ECONOMICS OF LOW COST HIGHWAY BRIDGES

REVIEWED BY

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The papers prepared by Mr. Seiler, Mr Frankland and Mr Fleming present every indication of having been well thought out and carefully prepared, and while each of the authors has succeeded in making out an excellent case for the particular construction material which he represents yet it is very gratifying to observe the omission of exaggerated or extravagant statement throughout the entire group Each of these papers bears the authorship of a highly trained structural specialist of long experience, yet each of the authors is now engaged in the development and exploitation of bridge types utilizing one particular construction material It is therefore inevitable that the papers should be somewhat partisan in character. This is no reflection upon the intellectual integrity of the authors, but simply a direct result of the fact that as each of these structural types is intensively studied, the possibilities of a more extensive and efficient use of the particular material involved become increasingly apparent.

The engineer in charge of public work is greatly indebted to the engineering departments maintained by the various trade extension associations for the advancement made during the past decade in the utilization of each of these construction materials, and while the observations which are to be made in regard to some of the statements contained in these papers may seem somewhat critical, they are nevertheless tempered by a most profound respect for the work done by the authors and the associations which they represent

DISCUSSION OF MR SEILER'S PAPER ON TREATED TIMBER TRESTLES

Mr Seiler makes out a rather strong case for the treated timber bridge in short span lengths, but carefully refrains from a discussion of longer span possibilities He is to be congratulated on the fairness to the other types of structural materials evidenced by this restriction It may be possible, and at times economical, to construct bridges of treated timber in longer span lengths; however, the propriety of such a procedure is somewhat problematical, the greatest field of utility for the treated timber bridge being for short span construction exactly as outlined by Mr Seiler.

All in all, the paper constitutes an excellent presentation of the subject, however, there are a few points which cannot be passed by without comment

Mr Seiler makes mention of the fact that the rates of change for the maintenance and amortization curves are approximately equal and compensating after a certain point has been reached so that the

sum of the two may, for all practical purposes, be taken as constant beyond that point Figure 1 which shows the data for steel and concrete bridges indicates that this is true, the combined curve (maintenance plus amortization) showing very little deviation from the horizontal for either steel or concrete through a range in service life between 35 and 80 years Mr Seiler states: "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"

This is absolutely true, however, it does not signify by any means that the *annual cost* of maintaining structures of different types is identical between these two limits

A careful study of Figure 1 of Mr Seiler's paper will indicate that the combined curve flattens out because of the flattening of the amortization curve and the rather constant character of the maintenance curve between the service life limits above noted In other words, while the difference between the sinking fund requirements for a 10 year amortization and a 35 year amortization is a considerable factor of expense, the difference between a 35 year and an 80 year amortization is a rather negligible factor From this fact it might be inferred that if a structure may be maintained in service for 35 or 40 years, there is no great financial advantage in maintaining it in service for a longer period However, this does not indicate that the annual cost for maintenance plus amortization is *equal for all structural types* as this combined cost is a direct function of the average annual maintenance cost In other words, notwithstanding the fact that the combined curve (maintenance plus amortization) for points beyond the

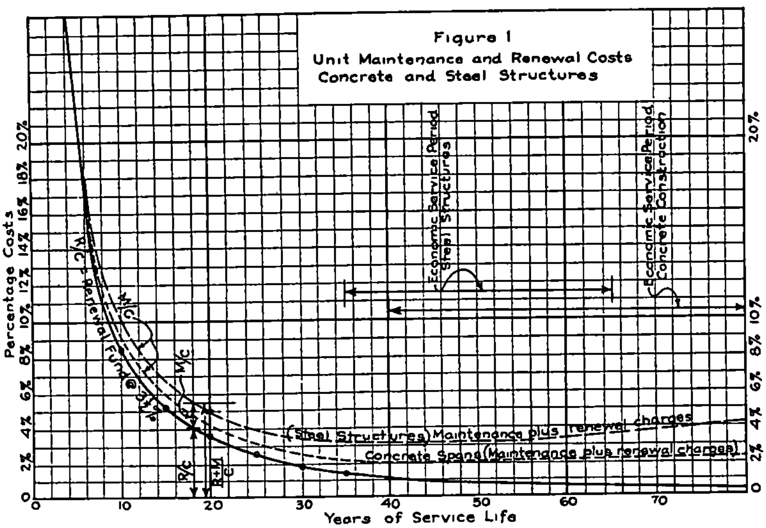

Figure 1

35 or 40 year service life period is very nearly horizontal, it does not follow that two curves representing different construction materials will be coincident, as a matter of fact, they will not be coincident unless the percentage maintenance costs for the two types is the same The entire question of annual costs for maintenance plus amortization therefore hinges upon the percentage average annual maintenance cost, and is somewhat independent of service life requirements

