A CHECK DESIGN OF A DECK TYPE HIGHWAY BRIDGE

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THESIS

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Bridges are numbered among the most ancient and honored evidences of the progress of civilization. Their background and tradition extend into the past almost as far as man's history. Structures built by man reflect his increased knowledge and progress; each era or age showing a definite style of design.

Bridges reflect this tendency more than any other type of structure and more than any other typify progress and have given man the opportunity to create with his hands an almost living monument of himself, his visions, and his imagination. A study of the history of bridges shows the gradual change in style throughout the ages, each reflecting the predominating ideas of the era. Bridges of the early 20th. century show decided efficiency but tend to be plain and inartistic, comparable to a machine performing its task in the most efficient manner. It should not be inferred that a bridge should not be efficient but the esthetic factor must also be taken into account. The more recent conception of bridge design involves economical and efficient design combined with more graceful and artistic lines, harmonizing with the immediate landscape and other location characteristics.

While bridges differ in style and design every structure follows and performs the duties and requisites as stated by Palladio in the 16th. century: "The convenience of bridges was first thought upon because many rivers are not fordable, upon which account it may be said that bridges are a principal part of the way and are nothing else but a street or way continued over water. Bridges therefore ought to have the self same qualifications that are judged requisite in all other fabriks, which are; they shall be convenient, beautiful, and durable." These are the cardinal principles of good bridge design and are followed to the letter in the design of the most modern structures.

It is not the purpose of this paper to develop the history of bridges or of bridge design but rather to develop the procedure followed in the design of a bridge and the variety of problems encountered; using an actual example as a graphic illustration. The bridge to be specifically used is a concrete slab, rolled beam, deck girder highway bridge. This type of structure is somewhat more involved than a railroad bridge due to the extreme freedom of the load placement.

In this and following pages, the terms, good practice, good design, and standard design will be encountered many times. The first two are terms applied to problems solved on the basis of experience. With years of experience and increasing familiarity with structures, valuable information is gradually acquired; sometimes by the tragic results of faulty design, the bridge engineer and designer acquires a mass of invaluable data for future reference.

Standard design is a term applied to design features computed from information and data compiled over a period of time. This type of design is constantly changing as the theories involved can be followed further with additional data. The State Highway Departments and the Federal Bureau of Roads are the agencies most directly concerned with this type of design. These organizations design the standard sections from the formula developed from the results of their construction and is intended to create a certain amount of uniformity of design in all structures under their supervision and authority. The economic factor also enters into standard design. The design features which the Department considers to be the best are gathered, compiled, and put into the form of Standard Specifications. These specifications are usually taken as the basis of design for all structures on state highways, and are corrected, changed, and added to as additional knowledge from their experience and that of others becomes available.

In the design and construction of a highway bridge, there is a definite procedure to be followed. First a petition to replace the existing structure: This requires action by the County Road Commission, the State Highway Department, and the Federal Bureau of Roads, if Federal Aid is expected. Second a complete survey is made of the site. This survey includes traffic surveys, boring logs, cross-sections, complete stream data, and a report of the type and condition of the existing structure. If the petition is approved, preliminary plans of the structure are drawn up and sent to the State Highway Department and the Federal Bureau of Roads for approval. The necessary changes and corrections are made on the preliminary plans and after final approval, the plans are detailed and completed along with the engineer's estimate of cost. The job is then bid on and contracted for construction. This is a brief resume of what actually takes place.

To illustrate the actual procedure, a definite example has been selected. The design of this bridge will be followed through to give a more graphic picture of the actual proceedings. In a sense this paper will also constitute a check design of the main features, proving the efficiency and worth of the bridge.

The bridge in question is located in Kalamazoo County, crossing the Kalamazoo River at Comstock, Michigan. The previous structure consisted of a through steel Pratt truss of six spans with the following dimensions: clear roadway 17'-6", center to center of pine 150.12', floor of planks covered with bituminous material. The structure was erected in 1904. A great deal of commercial traffic was carried over the truss and it was felt that the bridge was entirely inadequate under the increasing flow of traffic.

