indicate that structures on such roads should be of permanent construction

Certain lines of investigation are suggested as desirable to secure accurate data on which the importance of the question of permanent versus temporary structures can be evaluated They are

1 What percentage of the bridge structures erected on highways are abandoned before the expiration of their expected life because of changes in location? It seems to be indicated that this percentage is rather low and that it is much smaller than engineers have been led to believe At any rate no accurate information exists now.

2 In how many cases have low cost structures been erected at locations which were deemed to be temporary at the time the structure was designed but where the period of use indicates that a permanent structure would have been justified?

3. How many low cost structures have had to be replaced by permanent structures before their economic life had expired?

4. How important is the salvage value of highway bridges? In how many cases can the bridge material at the old location be used in a new location which is adjacent to the old one?

5 Except in well defined cases, how is the engineer to determine whether the location will be temporary or permanent?

6 What data are available to show the cost of constructing and maintaining detours around temporary structures which have had to be replaced?

7 Has any study been made of the relative safety to traffic in passing over temporary structures as opposed to permanent ones?

8 Cost data should be developed which will allow ready comparison of the economics of various type structures for given conditions Complete maintenance data on the various types of structures and under the variable conditions existing throughout the country are practically non-existent

THE ECONOMICS OF LOW COST BRIDGES

J F Seiler

American Wood Preservers' Association

SYNOPSIS

The principal factors which determine economy of bridges are first cost, interest rates, service life and maintenance These factors are analyzed and applications are made to methods for calculating the total carrying cost Experience is cited to show that creosoted timber in bridges may be expected to last until the structures are retired from obsolescence, which, according to the author, should be from 35 to 40 years Maintenance expense may be expected to commence after approximately 15 years of service and reach a maximum in about 35 years

The principal factors which determine the economy of any bridge structure are (1) First Cost, (2) Rates of Interest, (3) Service Life, and (4) Maintenance or Upkeep Costs These factors are not necessarily arranged in the order of their relative importance but rather in accordance with the certainty of their evaluation For example, (1) and (2) are definitely known items or they can be closely estimated, while the third and fourth items are matters of conjecture and cannot be predetermined for any given structure While experience is constantly adding to the possibility of estimating values for life expectancy and maintenance costs, these are and always will be affected by various causes, conditions or developments beyond our powers to foresee

OTHER FACTORS

There are obviously other considerations which affect the economy of bridge structures such as insurance against fire, flood and other disasters, location, the effect of the floor or pavement surface upon traffic and finally the economic value of appearance to the community. These factors are so difficult of evaluation and in some instances even to comprehend, that their consideration is not warranted except in certain well defined cases The fire hazard existing where timber construction is involved, is of course a factor although virtually negligible Actual experience indicates it to be less than one-quarter of one per cent per annum in terms of first (construction) cost for all timber construction

BASIC THEORIES

It is proposed in this paper to deal only with the four principal factors mentioned at the outset, although an allowance will be made in the economics equation for the fire hazard in structures employing timber. But in this connection it should be noted that insurance companies consider the flood hazard as greater in concrete and steel bridges than those employing timber, partly because of the salvage usually available Prior to the discussion of the value of preserved timber in bridge structures, it is proposed to consider briefly basic theories leading to the set up of the economics function or its graphical construction. In this case, to be conservative, the sinking fund method will be used assuming 3½ per cent interest compounded annually on the payments, and 5 per cent interest payable on the investment.

MAINTENANCE

It is obvious that the cost of maintaining a structure must increase with its age until it reaches a maximum Such a function is shown in Figure 1 Curve A represents in general the yearly cost of maintaining any structure in terms of time and percentage of first or construction cost Its form is entirely similar to the fundamental function of growth as in all vital statistics Curve B is derived from Curve A Any ordinate to this curve when multiplied by its corresponding abscissa gives a result equal to the area under the Curve A up to the

