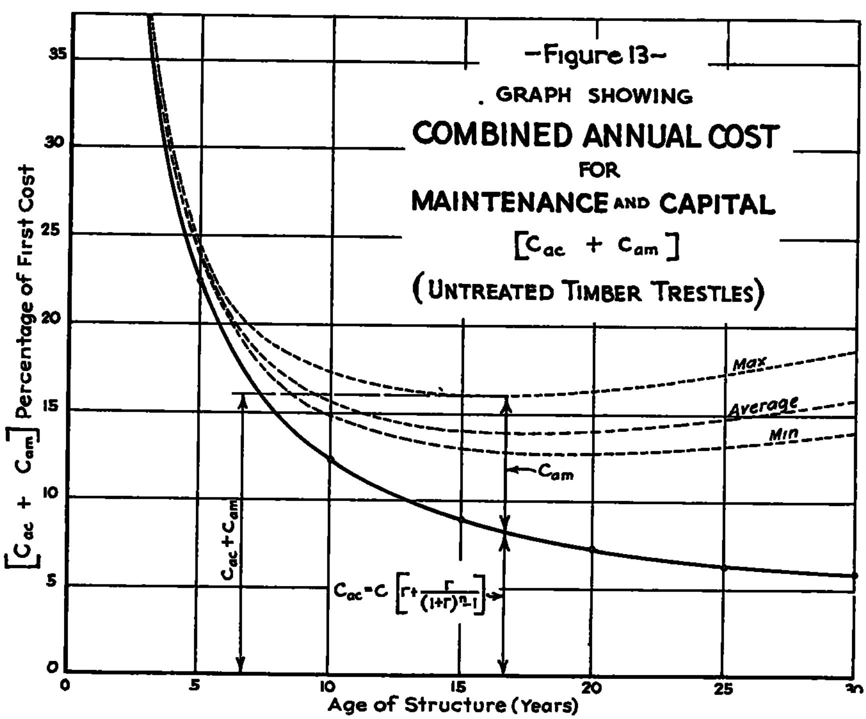
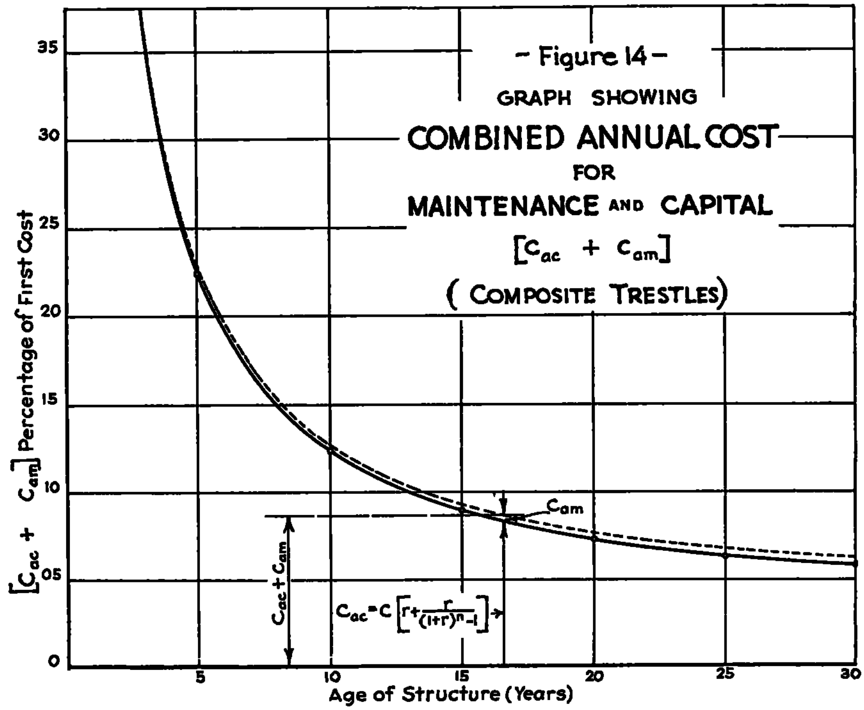