As this paper will be chiefly concerned with the design features of the bridge, it will suffice to say that it was decided to replace the existing bridge under a Secondary Federal Aid Allocation. The first step was the plotting and thorough study of the survey of the site. Reference to The General Plan of Site will show the problems to be considered and the information required of such a survey. The boring logs and contours are shown as is the proposed re-alignment designed to eliminate a skew crossing. Note should also be taken of the extent of the stream data required. The next step is the selection of the type of bridge to be used. It is at this point that experience plays an important role. A great many factors enter into this choice, many of which are covered in Sections A, B, and C of the Standard Specifications. Some of the principal points are: a minimum vertical clearance of one foot shall be provided between maximum high water and the superstructure, the channel opening shall not be impaired, and the footings for piers and abutments shall be so placed that there shall be no danger of failure by erosion. Other considerations are the factor of economy, good practice, allowances for expected future increases in traffic flow, and the esthetic factor.

The first step was to specify a 44' clear roadway with one 5'-0" and one 2'-6" walk due to the close proximity of the Village of Comstock. The type of structure was then debated. With the proposed width of roadway a through truss or girder was out of the question due to economy. It has been found that such structures are uneconomical for widths greater than 30', except under special conditions. A deck truss or girder would also be a futile consideration due to the lack of headroom. The next consideration was that of multiple spans structures. It was finally decided that a three span, reinforced concrete slab, deck girder bridge would be the most economical and intelligent choice for the existing conditions. This type of bridge can be economically designed in the width desired, the necessary vertical clearance could be obtained, and the channel openings would be adequate. Accordingly this choice was adopted.

The next problem was the choice of piers and abutments. The boring logs indicate that the soil was of such composition as to have a bearing power of between 3 and 5 tons per square foot. The control factors were that the top be of sufficient width to care for the bearing plates and there be protection against erosion. In the final analysis it was decided to use 18' cantilever type abutments of reinforced concrete; the footing elevation being set at 756.0'. Two piers of standard section were used and of the gravity type were selected; the footing elevations being set at 750.0'. These tentative selections fulfilled all of the necessary conditions and requirements and was the most economical choice for the conditions peculiar to this project.

The deck and floor slab are the first problem. Articles 17, 18, 19, 20, 21, 22, 24, 25, and 26 of The Standard Specifications of The Michigan State Highway Department, as of 1936, cover the requirements of this portion of the structure. Pavement slabs are usually of a specified standard cross-section. There are so many varied theories and disagreements on pavement slabs, that The Federal Bureau of Roads specifies a standard section based on the latest available knowledge. The strength of such a slab is more than adequate beyond any doubt. The steel reinforcement is also prescribed for the same reasons. The rules listed in The Standard Specifications are for use in detailing the sections. A pavement slab 7.5 inches thick was used with standard steel placement. An additional 13/16" was added to the thickness of the slab to allow it to fit over the flanges of the girder. In computing the dead loads, a 1/2" allowance was made for future wearing surface. A parabolic crown providing roadway drainage was computed in the following manner:

$C = .00187\ R^2$ Where C - crown in inches
R - width of roadway in feet

$C = (00187)\ (44)^2$

C = 3 5/8 inches

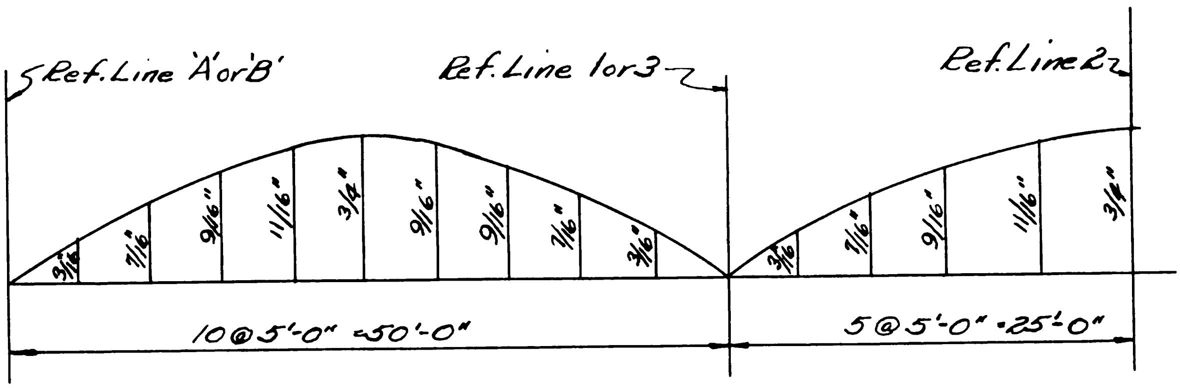
The curb and sidewalk with their steel are also a matter of standard section, being between 8 and 10 inches in height. In this case a height of 10 inches was used at the curb and 10 1/2 inches at the outside edge, the 1/2 inch providing for drainage.