The curves shown in Figure 1 of this discussion indicate an average maintenance expense of about one per cent for concrete and two per cent for steel at the end of a 40 year service life These costs increase gradually, but very slightly as the service life is extended to 80 years Mr Seiler predicts a total average annual maintenance expense of 1½ per cent for creosoted timber which would place this structural type about midway between steel and concrete I am somewhat reluctant to criticize figures of this kind because of the lack of first hand cost data regarding the maintenance of creosoted timber structures The curves indicated in Figure 1 of this discussion for concrete and steel have been plotted from actual cost data extending over a period of about 12 years, the curves being projected beyond this period along the general trend indicated by the 12 year records In projecting the maintenance curves beyond the range of actual cost figures, an attempt was made to take into consideration the probable increase in annual maintenance expense as the structures grew older so that the percentage figures err, if at all, on the side of safety

Cost records for untreated timber projected in the same manner indicate an average maintenance expense of about 12 per cent at the end of a 40 year service life Assuming the life of untreated timber at 10 years, and the life of treated timber at 40 years would indicate a possible maintenance expense ratio of 1 to 4 This would yield a value for treated timber of *three* per cent or *twice* the figure quoted by Mr Seiler, which would appear to be a much more reasonable and conservative figure to use, particularly in view of the present state of the art as regards selection, grading and fabrication of materials With the development of *preframing* and a more careful attention paid to selection and grading of timber, it may be possible to cut this maintenance expense, but I am inclined to think that for purposes of comparison, a three per cent maintenance change at the end of a 40 year service period is more nearly comparable with the figures for the other structural types indicated in Figure 1

Mr Seiler apparently makes much of the question of obsolescence, and there is no question but that a goodly number of highway structures become obsolete as regards location, grade, alignment, or traffic capacity before the economic life of the material has been reached, however, the flattening of the combined curves shown in Figure 1 of

his paper indicates that obsolescence beyond a 35 or 40 year life is not a material cost factor In other words, since the cost of carrying the structure 40 years is not materially different from that of carrying it 80 years, obsolescence would not enter as a materially modifying factor unless such obsolescence occurred prior to 35 or 40 years If, therefore, our highways may be located on an alignment which will warrant the prediction of a 40 year life, the question of obsolescence need not enter into the economic equation

One other point in Mr Seiler's paper which deserves comment is his dismissal of such factors as the effect of roadway surfaces on traffic costs and the economic value to the community of architectural appearance I can not agree with Mr Seiler in this regard However, this feature of the economic analysis is perhaps best reserved for the discussion of Mr Fleming's paper in which he goes into this question in considerable detail.

DISCUSSION OF MR FRANKLAND'S PAPER ON LOW COST STEEL HIGHWAY BRIDGES

As in the case of the paper on Creosoted Timber Structures, the author of this paper has made out an excellent case for the particular type of structure which he is advocating, and the paper as a whole will prove of distinct value to highway bridge engineers

As in the case of the creosoted timber structure, it seems to me that the author has been unduly optimistic as regards probable maintenance expense for the type of construction which he describes He estimates the cost of painting steel structures at $1 00 per ton per year, which probably covers the average case under favorable conditions of exposure For salt laden atmosphere or locations exposed to acid fumes, this cost would be considerably increased Table I of this discussion indicates the cost per ton for maintenance painting for 16 typical bridge structures on the Oregon state highway system from which it will be observed that the total cost for cleaning and painting will range from slightly over $2 00 to as high as $24 00 per ton, depending upon the amount of cleaning, spot painting and other incidental work necessary Experience in Oregon has indicated that steel structures exposed to salt laden air may require painting as often as every other year, and in one or two cases of extreme exposure, it was found necessary to paint steel once each year These, of course, are exceptional conditions, but bring out the fact that the economics of steel vs concrete should be studied in the light of location and atmospheric conditions