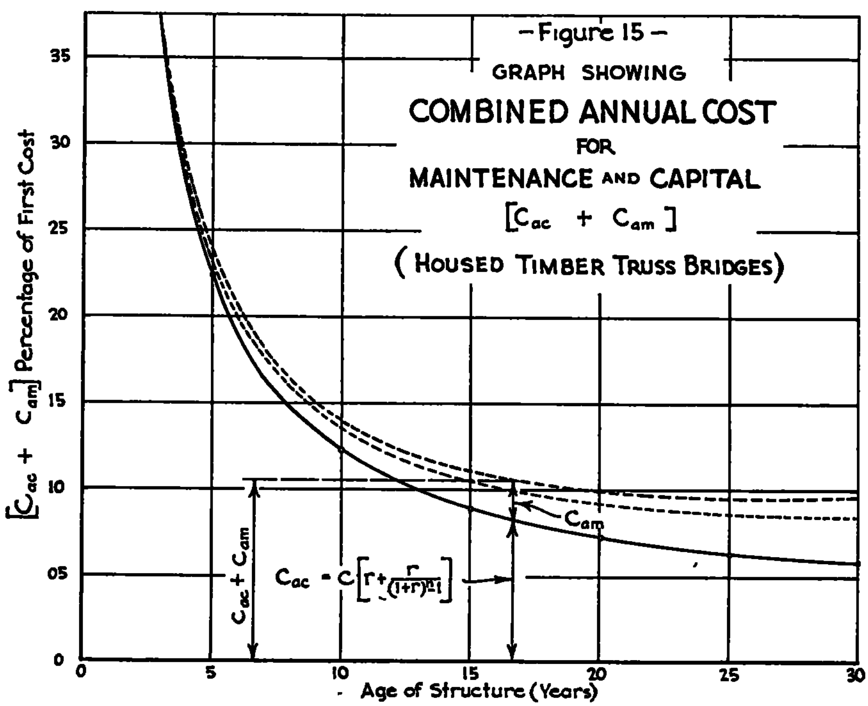
Figure 12. Graph Showing Average Annual Maintenance Costs—Concrete Bridges.

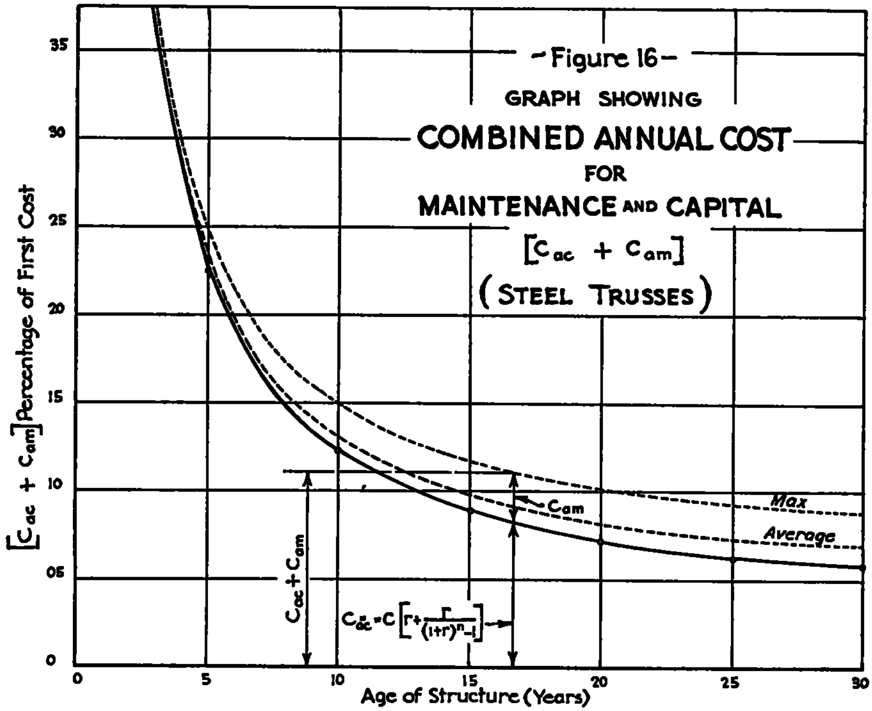


—Figure 13— GRAPH SHOWING COMBINED ANNUAL COST FOR MAINTENANCE AND CAPITAL $[C_{ac} + C_{am}]$ (UNTREATED TIMBER TRESTLES)