The railings and requirements are covered in articles 25 and 35 of The Standard Specifications. Like the majority of the deck, the railings are standard, consisting of reinforced concrete posts with steel grillwork between. The spacing of the posts is usually between 8' and 10', the latter figure being the maximum. The spacing is proportioned so as to preserve symmetry, the grill being designed to fit the spacing. On bridges having no curb, these railings are designed to withstand the shock of a colliding vehicle.

The last step in the design of the deck is camber. Camber has absolutely no structural value but is purely a psychological factor. Under the action of the dead loads, the beams will deflect a certain amount causing the fascia and shadow lines to show a decided sag. This action causes some anxiety in the mind of the average motorist who does not understand that it is a natural reaction. To overcome this appearance of failure, concrete is added to the top of the slab along the curve of a parabola parallel to the girders. Thus, under dead load deflection, the shadow lines and the fascia appear as straight lines. It amounts to filling in the dead load sag with concrete. Camber concrete is placed along a true parabolic section, the offset at the center being computed as follows:

$$\text{Defl. (Max.)} = \frac{5Wl^3}{384EI} \qquad W = \text{Total Dead Loads}$$

The offsets for various other points are then found by use of the parabolic formula $Y^2 = aX$. The camber diagram for this structure is shown below and allowance must be made for this when placing the slab forms.



CAMBER DIAGRAM

This completes the deck of the bridge and the next portion of the bridge to be considered are the girders.

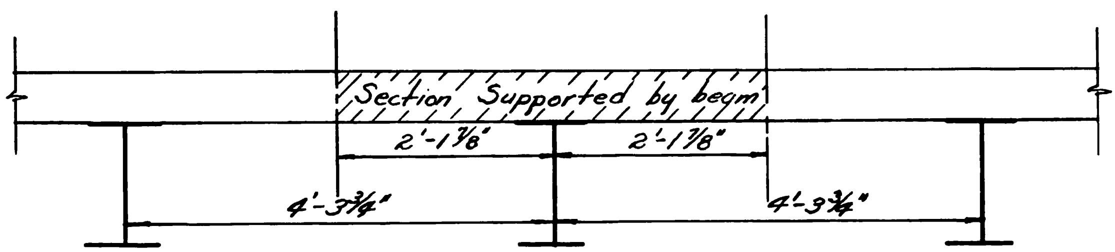
According to the specifications (77) the girders for the bridge are to be W.F. rolled sections. The first step in the design of the beams is to determine the spacing to be used. Good practice dictates that the spacing used with concrete floor slabs shall be between 4'-6" and 5'-6" and the outside of the flange of the outer beam must be at least 4" from the fascia. The problem is to determine the most economical spacing of the beams, i.e., whether it is cheaper to use a small spacing with a small section or to use a larger section and a greater spacing. Two control factors affecting the spacing in this particular case are that traffic must be allowed over one half of the bridge while the other is being constructed, and construction joints must lie over a girder. With these facts in mind the spacing was set at 12 spaces at 4'-3 3/4". The spacing having been determined, the beams may now be designed and a section selected. (See Articles 77 and

79 of The Standard Specifications.)

Using a depth ratio of 1/20, the tentative depth of the beam was set at 30". Referring to a table of standard sections a 30 x 10 1/2, 116 lb. W.F. beam is assumed. The beam is now checked for dead and live loading plus impact. The dead load is made up of the weight of the deck and the weight of the beam. The live load is the standard H-20 loading plus impact.

Dead Load Moment: (See Article 30)

The weight of deck supported by one beam is equal to 1/2 of the span on either side of the beam in question.