Mr Frankland's paper is particularly excellent in that it calls attention to some of the recent methods for further economies in design and the possibilities which exist as regards the reinforcement of

old structures. In regard to the newer developments and economies, Mr. Frankland mentions the utilization of continuity in truss and beam design. This is a point which may well be stressed at this time

TABLE I

UNIT COSTS FOR MAINTENANCE PAINTING STEEL HIGHWAY BRIDGES

Bridge No.	Cost Per Ton: Labor	Material	Equipment	Total	Remarks
1	1.36	1.39	0.64	3.39	One coat
2	1.66	1.12	0.75	3.53	One coat
3	1.90	1.05	0.50	3.45	One coat
4	5.22	1.54	1.84	8.60	Two coats
5	3.95	0.91	0.41	5.27	One coat
6	5.35	1.80	2.25	9.40	Two coats plus cleaning
7	7.28	1.40	2.12	10.80	Two coats plus cleaning
8	2.05	0.50	1.05	3.60	One coat
9	5.50	1.50	1.65	8.65	One coat
10	5.50	0.60	0.62	6.72	One coat
11	1.45	0.55	0.32	2.32	One coat
12	1.65	0.42	0.15	2.22	One coat
13	5.58	2.25	2.00	9.80	One coat
14	5.70	3.50	1.75	10.95	One coat
15	18.70	2.75	3.25	24.70	Two coats plus cleaning
16	6.88	2.09	1.58	10.55	Two coats plus spotting

as distinct economies are posible. Figure 2 is a photographic view of a three span continuous truss of 550 feet over all length recently built by this department over the Willamette River at Springfield.

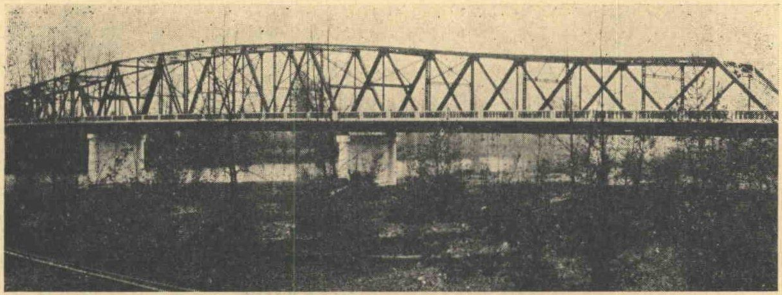

Figure 2. Continuous Truss Over Willamette River at Springfield, Oregon (550 Feet Total Length)

The total cost of the steel work was $68,900.00, and the employment of continuity resulted in a saving of $1,800.00 in first cost and the production of a chord outline considerably more pleasing than if three simple spans had been used. The employment of continuous I beam spans especially since the advent of the larger rolled sections, and the utilization of the rigid frame idea in steel offer further distinct possibilities in economical utilization of material.

Mr Frankland's point in regard to the facility with which a steel span may be reinforced for heavier traffic conditions is well taken I am, however, inclined to discount the value of movability Our experience has been that taking down an old steel bridge, moving it to another location, reerecting it, reinforcing it, repainting it and designing the balance of the structure in such manner as to fit in with the material on hand generally ends up in an expense nearly as great as that for a new structure complete, although in a number of instances, we have been quite successful in utilizing at other locations old steel structures which had become obsolete or inadequate in their existing locations

Mr Frankland states that "about 25 years ago there were a great many short span highway bridges built in Iowa and Nebraska with steel piles of rolled sections" He states that the experience with these bridges was "eminently satisfactory" although he does not state to whom the satisfaction accrued I was connected with the Iowa Highway Commission at the time mentioned by Mr Frankland, or shortly

TABLE II

Material	Location	Average Corrosion Loss in Inches Per Year
Wrought iron	Above ground	0 00018
Wrought iron	At ground line	0 00046
Wrought iron	Below ground line	0 00045
Steel	Above ground	0 00042
Steel	At ground line	0 00094
Steel	Below ground line	0 00075

thereafter, and can state from personal experience that there seems to be some question as regards the utility of this type of structure although it is doubtless true that the early unholy practices in regard to marketing operated to prejudice the minds of engineers in regard to its possibilities and relative advantages