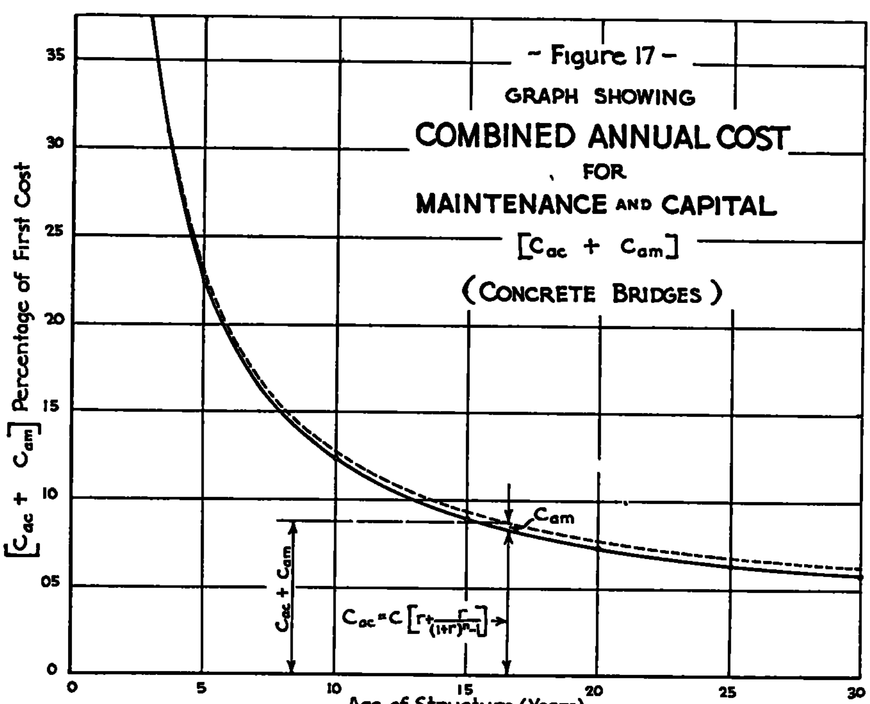
In Figures 13 to 17, the above curves are superimposed upon the amortization curve as a base. It is apparent, therefore, that the ordinates to these last curves represent the corresponding values of the term [C_{ac} + C_{am}] and that, furthermore, the abscissa at the low point or point of inflection represents the service life in years necessary for maximum economy A study of these curves indicates that, for maximum economy, untreated timber trestles should be renewed at intervals varying from 15 to 20 years (depending upon conditions) and that housed trusses should be reconstructed at intervals varying


- Figure 14 -
GRAPH SHOWING
COMBINED ANNUAL COST
FOR
MAINTENANCE AND CAPITAL
[Cac + Cam]
(COMPOSITE TRESTLES)
[Cac + Cam] Percentage of First Cost
Age of Structure (Years)
Cam
Cac + Cam
Cac = C [r + r/((1+r)^n - 1)]


- Figure 15 -
GRAPH SHOWING
COMBINED ANNUAL COST
FOR
MAINTENANCE AND CAPITAL
[Cac + Cam]
(HOUSED TIMBER TRUSS BRIDGES)
[Cac + Cam] Percentage of First Cost
Age of Structure (Years)
Cam
Cac + Cam
Cac = C [r + r/((1+r)^n - 1)]



- Figure 16 -
GRAPH SHOWING
COMBINED ANNUAL COST
FOR
MAINTENANCE AND CAPITAL
[Cac + Cam]
(STEEL TRUSSES)
[Cac + Cam] Percentage of First Cost
35
30
25
20
15
10
05
0
5
10
15
20
25
30
Age of Structure (Years)
Cac + Cam
Cam
Max
Average
$C_{ac} = C\left[r + \frac{r}{(1+r)^n - 1}\right]$