Slab = (11 7/8 + 3 5/8 + 3/4) (4'-3 3/4) (150)	-	639 lbs./ft.
Future wearing surface - 20 lbs./sq.ft.	-	86
Beams	-	120
Diaphragms (Est. 5 lbs./ft.)	-	5
w	=	846 lbs./ft.

$$\text{D. L. Mom.} = \frac{wl^2}{8}$$

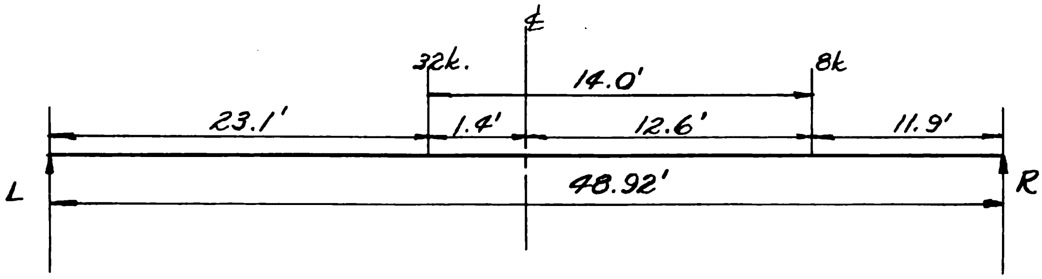
$$= \frac{846 \times (48.92)^2}{8}$$

$$= \underline{254 \text{ kip feet}}$$

It should be noted that the span was not taken as 50' but some 13" less. This is due to the fact that the beams are designed from the center to center of bearing. The center of bearing being considered at the point where the beams fit over the anchor bolts.

Live Load Moment: (See Articles 31, 32 and 43.)

The live load moment assumes the loading to be so placed as to obtain the maximum possible moment. This may be accomplished by so placing the loads that the equivalent of one complete axle load comes upon the beam.



$$\Sigma M_L = 0$$

$$R = \frac{32 \times 23.1 + 8 \times 37.1}{48.92} = 21.2 \text{ kips} \qquad L = 40 - 21.2 = 17.8 \text{ kips}$$

The distribution factor is found by application of Article 43, and in this case is found to be .431, assuming a traffic lane of 10' in width. The total live load moment is then found to be

$$L.L.M. = 17.8 \times 23.1 \times .431$$
$$= 177.5 \text{ kip ft.}$$

The impact allowance of the live load is found by application of the formula given in Article 37,

$$I = \frac{L+20}{6L+20} = \frac{50+20}{(6)(50)+(20)} \qquad L\text{- Span Length}$$
$$= .219$$

Impact Moment:

$$L.L.M. \times I = 177.5 \times .219$$
$$= 38 \text{ kip ft.}$$

Total Moment:

$$\text{Total } L.\&D.M. = 38 + 177.5 + 254$$
$$= 469.5 \text{ kip. ft.}$$

The section modulus, Z, is equal to the total moment divided by the allowable stress in the steel. (Section F of Standard Specifications.)

Section Modulus:

$$Z = \frac{469.5 \times 12}{18000}$$
$$= 314 \text{ in.}^3 \text{- Req'd}$$

Referring again to the table of standard sections it is found that the beam assumed provides a section modulus of 327.9 in.^{3} The next smaller size has a modulus of only 299 in.^{3} so that the assumed beam is the necessary size for the bending requirements.

In beams of this length bending moment rather than shear is the controlling factor. The shear, however, is checked as a precautionary measure. The maximum shear is found to occur at an infinitesimal distance from the support.

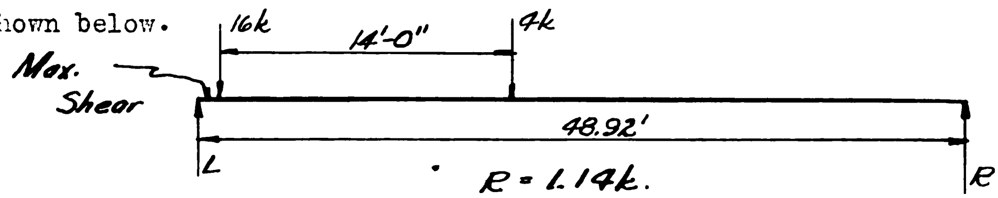
Dead Load Shear:

The dead loads are the same as for the bending moment.