The question of corrosion of steel I beam piling at the ground line has probably been somewhat exaggerated Table II is a summary of results which were made in Oregon in 1923 on steel and wrought iron tubes the steel tubes being 11 years old and the wrought iron tubes 31 years old It will be noted that the most rapid rate of corrosion occurred in the case of steel at the ground line, which was to be expected Even in this case, the total loss of metal over a hundred year period would only be about one-tenth of one inch These figures are particularly favorable, and undoubtedly steel piles in alkali or salt laden soils will show a rate of corrosion many times as great However, it is reasonably safe to assume that with proper maintenance, corrosion of metal piles in the ordinary case will not seriously curtail their economic life

The most serious objection to the use of the steel pile lies in the economic waste involved For foundation work, timber piles will answer every purpose at a greatly decreased cost, except where exceptional conditions render it impossible to drive them For trestle work creosoted timber will prove quite as durable except in certain cases, and considerably less expensive There may of course be cases wherein the steel I beam pile offers distinct possibilities, but its field of competition with the concrete pile or treated timber pile is such as to warrant the prediction that its use will always be somewhat limited

Mr Frankland presents some interesting facts in regard to the utilization of steel plate floors, and while we have had no personal experience with this type of construction, the prediction is ventured that the development of a light type metal floor either of horizontal plates or of interlocked bars in a vertical plane presents distinct possibilities as regards savings in dead load and ultimate structural economy

DISCUSSION OF MR FLEMING'S PAPER ON THE USE OF CONCRETE AS AN ECONOMIC HIGHWAY BRIDGE MATERIAL

As in the case of the other two papers, Mr Fleming's discussion constitutes a distinct contribution to the engineering literature pertinent to highway bridge types His description of improved details, the review of current design practice and his comparative economic analyses are exceedingly interesting and instructive

As in the case of the other papers, there are a few points which seem to merit special comment

In his opening paragraphs, it appears that Mr Fleming has taken a view regarding obsolescence diametrically opposed to that expressed by Mr Seiler Mr Fleming's position is that for main travelled highways, the adopted location has generally been reduced to a degree of stability sufficient to render obsolescence from this cause an unlikely occurrence, while in local, lateral or feeder roads the necessity for a re-alignment is a contingency so remote as to render it feasible to place permanent control points at the stream crossings

As pointed out in the discussion of Mr Seiler's paper, obsolescence ceases to be a materially modifying factor after the expiration of a service life of 35 or 40 years, and it seems easier to believe that primary highways can be located with this degree of permanence than that feeder highways will be left on their present location for a period of time as long as this In other words, Mr Fleming appears to be following somewhat the same procedure as that adopted by Mr Frankland in his discussion of the steel pile trestle, that is to say, extending the field of utility of the particular construction material under discussion slightly farther than circumstances will at present warrant

It is doubtless possible to organize, for any district or region, an engineering department of sufficient magnitude to conduct reconnaissance surveys by means of which stream crossing control points may be established on secondary as well as primary highways If this were done the question of obsolescence would indeed assume a degree of unimportance such as accorded it by Mr Fleming With present engineering organizations, however, and with the present tendency to further curtail engineering expenditures such a procedure is not a practical possibility, and on many of the secondary roads, the uncertainty as regards future alignment developments will warrant the use of low *first cost* bridges for some years to come.

In the development of his economic comparisons, Mr Fleming has paid me the compliment of using my economic equations without change, and while this courtesy is deeply appreciated, it is felt that in justice to the creosoted timber trestle type, certain impressions conveyed by Mr Fleming's paper should be corrected

In the table quoted by Mr Fleming giving for various structural types, the economic life and the combined percentage cost for maintenance plus amortization, the creosoted timber trestle is listed with a life of 22 to 28 years This structural type was not included in my original recapitulation of types, but was referred to later in discussing the economies of timber treatment in which discussion the following statement was made. "Unfortunately the writer does not have tabulated maintenance costs for the treated type of timber construction over a sufficient period of years to warrant any assumption that can carry much weight, however, it seems *safe to assume* that maintenance costs will be reduced to a value *not more* than 50 per cent of the minimum values given for untreated timber" Based upon this hypothetical assumption and *purely as an illustrative problem,* an economic life of 22 to 28 years and a combined percentage cost for maintenance plus amortization equal to 5 2 per cent was developed Mr Fleming has used these figures and has placed them in his table thus creating the impression that these values have the same weight and degree of credibility as the other percentage factors, whereas as a matter of fact, they were not so intended and were only used to furnish data for an illustrative problem

Mr Seiler would have us adopt an average annual maintenance cost of 1½ per cent at the end of a 40 year service life which would cut the combined cost (maintenance plus amortization) from 5 2 to 2½ per cent, or a figure midway between that for concrete and steel As pointed out in the discussion of Mr Seiler's paper, I am of the opinion that this figure is not much more than half of the maintenance cost which can be reasonably expected in the average case If we adopt a maintenance figure equal to twice Mr. Seiler's figure (or three per

cent) the combined cost at the end of a 40 year service life will amount to four per cent or slightly greater than that for either concrete or steel.