- Figure 17 -
GRAPH SHOWING
COMBINED ANNUAL COST
FOR
MAINTENANCE AND CAPITAL
[Cac + Cam]
(CONCRETE BRIDGES)
[Cac + Cam] Percentage of First Cost
35
30
25
20
15
10
05
0
5
10
15
20
25
30
Age of Structure (Years)
Cac + Cam
Cam
$C_{ac} = C\left[r + \frac{r}{(1+r)^n - 1}\right]$

from 25 to 30 years; whereas composite construction and steel and concrete spans can theoretically be carried in service indefinitely. In connection with this latter conclusion, however, a word of caution is perhaps in order. A period of from 30 to 40 years should doubtless be taken as a maximum amortization period for all improvements. This represents about the life of one generation and is about the maximum time period for which it is at all possible to predict trends and tendencies in traffic and in industrial development. Even within this period, future predictions may be in error, but beyond this they can be regarded as little better than conjecture For this reason, any basis for computation of annual costs should comprehend the amortization of all investments within a period not greater than the above, regardless of the permanency which the structure seems to possess at the time of its construction

Utilizing 30 years as a maximum, even for the so-called "permanent construction," the total annual cost, $C_a = C_{ac} + C_{am}$, for the five structural types compared is as follows:

	per cent
Untreated timber trestle construction	12 6–16.0
Housed truss construction	8 5– 9 5
Composite (concrete and timber) construction	6 35
Steel structures	7 0– 8.7
Reinforced concrete structures	6 0

With these percentages, the calculation of comparative annual costs is a simple matter once first costs are determined To illustrate, assume that in the coast region (maximum maintenance conditions) we wish to compare an untreated timber trestle costing $30 per foot with a concrete viaduct costing $100 per foot. Employing the foregoing percentages, the annual costs would be:

For the concrete viaduct, 6 per cent of $100 00 = $6 00 per foot.

For the timber trestle, 16 per cent of $30.00 = $4 80 per foot

If no other consideration were controlling, the untreated timber trestle would be the economical selection in the above case.

In addition to the considerations enumerated, there are other factors which sometimes enter into an economic analysis of this kind.

In the case of untreated timber bridges, there is some fire hazard so that an annual charge, C_{ai}, representing the expense of insuring such a structure would be a proper factor in the comparison. Thus, the annual cost would read.

$$C_a = C_{ac} + C_{am} + C_{ai} \qquad (3)$$

Furthermore, in certain locations where architectural considerations are controlling, such influence may be introduced into the economic comparison by the deduction of a fixed rental charge for the structure so that the economic equation would then read

$$C_a = C_{ac} + C_{am} + C_{ai} - R \qquad (4)$$

where R represents the percentage of first cost deducted to compensate for what might be termed the "intangible earning capacity" of the bridge, that is to say, its efficacy in the development of scenic resources, enhancement of adjacent property values, advertising to the community, and other attendant gains. In locations where architectural excellence is especially to be desired, a rental value of as high as from one to two per cent per annum may be easily justified if for no other reason than its effect in state-wide advertising

In closing, it should be observed that the problem of type selection is not one susceptible of an exact mathematical solution. In many instances, the final choice must be, to a certain extent, tempered by a knowledge of individual conditions and needs. The above equations, however, assist materially in aiding judgment and in the formulation of an intelligent approach.

DISCUSSION ON TIMBER HIGHWAY BRIDGES

MR. C G. MARILLEY, *Civil Engineer, Timber Engineering Company:* This paper is very interesting from the maintenance angle especially, as the authors have done a good job of showing comparative maintenance costs from State records covering a variety of bridges

We regret that figures were not included for the modern connector type of timber truss bridge The timber bridges covered by the paper represent the older hand-framed type with single solid members used largely throughout Some designers may like the sturdy appearance of the single solid end posts, but the laminated members of connectored trusses will be found to absorb shock with less probability of displacement on collision or rupture of all laminations than single solid members, which might be broken or displaced with resultant collapse of structure

Other advantages in the use of the connector system result from the ease of prefabrication, which lowers first cost, and from treatment before assembly, giving an unbroken envelope, which prevents entry of decay and therefore reduces maintenance cost and lengthens life