$$L = \frac{wl}{2} = \frac{846 \times 48.92}{2}$$
$$= 20.7 \text{ kips}$$

Live Load Shear:

For live shear, the loads are placed on the beam in the position shown below.



$$R = 1.14k.$$
$$L = 18.86k.$$

Impact:

The same impact allowance is made for shear as for bending.

$$I = .219 \times 18.86 = 4.13k.$$

The maximum shear occurs at the section indicated above and is equal numerically to the reaction.

$$V = 20.7 + 18.86 + 4.13$$
$$= 43.7 \text{ kips}$$

The area required for shear is:

$$A = \frac{V}{S} = \frac{43.7 \times 1000}{12000}$$
$$= 5.6 \text{ in.}^2$$

The girder in question gives a cross-sectional area 34.13 sq.in., which is more than adequate for the shearing demands.

It will be noted that this choice of beam and spacing is somewhat uneconomical. As mentioned before, however, the requirements of the deck exert a controlling influence on the beam selection. These ideas are now considered obsolete, construction joints having no control of the beam spacing. Under the existing conditions the assumed beam will be accepted.

To provide against lateral buckling and bending, diaphragms are specified at the third points of the girders (Article 124). The diaphragms are connected to the beams by the use of hitch angles, 3/4 in. rivets being used throughout. The intermediate diaphragms consist of the largest size plate which can be fitted between the flanges of the girders. The sections at the ends of the beams consist of fairly small channels, connected to the girders in the same manner as the intermediate type. These latter members serve a slightly different purpose than the intermediate sections. The expansion distance between the girders plus the necessary steel coverage in the concrete deck slab leaves some little distance of the slab without any reinforcement. To avoid the danger of failure at these points, the slab is cast to the top flange of these diaphragms, thereby giving a supporting effect to the slab.

The bearing plates in this case are specified by The Federal Bureau of Roads and consist of structural plates 10" x 3 1/2" x 1'-0" continuously welded to the lower flange of the beams. There are two reasons for specifying a plate of these dimensions. In the first case it tends to raise the girder off of the abutment bridge seat and gives free access to all parts of the beams for the purpose of protective painting. The second reason is that a plate of this size insures the proper distribution of the load over the piers and abutments and avoids the introduction of a large concentrated loading with the deformation of the bearing plate. In ordinary design the bearing plate would be designed for the actual loads and would not be of this size. The next point to be considered is that of expansion. Articles 110 and 111 of The Standard Specifications state that provision shall be made for expansion and contraction to the extent of 1/8" per 10' of span. For spans 70' or less, the expansion may be cared for by metal plates sliding upon one another. In this case 1/2" steel sole plates were used; the bearing plate riding upon them and forming an expansion bearing. The sole plates have no movement, being firmly anchored to the abutment and piers. The movement of the beams is taken up by means of slotted holes in the expansion ends of the beams flanges and bearing plates.

The last point in the design of the superstructure are the anchor bolts as specified in Article 117. The bolts used were 1" in diameter, 1'-6" in length, and provided with hex heads. The pier anchors were threaded for a length of 3 1/2" and provided with nuts and washers for securely fastening the beam to the substructure. The abutment anchors are left unthreaded and the flanges of the beams are not drilled at this point due to the possibility of becoming fouled with concrete when the backwall is cast. To insure firm anchorage the bolts are so designed that at least 10" of the bolt may be imbedded in the concrete.

The superstructure having been designed, attention is now focused on the substructure. The Standard Specifications state that such structures, to resist the pressure exerted by fill material, shall be designed in accordance with Rankine's Theory of pressure distribution and that there shall be no structure designed for an equivalent pressure of less than 30 lb./sq.ft. To provide for live load, an equivalent surcharge of four feet shall be applied over all surfaces subject to highway loading.

The practical design in this case utilized the equivalent pressure of 30 lb./sq.ft. and assumed as a starting point, dimensions similar to other structures having like characteristics. The assumed cross-sections are then checked to obtain the most efficient size. Care must be taken, however, to insure stability of the structure and to keep the pressure within the bearing power of the soil.