This last value (four per cent) is about a mean between the combined percentage costs assumed by Mr Seiler and those assumed by Mr Fleming. It would seem, therefore, that in the type comparisons made by Mr Fleming, the use of a 5 2 percentage coefficient is slightly unfair to creosoted timber

Mr Fleming charges the timber structure with an insurance rate varying from 0 5 to 0 75 per cent per annum while Mr Seiler employs a rate of 0 25 per cent per annum Here again it would seem that the mean of the two values constitutes a figure not far from the truth

Mr Fleming's analysis includes the cost of traffic operation and also a deduction for "rental values" while Mr Seiler dismisses the question of traffic operation costs and rental values with the statement "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" Discussing this question subsequently, Mr Fleming states that "a bridge lacking beauty of line, mass and detail is expensive at any price for it must soon make way for a more attractive structure as the demands of the locality require it The attractive bridge will be maintained and preserved longer than the ugly structure which fulfills only a utilitarian purpose, thereby reducing depreciation charges and the ultimate cost of the bridge"

I am strongly impressed with Mr Fleming's statement and his method of analysis An appreciation of beauty is an inherent and fundamental characteristic of mankind The individual pays a premium for oriental rugs, imported tapestries, luxuriously appointed automobiles, and a dwelling house of pleasing architecture because he is willing to concede that beautiful surroundings possess a distinct psychological significance and have a momentary value Fifty generations of civilization have only intensified this feeling, and since it is impossible to eradicate it in the individual, it is folly to ignore it in the community More and more does the public demand architectural excellence in its buildings and public structures More and more does it demand highways which are scenic as well as utilitarian, and Mr Fleming's point that the attractive structure will be maintained and preserved much longer than the ugly one, regardless of structural conditions, is extremely well taken

SUMMARY

In conclusion, let me state that each of the papers discussed constitutes a distinct contribution to available engineering literature pertinent to highway bridge types; each of the authors has made out

a rather excellent prima facie case for the particular structural material discussed, and each, in the main, has been rather fair in his statements

It would appear that Mr Seiler has failed to take into account the value of architectural possibilities and has perhaps made too much of the matter of obsolescence He is also perhaps somewhat overly optimistic as regards average maintenance expense for treated timber

Mr Frankland has also shown a tendency to minimize maintenance costs and in the case of the steel pile bridge, to extend the use of steel into a field where the possibility of its successful competition is problematical

Mr Fleming has presented a rather more complete economic analysis than either of the other writers, but has used a percentage rate for maintenance plus amortization for creosoted timber which places this latter material at a slight disadvantage In advocating the use of permanent construction for lateral roads Mr Fleming appears to attempt the extension of concrete slightly beyond its true field of economic utility.

It is extremely improbable that any one structural type will ever gain absolute predominance unless revolutionary changes are made in market prices For short span structures creosoted timber and concrete are highly competitive while steel is somewhat at a disadvantage. For secondary roads the creosoted timber structure becomes a more formidable competitor As span lengths are increased, the advantages of creosoted timber become less apparent and concrete and steel assume a position of close competition with creosoted timber at a disadvantage As span lengths are further increased, particularly where foundation conditions rule out the elastic arch, the steel span becomes a more formidable competitor while for movable bridges the steel structure has the field pretty much to itself

Type selection in each particular instance will be modified by local climatic conditions as regards corrosion, decay and marine borer activity and also by such considerations as stream behavior, requirements of navigation, traffic conditions, scenic features and the question of available funds

Trade extension organizations will doubtless always seek to extend the use of that particular structural material which they advocate somewhat beyond its true field of utility, however, this is a healthy and rather desirable condition resulting in the dissemination of much useful information to public works engineers and the constant development of higher and more efficient structural types