The authors have not considered the possible advantageous use of increased working stresses for timber where the loads are of short duration, as in bridges This is no encroachment on the factor of safety. A discussion of this can be found in the paper, "Timber Structures," published in *Civil Engineering* October, 1942. Also in this connection we must call attention to WPB Directive 29, making increased stresses mandatory for the use of stress-grade lumber after November 1, 1943 for government construction or structures built under government approval. This increase of approximately 20 percent in stresses is an adjustment merited by improved methods of manufacture and grading rather than an arbitrary increase. R P. A. Johnson, formerly Wood Consultant for the War Production Board, and a member of the Technical Staff of the Forest Products Laboratory for approximately 30 years, has stated: "While the Directive will be mandatory only for the duration, we believe that the stresses recommended will prove sound in practice and will be used after the emergency has passed."

Advantage of higher allowable stresses should be taken with no allowance necessary for decay, which can be cared for by treatment or other means, nor for deflection due to dead load, which can be compensated by camber or increased depth of truss and, in floor systems, by shaping the wearing surface

In regard to availability of structural timber, it is now possible to get 3-in and thicker. Since March 26, 1943, when the paper was submitted to the Highway Research Board, there has been a great improvement in availability of heavy timber, as can be seen in the Materials Substitution and Supply List issued by WPB from Washington, D C on October 1, 1943.

Regarding economical type bridges to fit special conditions, we would like to mention a type of timber structure not covered by the paper. Where crossings must be made at low level over streams subject to flash floods which carry a lot of driftwood and debris, we call attention to the use of creosoted pile bents, with stringers and deck untreated. Each span should be a separate unit, bolt connected for easy dis-assembly, and loosely pinned to pile caps. A steel cable threaded through eye bolts on each side of these sections and well anchored on either shore permits easy recapture when carried away by the flood. This type structure has the advantage of low first cost and quick restoration after flood. It should have consideration on secondary roads where interruption of traffic would not be serious

In their discussion of timber trestles the authors cover quite thoroughly the development of improved floor systems and decks that tend to lengthen life and reduce repairs. We suggest that new methods of stiffening the substructure by using malleable iron spike grids at joints also reduce wear and consequently improve their economic performance. Railroads have been known to prolong the usable life of trestles, already scheduled for replacement, by merely opening the joints one by one and installing the grids.

Where the authors mention the difficulty of locating large-dimension floor beams, such as 16 by 36 in., may we suggest that shallow trusses or glued laminated members be used? With waterproof synthetic glues as used today and available to the public after the war, the only limiting factors to size of members will be handling and shipping facilities. The glued laminated keel has been proved more satisfactory in ship construction, even for seagoing vessels, than the solid keel

Regarding housed trusses, the authors state that they "have lasted up to 25 years under heavy traffic." We wish to call their attention to Am Soc. C. E paper No. 1864, "A History of the Development of Wooden Bridges", by Robert Fletcher and J. P. Snow, members Am. Soc. C E , originally published in Proceedings Am Soc. C E. for November, 1932 Here you will find bridges that served continuously for more than one hundred years. Most of them were in use until flood or fire destroyed them or heavier loads made them obsolete. Also on this matter, we have a letter dated January 12, 1943 from Charles T. Butler, Engineer-Surveyor, Jennings County, Scipio, Indiana, from which we read ". . I believe we have a real land mark and type of wooden covered bridge that is rare to date. The bridge was built in 1886—three wooden trusses, box type, 16½ft clear roadway, 165 ft span, 30 ft bottom cord to low water. I think it is long leaf pine . . . (and) native stone abutments. Until 1931—main State Road No. 7 over sand creek near Scipio on No. 7, Geneva Town, Jennings Co. When the State of Indiana, about 1920, took over the main roads into a State Highway System, they removed the siding for better auto and driving vision, leaving the structure exposed to the elements. The original load limit, I believe, was about 5 tons, and of recent years it has taken estimated 30-ton loads, or any load approaching has crossed."