Plate I shows the size and shape of the section selected and the pressure distribution triangle. Abutments are usually checked for three cases. First, backfill only; second, superstructure loads and live load surcharge; and third, superstructure live and dead loads with no live load surcharge. All cases are checked but the third case is usually taken as the criteria due to the fact that there must be no failure of the wall under backfill and truck pressure before the deck is placed.

<u>Case I</u> - Backfill only.

Moments are considered about the toe of the footing.

Overturning Moment

$$113 \times 14.25 = 1610 \times 7.12 = 11{,}450$$

$$\frac{540-113}{2} \times 14.25 = 3035 \times 4.75 = \underline{14420}$$

$$25870 \text{ ft.lb.}$$

Resisting Moment - 12696 lb $= 65{,}180$ ft.lb.

Resultant Moment $= 39{,}310$ ft.lb.

$$R = \frac{39310}{12696} = 3.1 \text{ ft.}$$

$$\text{Middle Third} - \frac{8.5}{3} = 2.83 \text{ ft.}$$

$$f = \frac{39310}{25870} = 1.53$$

Under these conditions the wall is safe against overturning and the resultant pressure falls within the middle third. The wall also has a safety factor of 1.53 against sliding.

<u>Case II</u> - Superstructure L.L. and D.L. plus L.L. Surcharge.

Overturning Moment - 38050 ft.lb.

Resisting Moment - 17306 lb - 83980 ft.lb.

$$R = \frac{45930}{38050} = 2.66 \text{ ft}$$

$$s.f. = \frac{83980}{38050} = 2.21$$

Middle Third - $\frac{8.5}{3} = 2.83$ ft.

The structure is also safe under the conditions of the second case loading.

<u>Case III</u> - Superstructure L.L. and D.L. No L.L. Surcharge.

Overturning Moment - 25870 ft.lb.

Resisting Moment - 18866 lb. - 90340 ft.lb.

Resultant Moment - 64470 ft.lb.

$$R = \frac{64470}{18870} = 3.42 \text{ ft.}$$

Middle Third - 2.83 ft.

$$s.f. = \frac{90340}{25870} = 3.5$$

The abutment is also safe under the third condition of loading. The resisting moment is sufficient against overturning, the resultant falls within the middle third, and the wall is safe against sliding.

The results of the last computation indicate that to some extent the wall might be more economically designed by the use of a more exact application of Rankine's Theory using a pressure coefficient for the type of soil involved. The saving in all probability would be of less value than the time consumed in rechecking the design. The abutment as it stands is adequate for the loadings.

The strength of the wall must now be developed by the introduction of reinforcing steel. The stem steel will be computed first.

Stem Steel:

Overturning Mom. at top of Footing

$$\bar{V} = 4805 \quad - \quad M = 24160 \text{ ft. lb.}$$

$$A_s = \frac{M}{f_s jd} = \frac{24160 \times 12}{18000 \times .875 \times 17.5} = 1.053 \text{ in.}^2$$

$$1''\phi @ 9'' = 1.05 \text{ in.}^2$$

$$\Sigma_0 = \frac{\bar{V}}{u f_s jd} = \frac{4805}{150 \times .875 \times 17.5} = 2.09 \text{ in.}$$

$$1''\phi @ 9'' = 4.18 \text{ in.}$$

Overturning Mom. 3' above top of footing

$$M - 12270 \text{ ft. lb.}$$

$$A_s = \frac{M}{f_s jd} = \frac{12270 \times 12}{18000 \times .875 \times 17.5}$$

$$= .535 \text{ in.}^2$$

Use $1''\phi @ 18''$

As the height above the top of footing increases, the moment decreases rapidly. Therefore, the wall steel is spaced at 9" and every other bar is cut off 4'-0" above the top of the footing.

