1879

The cost of a structure which is to take the place of the Beaver Bridge

Rudolph C. Hoyer

THESIS

BEAVER BRIDGE STRUCTURE

HOYER

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A Thesis

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This bridge is located on the St. L. and San F. Rwy., four miles southwest of Rolla and it spans a deep valley nearly a 1000 ft. in width in the bottom of which runs a small stream. The course of roadway over the bridge is N. 24½ E.

The old wooden Howe Truss bridge being no longer considered perfectly safe, on account of its age, measure was taken to supply its place with some new structure that, with the least expenditure, would carry the road safely over the valley. Now the question before us is, this: whether in this case it will cost more; to build an Iron Truss bridge, or to construct an embankment; using in the former the peers of the old bridge.

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Cost of Earthwork.

It is advisable to pay for this kind of work by the cu. yd. of excavation only, instead of allowing separate prices for excavation and embankment. By this means we get rid of the difficulties of measurements, as well as the controversies and lawsuits which often attend the determination of the allowance to be made for the settlement or subsidence of the embankments.

It is now moreover, the opinion that justice to the contractor should lead to the English practice of paying the laborers by the cubic yard, instead of by the day. Experience fully proves that when laborers are scarce and wages high men can scarcely be depended upon to do three-fourths of the work which they readily accomplish when wages are low, and when fresh hands are waiting to be hired in case any are discharged. The contractor is thus placed at mercy of his men. The writer has known the

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Ellwood Morris, C.E., of Philadelphia,
was, we believe, the first person
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elements of cost of earthwork, and
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curacy. He published his results
in the Journal of the Franklin
Institute in 1841. His paper forms
the basis on which, with Some
variations, we shall consider the matter
and on which we shall extend it
to wheel-barrows, as well as to carts.
Throughout this paper we speake
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close approximations or averages. As before stated, the men do less work when wages are high, and more when they are low. A great deal besides depends on the skill, observation, and energy of the contractor and his superintendents. It is no unusual thing to see two contractors working at the same prices, in precisely similar material, where one is making money, and the other loosing it, from a want of tact in the proper distribution of his forces, keeping his roads in order, having his carts and barrows well filled, etc. Uncommonly long spells of wet weather may seriously affect the cost of executing earthwork, by making it more difficult to loosen, load or empty; besides keeping the road in bad order for hauling.

The aggregate cost of excavating and removing earth is made up by the following items, namely:

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Loosening the earth ready for the shovelers.

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I.

Loosening the earth ready for the shovelers.

II.

Loading it by shovels into carts or barrows.

III.

Hauling or whaling it away including emptying and returning.

IV.

Spreading it out into sucessive layers on the embankment.

V.

Keeping the hauling roads for carts, or the plank gangways for barrows in good order.

VI.

Wear, sharpening, depriciation, and interest on cost of tools.

VII.

Superintendence and water-carriers.

VIII.

Profit to contractor.

Loosening the earth ready for shovelers. This is generally done either by ploughs or by picks; more cheaply by the first. A plough with two horses, and 2 men manage them, at $1 per day for labor, 75 cents per day for each horse, and 37 cents per day for plough, in-

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cluding harness, wear, repairs, etc., or a total of $3.87, will loosen, of strong heavy soils, from 200 to 300 cu. yds. a day, at from 1.93 to 1.29 cents per yd.; or of ordinary loam, from 400 to 600 cu. yds a day, at from .97 to .64 cents per yd. Therefore, as an ordinary average, we may assume the actual cost to the contractor for loosening by the plough, as follows: strong heavy soils, 1.5 cents; com̄on loam, .8 cents; light sandy soils, .4 cents. Very stiff pure clay, or obstinate cemented gravel, may be set down at 2.5 cents; they require three or four horses. By the pick, a fair day's work is about 14 yds of stiff pure clay, or of cemented gravel; 25 yds of strong heavy soils; 40 yds of com̄on loam; 60 yds of light sandy soils—all measured in place; which at $1.00 per day for labor, gives for stiff clay, 7 cts.; heavy soils 4 cents; loam 2.5 cents; light sandy soils 1.666 cents.