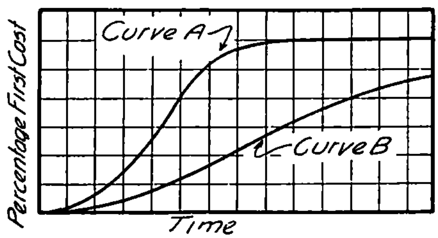

Figure 1

point in question In other words Curve B gives the average annual cost of maintenance over any given period of time, corresponding to the data of Curve A Obviously Curve B is asymptotic to the horizontal line representing the maximum ordinate of Curve A This is the feature of importance in further consideration of this function

The shorter the life of a structure, the greater must be the maximum value of the maintenance ordinate (Curve A) and the smaller the corresponding abscissa representing the time at which the function reaches the maximum value As described by McCullough this maximum ordinate may in some cases represent " a piece-meal renewal," part by part of the structure Ultimate maintenance of a railway track serves as an example

AMORTIZATION

The sinking fund curve C is shown in Figure 2 Curve B of Figure 1 is similar in significance to the sinking fund curve of Figure 2, and

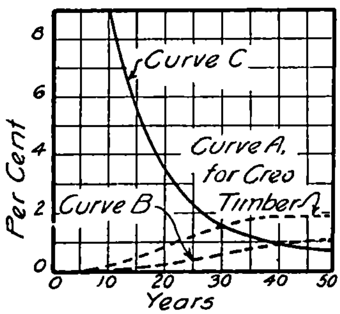

Figure 2

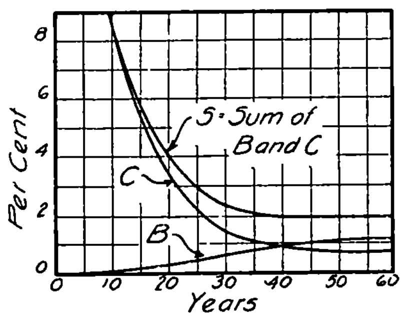

Figure 3

can be superimposed on it The result is the total annual cost to date of maintenance and sinking fund requirements

The maintenance "to date" and sinking fund curves are further similar in that they are both asymptotic to horizontal lines One is increasing as the other is waning and the facts will show that the rate of change is approximately equal in each curve *after the point* of their intersection has been reached so that the sum of the two may for all practical purposes be taken as constant after that point This fact is very important, because it means there is not necessarily a critical time at which it is most economical to replace the structure Figure 3 shows the maintenance Curve B, the sinking fund Curve C and their sum S

OBSOLESCENCE AND SERVICE LIFE

In highway bridge structures obsolescence will probably be the factor determining service life, neglecting of course disaster to the structure The writer advances the theory that this factor when considered in terms of time operates in three principal degrees or forms In what may be called its violent form, obsolescence comes as a result of certain developments whereby an entire change of location or design is required within 10 to 15 years after the structure is built In its milder form it comes later on, usually as a result of localized refinements in alignment and grade, or other factors requiring a change in location or design say within 15 to 30 or 35 years after original construction. Various cases of highway reconstruction are reported in which it is found economical to change the location, considering total costs of detouring Lastly in the absence of other factors, obsolescence operates as a result of popular desire for new improvements within 35 to 50 years after the original construction It is exceedingly doubtful if any but our most important structures will survive over 50 or 60 years This is of course the reason for the present trend towards low-cost bridges which show economy for service lives of from 30 to 40 years

APPLICATION TO ECONOMICS FUNCTION

In Figure 4 is drawn the Curve S representing the sum of sinking fund and maintenance charges, and also the Curve T which is Curve S with 5 per cent interest charges on the investment and 0 25 per cent for the fire hazard added, representing thus the total carrying charges on the structure Now the question is not to determine at what point or period the structure should be renewed, but rather at what point the *investment shall be retired* in order that the structure may be carried thereafter with maintenance charges only By such time yearly maintenance costs have become nearly constant at their maximum, while sinking fund charges have also become nearly constant and so low that no advantage is secured by carrying the investment for a longer period

Figure 5 shows the method used to calculate the total cost of carrying the structure when the time at which the investment is to be retired has been predetermined, and its service life has been assumed Obviously if the theory expressed by the maintenance curve is carried to its ultimate conclusion, any length of service life may be assigned. From a practical standpoint it should be assumed that obsolescence will require replacement at the end of 35 to 40 years It is on this basis that the economics of low-cost bridges will be considered