In further connection with the authors' discussion of the economic life of highway bridges, we suggest that a study of highway department records might produce some interesting figures on economic loss due to abandonment of all types of bridges, on one hand due to improved highway alignment—on the other hand due to replacement for heavier load capacity. We believe in the state of Oregon there is a bridge over McCarthy Creek that may be cited as an example. There a treated fir composite-type bridge has been built on new alignment within sight of the previous structure, which is of concrete construction but now unused although comparatively young in years.

In conclusion, it is quite possible that a study of the useful life of bridges, in that size range where steel, concrete, or timber would be optional materials, might show the average useful life to be well within the economic life of treated timber structures of modern design and the bridge cost on projected new highways to be reduced materially by their use.

J. F. Seiler, *Service Bureau, American Wood Preservers Association:* The authors present a very complete analysis of the economics of bridge type selection, and the fact that they are able to draw on a 20-yr. accumulation of maintenance cost data covering numerous types of bridges adds a great deal to the value of the discussion. In this connection we remember, of course, that maintenance and the debt service charges are the basic terms in the annual cost equation· superimposed, one upon the other, they will usually determine the relative economy of a given type of bridge The operating term is rightly neglected in the present discussion and, accordingly, will be dismissed from further consideration here. The insurance term is properly included in the cost function and will be commented on The foregoing items comprise the sum total of the actual financial transactions involved throughout the life of any structure The authors would have us include still another term: one of the abstract variety referred to as the "Rental" term and assumed as having a definite earning capacity based upon the value of the structure to the community from a standpoint of its architectural or aesthetic qualities. We find no precedent for, and question the propriety of intermingling with the perfectly definitive terms above outlined, a rather nebulous and vague item for the determination of which neither theoretical nor empirical means are at hand. We shall take occasion further to explore this term with all its implications, in what presently follows.

Generally speaking, this discussion will be confined to the several terms making up the annual cost function; however, I wish to comment briefly on the subject of timber culverts referred to in the paper The authors are to be commended on the objective viewpoint assumed regarding this type of structure which deserves a much better place in the construction picture than it has had in the past. For conditions under which its first cost is "in line," the creosoted wood culvert will be found most economical in other respects. Outside of foundation piles, the best service records of creosoted timber to be found on an extensive scale are those of culverts such, for example, as the more than 3,000 creosoted wood culverts of the Southern Pacific railroad, all more than 35 years old and all in good condition. The greater amount of preservative in the assembled culvert, noted by the authors, is a contributing factor; a favorable exposure condition and cutting of individual pieces to length and framing where required, before treatment, round out the picture. The culvert design shown by the authors seems adapted for exceptionally heavy duty: the question suggests itself whether considerably lighter, but carefully framed construction would not serve in a majority of cases At any rate there is no reason why the use of creosoted wood culverts should not be encouraged on a much larger scale, even for improvements where the maximum service life is an indispensable requirement.

Figure 10 showing average annual maintenance costs of housed timber trusses arrests attention because of the authors' statement that such structures have yielded a life of only about 20 to 25 years. At this period Figure 10 indicates less than 3 per cent annual maintenance cost and accordingly it would appear that a much longer economic life should be obtained It is also difficult to reconcile this experience with that of the many historic covered wooden bridges in the United States which have given extremely long service under comparable conditions

The maintenance function obviously is a fluctuating curve reflecting the fact that substantial repairs may be effected periodically. Eventually the curve tends to smooth out as either the repair periods come closer together or the structure ages, which simply means a longer period over which to distribute the cost. This is indicated in the charts submitted by the authors where a more or less characteristic "hump" occurs in the curves after a period of five years or more. The point is mentioned here because of its possible application to Figures 9 and 12 where the curves of average maintenance cost, for composite trestles and concrete bridges, respectively, are projected beyond the point for which actual records are available

It will be seen, for example, that the position of the "hump" in each curve determines the course of the projected line: in Figure 9 the curve seems to be approaching a second crest at the 20-year point and the projected line accordingly takes a slightly upward course. In Figure 12, on the other hand, the curve is receding from a recently attained crest and its continuation as a decreasing function appears to give the advantage to this particular type of bridge While actual records of the Oregon Department are not to be questioned, there is considerable reason to believe that more complete data on composite trestles will show the "hump" occurring at a period comparable with that of the concrete bridge, and in both cases it is likely that after 20 to 25 years the curves will become approximately constant at some level below one per cent of construction cost.