Shovelling the loosened earth into carts.— The amount shovelled per day depends partly on the weights of the material, but more upon

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so proportioning the number of pickers and of carts to that of shovellers, as not to keep the later waiting for either material or carts.
In fairly regulated gangs, the shovellers into carts are not actually engaged in shovelling for more than six-tenths of their time, thus being occupied but four-tenths of it; while, under bad management, they loose considerably more than ½ of it. A shoveller can readily load into a cart one-third of a cu. yd. measured in place (and which is an average working cart-load), of sandy soil, in five minutes; of loam in six minutes; and of any of the heavy soils in seven minutes. This would give for a day of 10 working hours, 120 loads, or 40 cu. yds. of light sandy soils; 100 loads or $33\frac{1}{3}$ cu. yds. of loam; or 86 loads, or 28.7 yds of the heavy soils. But from these amounts we must deduct four-tenths for time necessarily lost; thus reducing the actual working quantities to 24 yards of light sandy soil, 20 yards of loam,

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17.2 yards of the heavy soils. When the shovellers do less than this their is some mismanagement. Assuming these as fair quantities, then at \$1 per day for labor, the actual cost to the contractor for shovelling per cubic yard measured in place, will be, for sandy soils, 4.167 cents loam, 5 cents; heavy soils, clays, etc., 5.81 cents. In practise, the carts are not usually loaded to any less extent with the heavier soils than with the lighter ones. Nor indeed, is there any necessity for so doing, inasmuch as the difference of weight of a cart one-third of a cubic yard of the various soils is too slight to need any attention; especially when the cart road is kept in good order, as it will be by any contractor who understands his own interest. Neither is it necessary to modify the load on account of any slight inclination which may occur in the grading of roads. An earth-cart weighs by itself about a half ton.

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Hauling away the earth, dumping or emptying, and returning to reload.—

The average speed of horses in hauling is about 2⅓ miles per hour, or 200 ft. per minute; which is equal to 100 ft. of trip each way; or to 100 ft. of lead, as the distance to which the earth is hauled is technically called. Besides this there is a loss of about four minutes in every trip, whether long or short, in waiting to load, dumping, turning, etc. Hence every trip will occupy as many minutes as there are lengths of 100 ft each in the lead; and four minutes besides. Therefore to find the number of trips per day over any given average lead, we divide the number of minutes in a working day by the sum of four added to the number of 100 ft lengths contained in the distance to which the earth has to be removed; that is,

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$$\frac{\text{The number (600) of min. in a working day}}{4 + \text{the number of 100 ft. lengths in the lead}} = \text{The number of trips removed per day, per cart}$$

And since ⅓ of a cubic yard measured before being loosend makes an average cart load, the number of loads, divided by three will give the number of cubic yards removed per day by each cart; and the cubic yards divided into the total expense of a cart per day, will give the cost per cubic yard for hauling. In leads of ordinary length one driver can attend to 4 carts; which at $1.00 per day, will give the cost per cart 25 cents. When labor is at $1.00 per day, the expense of a horse is usually about 75 cents; and that of the cart, including harness, tar, repairs, etc., 25¢ making the total daily cost per cart $1.25. The expense of the horse is the same on Sundays and rainy days, as when at work; and this consideration is included in the 75 cents, Som contractors employ

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a great number of drivers,
who also help to load the carts
so that the expense is about
the same in either case.

Spreading, or levelling off the
earth into regular thin layers
on the embankment.–

A bankman will spread from
500 to 100 cubic yards of either comm
loam, or any of the hevier soils,
clays, etc., depending on their
dryness. This, at $1.00 per day,
is 1 to 2 cents per cubic yard.;
and we may assume 1½¢ as
fair average for such soils;
while 1 cent will suffice for light
sandy soils. This expense for
spreading is saved when the earth
is either dumped over the end
of the embankment, or is wast-
ed; still, about ¼ cent per yd
should be allowed in either
case for keeping the dumping
places clear and in order.

Remark.– When removing loose
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$$\frac{\text{No. of min. (600) in a working day}}{6 + \text{No. of 100 ft lengths of lead}} = \text{No. of loads removed per day, per cart.}$$

Keeping the cart road in good order for hauling.— No ruts or puddles should be allowed to remain unfilled; rain should at once be led off by shallow ditches; and the road be carefully kept in good order; otherwise the labor of the horses, and the wear of the carts, will be very greatly increased. It is usual to allow so much per cubic yard for road repairs; but we suggest so much per cubic yard, per 100 ft of lead; say $\frac{1}{10}$ of a cent.

Wear, Sharpening, and deprecia-tions of picks and shovels.— Experience shows that about $\frac{1}{4}$ of a cent per cubic yard will cover this item.

Superintendence and water-carriers.— These expenses will vary with local circumstances; but we agree

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These expenses will vary with local circumstances; but we agree

with Mr Morris, that 1½ cents per cubic yard will, under ordinary circumstances, cover both of them. An allowance of about ¼ cent may in justice be added for extra trouble in digging the side-ditches; levelling off the bottom of the cut to the grade; and general trimming up. In very light cuttings this may be increased to ½ cent per every yard. At ¼ cent, all the items in this article amount to 2 cents per cu. yd. of cut.