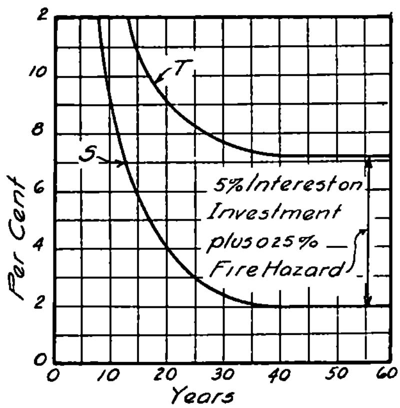

Figure 4

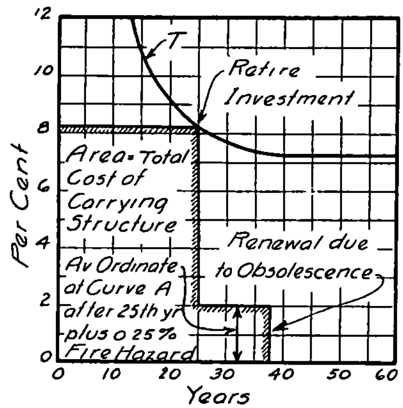

Figure 5

APPLICATION OF CREOSOTED TIMBER TO LOW-COST BRIDGES

DURABILITY

While it is becoming generally recognized that structures of creosoted timber will probably have a life of upwards of 35 years, it is proposed to discuss this question briefly with a view not only of establishing such a claim but to show that the life of sound timber well treated and handled may be much in excess of this depending upon conditions of exposure

Everyone knows that there have been failures due to decay even in well creosoted timber, but few seem to realize that such failures are due to decay not in the treated, but in the untreated portion of the piece. Such failures are due to two causes First, possible incipient decay present in the timber before treatment, and second, exposure of the inner wood due to cutting, checking or mutilation of the treated protective coating The first is prevented by a reasonable inspection of the material for soundness followed by adequate treatment, which will check any further advance of incipient decay The second can and is being avoided by improved field technique in the handling and erection of treated material and particularly by the increased tendency to specify the pre-framing of material

Neglecting for the moment these factors, the eventual deterioration of a piece of treated timber must depend upon the evaporation of the preservative to a point where it is no longer effective as a toxic agent. Independent investigations made by the U S Forest Products Laboratory and the American Tel and Tel Co on the creosoted (A. T & T.) poles of the Norfolk-Washington Line (Erected 1897) indicated that the toxic life of these poles would be 55 years The calculations take into account the analysis of the oil used, its toxicity, quantity injected into the wood, and the condition of exposure These values are used in the volatility equation and the toxic life of the wood thus determined The life of treated timber in any location can be similarly determined if the analysis and quantity of oil injected is known and if the material has been in service for a period sufficient to determine the constant of exposure

CONDITIONS OF EXPOSURE

The exposure of poles to the action of the elements is more severe probably than that of other examples of construction excepting railway cross-ties At the present time the count of cross-tie renewals on many railroads indicates that a life of 30 years (See Table cross-tie renewals, presented 1931 Convention A W P A) is being secured where the creosote treatment is used In Europe the life of creosoted ties is much longer than in this country, ranging from 30 years upwards, in certain cases to 40 and even 50 years with still a large percentage failing from wear rather than decay. There is every reason to believe that the same will be true in this country as mechanical wear is reduced and heavier treatments given to develop the possible life In present practice cross-ties receive only about half as heavy treatment as bridge timbers

Timber bridge floors where unprotected by wearing surface are of course subject to severe conditions of exposure and wear In this paper it is assumed that such a condition need not be considered Where properly protected by wearing surfaces such as are in general use the condition of exposure is very favorable and the life of such floors, creosoted, should without any doubt be equal to the assigned life of the structure, assuming rigid and adequate construction Timber stringers, particularly the interior stringers, have the most favorable exposure and should last indefinitely, especially where precautions are taken in spiking down the floors, or where concrete floors are used Experience indicates that where proper construction methods are used there is rarely any need of replacements Caps where extending beyond the floor are in unfavorable exposure, particularly where the top surface is exposed to rapid extremes of hot dry sunshine and heavy precipitation Some of the leading railroads cover the caps with bituminous material and the Santa Fe Railroad, for example, reports that an investigation of covered caps after 25 years' service discloses a remarkable freshness of treatment As regards piling, thousands of examples indicate that 40 years life is a most reasonable estimate where proper precautions are taken to protect the cut-offs.