It is gratifying to note the authors' conclusion that a period of from 30 to 40 years should be taken as a maximum amortization period for *all* improvements. This conclusion marks an important milestone in the development of an accepted economic theory with respect to bridge type selection and is a tribute to the realistic thinking of the authors. It is hoped it will be widely accepted for the fact that it is, which should do much to promote every consistent saving in the execution of public construction programs

The authors have seen fit to limit their discussion of the Insurance item to a brief sentence or two. As indicative of its importance from a dollars and cents standpoint, this is well. on the other hand, if the term is to appear in the cost function, some value established by recorded experience should be assigned for the benefit of the student of bridge economics who is otherwise faced with the uncertainty of what allowance to make for this factor. With the extended experience Oregon has had with timber bridges, and its excellent and complete records, it would seem the authors might have computed an actual percentage of cost to be employed for this term and thus, for the first time, have contributed something on this particular subject that we could really "get our teeth into" From what records we have been able to obtain, both from railroads and State highway departments, the insurance term amounts, certainly, to less than 0.1 per cent per annum, or in other words it is practically a negligible factor.

Our attitude toward employment of the "rental" term in cost studies, as roughly indicated at the outset of this discussion, is not to be construed as a lack of appreciation of the value of architecturally pleasing features when properly employed in bridges or other structures It is, rather, one of caution against the use of the term as a convenient means of justifying the cost of needlessly expensive or extravagantly designed bridges. Surely, the authors themselves will concede that in the great majority of cases the economic equation will be satisfied so far as the rental term is concerned, through proper attention to design details and a decent regard for appearance of that applicable structure which is actually most economical. It is conceded that certain conditions require special types of structures and architectural treatment befitting them, but considering the field as a whole, the timber bridge, if you will, has no apology to offer in this respect

Let us analyze the rental term further in connection with the authors' suggestion that a value of from 1 to 2 per cent of the construction cost may be justified Shall the percentage apply to all types of bridges, or only stone, concrete and steel bridges? Shall the percentage be fixed, or vary in amount according to conditions, and how shall that be determined? Again it may be asked, shall the allowance be made for particular architectural types such as rigid frame, arch or suspension bridge designs or may all types participate in the assumed saving? Finally, will the item be valid in all locations or be limited in its application to metropolitan, scenic or memorial areas where a premium on appearance may be claimed?

If the proposal be reduced to a concrete basis it means either that there is an imaginary saving which, if set up in a sinking fund, would reproduce the construction cost in 30 to 40 years, depending on the value assigned the term;—or, that from 20 per cent to about 40 per cent of the total construction cost, depending on per cent and amortization period, may be charged to appearance of the structure. Is it possible that any community could be persuaded to pay (in the first case) the annual sum involved in order to replace the structure in the period noted, solely on the grounds of appearance? And what shall we say about the reaction of the community to the alternate proposal?

The real answer to this question is not how much we can afford to pay for this or that type of structure with its appropriate architectural treatment, and how we are going to justify the cost, but rather, what kind of structure is the only and eminently right one for the particular place, where anything else would violate all the principles or plans of community development or the special requirements of the location as determined by historic, scenic or other considerations If we can leave the matter in the hands of those who understand and know how to deal with this problem, the abstract term of the cost expression need not concern us since it will not enter into the economic calculations in any case.

Where free rein is given the application of the rental term and its use encouraged, it is inevitable that construction programs and their cost will be attended with enormous financial loss The natural pride of the designer or engineer responsible for improvements will frequently provide the incentive which somehow or other will find the necessary justification—through this term—for whatever the occasion may be deemed by him to require It is even conceivable that unrestricted use of the theory may tend to result in a shorter service life of structures, thus taking a double toll like the traditional candle burning at both ends. The safe course is to remove the rental term beyond the reach of those who are not capable of using it, and thereby avoid all risk of danger. Meanwhile we shall not hamstring the qualified official or deprive him of the privileges and latitude he needs in the planning of major construction programs