Profit to the contractor.— This may generally be set down at from 6 to 15 per cent., according to the magnitude of the work, the risks incurred, and various incidental circumstances. Out of this item the contractor generally has to pay clerks, storekeepers, and other agents, as well as the expenses of shantees etc. although these are in most cases repaid by the profits of the stores; and by the rates of boarding

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and lodging paid to the contractors by the laborers.

A knowledge of the foregoing items enables us to calculate with tolerable accuracy the cost of removing earth.
In this case it is required to ascertain the cost per cubic yard of excavating common loam, measured in place; and of removing it into embankment, with an average haul or lead of 1000 ft.; the wages of laborers being $1.00 per day of 10 working hours; a horse 75 cents a day; and a cart 25¢. One driver to four carts.

Here we have cost of loosenig by pick, per cu. yd.			2.50 ¢.
Loading into carts	"	"	5.00 "
Hauling 1000 ft.,	"	"	8.72 "
Spreading into layers,	"	"	1.50 "
Keeping cart road in repaire, 10 lengths of 100 ft each			1.00 "
Wear, Sharpening etc.,			2.00 "
Total cost to contractor,			20.72 "
Contractors profit 10%,			2.072 "
Total cost per cu. yd. to company.			22.792 cents

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Hauling 1000 ft., " " 8.72 "
Spreading into layers " " 1.50 "
Keeping cart road in repairs, 10 lengths of 100 ft. each 1.00 "
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I find the number of cubic yards in our embankment to be 140097.17 and multiplying this by 22.792 cents the cost of a cubic yard gives us $31930.946 for the total cost of earth-work. To this must be added the cost of a culvert which is to be constructed through the embankment. This culvert will contain 1200 cu. yds. cut masonry for the construction of culverts being furnished at $10.00 per yd. the cost of this culvert will be $12000.00. Giving us $43930.946 as the cost of the embankment completed.

In embanking over culverts care must be taken not to injure the masonry by shocks from the fall of the earth, or by ill-distributed or sudden pressures. For the purpose of preventing shocks the earth should be spread in immediate contact with the masonry in thin layers and ramming each layer. For this purpose dry materials should be chosen that will let water drain off easily such as shivers of stone, gravel and clean

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———— " ————

Before finding the cost of the bridge I will give you the following treatise by Thomas C. Clarke. from which we can get some ideas as to the economy and best methods of construction in bridge building.

American Iron Bridges.

Some philosopher has said that results come from internal impulses modified by external conditions, applying this to European bridges, we find that the internal impulse is first to make as strong and as safe and as durable a structure as possible, and that the question of cost holds a secondary place. The external conditions are, plenty of time and rivers of comparatively uniform regimen, so that there is but little danger of scaffoldings

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being washed out by the floods during erection.
Hence we find consecutively– stone arches; cast iron arches; plate-girders; and, finaly, latice girders of plates and angles riveted together, copying the proportions all ready established for plate girders.

In this country, on the other hand, the internal impulse is to build the bridge (and in fact everything else), in as short a time as possible, and for the least possible sum. Hence our rail-way bridges were originally made of the most abundant and cheapest material– wood; and so designed as to be put together with the utmost rapidity, inasmuch as our rivers are subject to sudden and heavy freshets, and it never is safe to trust the bridge supported by staging which may be washed out in a night.
Hence when we began to build our iron bridges we copied the

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proportions already established as
most economical in wooden trusses,
and instead of riveting the several
parts together on the scaffolds, we
adopted the use of tenons and
sliding-joints for the compressive
members, and of pins and eye
bars for those in tension, which
enables us to erect our bridges,
without fitting very rapidly.
Having begun in this path
we have seen no reason to depart
from it. We find that great econo-
my of material (which simply
means little dead weight) is
got by concentrating the iron
along the lines of strain, by
making long panels (which means
few parts), and by proportioning
our girders of a depth of never
less and often more than ⅛ of
their span.
The form of truss now almost
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has almost driven out of use the
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parts together on the scaffolds, we
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sliding-joints for the compression
members, and of pins and eye
bars for those in tension, which
enables us to erect our bridges,
without fitting very rapidly.
Having begun in this path
we have seen no reason to depart
from it. We find that great economy
of material (which simply
means little dead weight) is
got by concentrating the iron
along the lines of strain, by
making long-panels (which means
few parts), and by proportioning
our girders of a depth of never
less and often more than ⅛ of
their span.