ANNUAL COST OF MAINTENANCE

With good design and construction the principal items involved in maintaining the structure wlll be repair and renewals of wearing surface, the occasional renewal of a defective member, painting and minor repairs to handrail, etc. No painting is required for any of the creosoted members The cheaper types of wearing surface require more frequent renewal, depending of course upon traffic density, but a fair idea of the cost of maintaining surface may be had from assuming the replacement at 15 year periods of 1½ inch asphalt plank, costing not over $2 00 per square yard in place. The manufacturers estimate 20 years' service for this material under heavy traffic Fifteen years appears to be conservative, judging from service records thus far This amounts to about 0 8 per cent per annum, based on a 20 foot roadway Minor replacements due to breakage, field cuts or an occasional defective piece may be taken at half this value or about 0 4 per cent per annum Tightening of bolts, including removal of sway brace bolts, spraying of holes and replacing of bolts at ten year intervals, computed at $1 00 per foot of bridge, gives an additional 0 3 per cent per annum, making thus a total of 1 5 per cent Painting of hand-rail, cleaning of rubbish and other details may be expected to bring this total to two per cent per annum The maintenance function Figure 2 is drawn to correspond with this assumption.

Data on the maintenance costs of highway bridges are meagre, particularly for treated timber structures and the data that are available are erratic and of little or no use They are based generally on inadequately designed structures, often without wearing surfaces, with poorly selected and graded timbers and in many cases with poorly treated material Until recently few timber structures have been built where any of the material has been preframed and in frequent instances there has been lack of protective measures as well as abuse of the pieces during handling and erection.

Some data however have been secured from several of the railway companies, although many of those written to stated that no figures were available Most railroads now are constructing ballast deck timber structures in order to avoid the mechanical wear on the deck due to rail cutting and creeping of track, decay due to moisture getting into spike and bolt holes, and also to improve conditions of loading and exposure Although these structures are subjected to much more severe service conditions than are highway structures, it is considered that their maintenance costs should apply fairly well to the case of timber highway bridges equipped with suitable wearing surfaces

The Illinois Central System with 27 years' use of creosoted timber structures states as follows· "We find that ballast deck trestles in which the material has all been well treated, require very little if any maintenance for the first 10 or 15 years, after which time maintenance expense will start and increase year by year as the structure ages"

The Seaboard Air Line Railway writes as follows· "We have been using treated timber on our ballast deck trestles for about 18 years and while we have no definite information as yet, we estimate that we will secure about 30 years' service life with an exceedingly small percentage of replacements per annum There is usually no maintenance required during the first 7 or 8 years"

The Southern Railway System writes· "We have been using creosoted ballast deck trestles for something around 20 years . . (describes construction) . . . . We have had very little maintenance relatively speaking on these structures"

The late A F Robinson, Bridge Engineer of the Santa Fe Railway Co, users of creosoted timber bridges for over 40 years, stated in reference to their creosoted ballast deck trestles. "They have been in service for years and years and have not cost ten dollars per hundred feet for repairs."

The Southern Pacific Company states: "We have been using treated trestles since 1894. With a well designed structure practically no maintenance is required outside of tightening bolts We have many structures 30 years old that have not been repaired in any way"

The Baltimore and Ohio R R Co states in reference to creosoted ballast deck trestles constructed in 1910 and since: "There has been practically no maintenance on the structure materials"

The Chicago Rock Island and Pacific Ry Co writes: "Since 1909 we have bridges that have been in for 20 years and but very little work has been done on them since I would say however as a general rule that in the first 10 to 15 years there would be practically no maintenance work on a fully creosoted pile bridge properly put in"

The Kansas City Southern Ry writes· "No maintenance to date on creosoted ballast deck bridges, oldest being 15 years old"