The form of truss now almost
universally adopted, and which
(by a process of material selection)
has almost driven out of use the
Bollman, Fink and Triangular girder
is the Quadrangular girder with

vertical posts and main tie bars inclined at an angle as nearly 45° as possible. This has the merit of subjecting the iron to strains in one direction only – either tension or compression, and if we agree with Herr Wöhler that iron strained both ways is as highly strained as if the tension and compression were added together – this is a point of no small importance. We prefer to hang our cross floor beams from the pin, because then the load is transferred directly by the diagonal tie bars, without any bending moment.

Our peculiar web system allows us to give great height to our trusses, sufficient to enable us to put in vertical transverse bracing high enough to clear the smoke-stacks of the locomotives, which, we think, adds much to the lateral stiffness of our bridges.

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of 4,000 lb per ft. for spans of 50 ft and below; 50 to 100, 3000 lb; 100 to 150, 2750 lb; 150 to 250, 2500 lb; 250 to 300, 2250 lb; above 300, 2000 lb. In addition to this, the floor and panel system is strengthened to provide for a load arising from the concentrated weight of the engine of 3500 and sometimes 4000 lb. per ft. lineal. Strains in tension are taken at 10,000 lb per sq. in., and in compression 5000 to 10,000 for chords of 10 to 14 diameters, and 4000 to 6000 for posts of 20 to 30 diameters.

So much for the design of our bridges. When we come to examine the methods of construction we shall see that marked feature is the use of special machine tools by which the sizes and lengths of all the parts are fitted with the utmost exactness at the place of manufacture. The ends of the upper chords and of the columns are faced in laths; and the lower chord bars and diagonal tie bars are drilled with a pair of drills set on a wrought iron bed so as to give absolute accuracy of length. The pins are turned and fill the holes so well that 1-100 of an inch is the limit of end allowed.

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Now the point to which I particularly wish to call your attention is that when once the machinery is provided this accuracy of workmanship costs nothing. Hence there can be no disposition to slight work and make imperfect joints and bearings. The process of manufacture is the best inspection possible. The bridge is calculated to come to a certain camber, and if it does not come to that camber, or if any of the eyebars are loose something must be wrong. Now, every one who has ever built riveted lattice bridges knows that unless iron templates are used and the greatest possible care taken in laying out the work that the rivet holes will not come opposite each other, and either driffling or rimming must be allowed. Exactness of workmanship can be attained, but it costs the maker a great deal more money than rough fitting, while in the machine made bridges there is no inducement to poor work. As to the actual economy of material, perhaps the best illustration that I can give you is to quote the weights of the 200 ft spans over the Minamadic River, on the Intercolonial Railway of Canada. Tenders were re-

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ceived for these bridges from various European, English and American bridge-builders. There were 17 spans of uniform length and these were all designed on the same specification, viz., to carry a general moving load of 2800 lb per lineal ft. and a load on floor system of 3.600 lb per ft. strain in tension 10.000 lb per sq. in.; in compression, on chords 7500 to 8000 lb per sq. in., or posts 4000 to 6000 lb. The different designs may be divided for purpose of comparison into 4 classes:

1. Riveted lattice girders, panels 9 to 10½ ft. long trusses 20 ft. high; weights 141, 140, 137, 144½ tons.
2. Riveted lattice girders, short panels, 6 to 8 ft. long; low trusses, 16 to 18 ft high; weights 244½, 221, 206½, 202 tons.
3. Pin connected trusses, panels, 9 to 11 ft.; trusses 20/25 to 22/28 ft.; weights, 128½, 126½, 122 tons.
4. Pin connected trusses, panels 12 to 14 ft.; trusses 25 to 28 ft.; weights, 111, 109½, 102 tons.

It will be observed that saving of dead weight is due more to the design than to the difference between riveted and pin connections. We may say roughly that the difference due to this cause alone, is nothing for spans under 100 ft from 100 to 200, 5 to 20 per cent. Above 200, the increase is rapid in favor of pin connections.

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When we come to examine the question of rapidity of erection, the pin connections have a great advantage. They can not only be built much quicker but they require no skilled labor; any ordinarily intelligent laborers can erect them, under a good foreman. Spans up to 150 ft can be erected by a gang of 20 men in a single day, if necessary a 200 ft span, two or three days; a 250 ft, three to four etc.

The total weight of our bridge is 1246947 ℔ nearly, including weights of floor, lateral bracing complete for a single track. Now a machine made bridge can be furnished here for 5 cents per ℔ of the weight.

This would give for the total cost of bridge $62347.375 which is $18416.429 more than the cost of the embankment; consequently, an embankment is the more profitable to the company.

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