The Chicago Burlington and Quincy R R Co writes: "It is rather difficult to get accurate maintenance figures but we estimate the average annual maintenance expense on an open deck pile trestle to be $1 25 per foot per year while on creosoted ballast deck trestles we estimate the cost to be five cents per foot per year on the structure and 20 cents per foot per year on the track The main factor in the maintenance of open deck pile trestle bridges is the lining and surfacing of the structures, this being taken care of by track men on the ballasted deck bridges" Quoting another letter "It is our present thought that exposed treated timber in locations such as bridges will give 40 years' life"

The Louisville and Nashville R R Co writes. "On creosoted ballast deck trestles there is no maintenance required provided the piles do not settle" This statement made by the Chief Engineer of this railroad may be further explained as follows: The custom of this company is to assume for statistical purposes the life of these structures to be 25 years, with no maintenance involved Based on their long experience, the Bridge Engineer of this company stated to the writer personally that a much longer average life was anticipated and actually secured and in general maintenance costs began after the structures are about 25 years old (neglecting structures in marine waters).

Mr E A Craft, of the Southern Pacific Lines in Texas and Louisiana, writes: "For ballast decks the maintenance consists of replacing piling, caps, bulkheads, bracing and bracing bolts, which usually become necessary after a period of approximately 20 years" He gives 60 cents per lineal foot as the annual cost of maintaining these structures, which is about double the figure given by the C B & Q Company (including track work)

The character of construction is clearly reflected in the maintenance figures submitted by the various railway companies Where highest grade construction is practiced maintenance costs are a minimum Considerable maintenance expense has been necessary in some cases, particularly of old structures where the increase in loadings has been responsible for replacement of crushed material (usually caps) and placing of additional members

The writer naturally has been interested in the service of creosoted structures in the State of Wyoming where about ten years ago this type was introduced in highway construction under his supervision as bridge engineer, since when this policy has been adhered to in all cases where such construction is adapted Mr Z E. Sevison, State Highway Engineer, stated recently that to date there had been virtually no maintenance on these structures A total of ten stringers on seven bridges had been replaced due to structurally defective material, and a few wearing surfaces of the thin mat type had been renewed, out of a total of over 500 bridges

The data presented above indicate that maintenance expense may be expected to commence after approximately 15 years of service and reach its maximum in about 35 years by which time all such members as have been poorly selected or treated will have revealed themselves and expense thereafter will be due to regular measures as suggested above

RECAPITULATION AND CONCLUSIONS

The maximum annual maintenance charge of two per cent as suggested appears therefore to be conservative, particularly in view of statements and data submitted by the railway companies As outlined above this total is made up of the following items.

	Per cent
Replacement of wearing surface	0 8
Replacement and repair minor parts and members	0 4
Tightening fastenings, removing and replacing sway brace bolts, spraying holes, etc	0.3
Painting and repairs to handrail, clearing trash and other miscellaneous items	0 5
Total	2 0

These figures are intended to apply to the all-timber structure. Where a concrete floor is used on timber stringers it is doubtful whether much reduction in the maintenance cost should be assumed because sooner or later a wearing surface may be required, which will then need periodic replacement Where I-Beams are used as stringers, the painting assumed to be done at usual intervals will add considerably to the maintenance costs In some localities, particularly in coastal regions, this may add ½ per cent or more to the annual cost

The principal conclusions that may be drawn here are:

First Assuming the successful application and service of concrete floors on timber stringers, maintenance charges will probably be a minimum Economy will then depend on first cost

Second· Maintenance of I-Beam spans on timber bents will be greater than in the first case Where timber decks are placed on I-Beams, thus permitting a slight lengthening of the span with the same weight stringers, this condition may be compensated for to some extent

Third: The maintenance of properly designed and constructed all-timber (creosoted) structures will fall between the two cases mentioned above

While a plea is made for adequate design and rigid construction of all timber structures, it is desired to point out one fact which may influence first cost when I-Beam and timber stringer designs are compared In this connection there has been noted a tendency to specify certain loadings to be used "without Impact." In such a case the actual live load plus impact capacity of the timber stringers is double 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*
Of Engineering Service, American Institute of Steel Construction, Inc

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