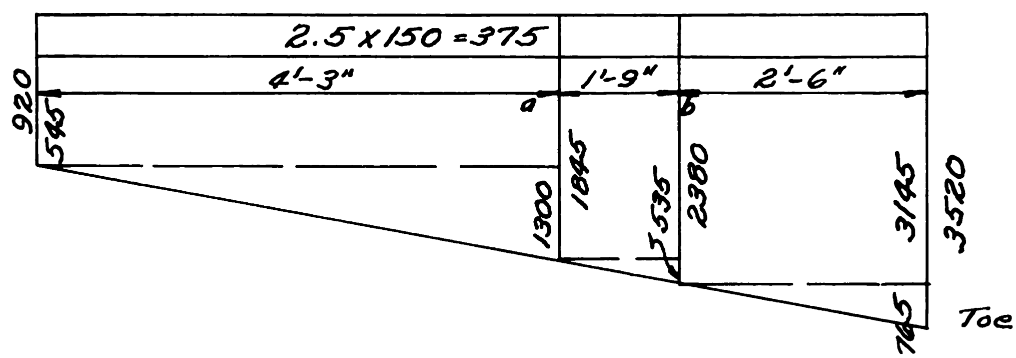
The steel necessary in the footing is the next step. The footing pressure at heel and toe are found as follows: The weights used are the same as used in checking the wall dimensions.

$$P = \frac{W}{b}\left[1 \pm \frac{6e}{b}\right]$$

$$= \frac{18870}{8.5}\left[1 \pm \frac{6(4.25-3.42)}{8.5}\right]$$

$$= 3520 \text{ lb./ft.}^2 \text{ at toe}$$

$$920 \text{ lb./ft.}^2 \text{ at heel}$$



These values are well within the bearing power of the soil, which, as stated before, runs between 3 and 5 tons per square foot.

<u>Toe Steel</u>:

$$\Sigma M_b = 0$$

$2380 \times 2.5 = 5950 \times 15''$		$= 89250$
$\frac{765 \times 2.5}{2} =$	957×20	$= 19130$
	$\bar{V} = 6907$	108380 in. lb.

$$A_s = \frac{M}{f_s j d}$$

$$= \frac{108380}{18000 \times .875 \times 27}$$

$$= .255 \text{ in.}^2$$

$$5/8''\phi @ 12'' = .31 \text{ in.}^2$$

$$\Sigma_o = \frac{\bar{V}}{\mu j d}$$

$$= \frac{6907}{150 \times .875 \times 27}$$

$$= 1.97 \text{ in.}$$

$$5/8''\phi @ 12'' = 1.96 \text{ in.}$$

Heel Steel:

$$\bar{V} = 3195 \qquad M = 105500 \text{ in. lb}$$

$$A_s = \frac{M}{f_s j d} = \frac{105500}{18000 \times .875 \times 27}$$

$$= .248 \text{ in}^2$$

$$5/8'' \phi @ 12'' = .31 \text{ in}^2$$

$$\Sigma_0 = \frac{V}{\mu j d} = \frac{3195}{150 \times .875 \times 27} = .908 \text{ in.}$$

$$5/8'' \phi @ 12'' = 1.96 \text{ in.}$$

This constitutes the main steel but in addition reinforcing must be provided for shrinkage, temperature, and beam expansion stresses. Article 66 of The Standard Specifications states that such steel shall be placed normal to the main reinforcing and shall provide not less than 1/8 sq.in. of reinforcement per foot of width of surface, and shall be placed at all exposed surfaces.

Two way steel was placed in the top and bottom of the footing and in both faces of the wall in accordance with this specification. Reference to steel tables indicated that 5/8" ϕ and 1/2" ϕ steel suitably placed gave the best results.

The selection of the elevation of the abutment footings are of special interest in this case. Reference to the general plan of structure will show that this point is some 7' above the bed of stream. The usual practice is to place the footing at least two feet below this point, preventing undermining of the footing and possibility of failure, and as a protection against heaving resulting from frost.

To follow that practice in this case would involve a much larger wall section and greatly increase the cost. Again referring to the plans, it will be seen that interlocking steel sheet piling was driven to the waters edge in front of the abutment and left in place. In this manner the cost was substantially reduced and a safe abutment provided.

The gravity type piers of reinforced concrete measured 24'-0" from crown of roadway to bottom of footing. A standard pier section was utilized, dimensions being selected to fit the individual conditions. The plan and elevation of the section are shown on Plate II. A section is also shown on the General Plans of Structure. It will be noted that the rounded noses of the piers offer a minimum amount of water resistance, thereby reducing erosion, and at the same time offer a pleasing appearance. The control factors in the design of such a pier are that the top of the wall be of sufficient width to hold the bearing plates and that the stability of the wall is maintained.

The results of previous designs are often utilized as a starting point for new designs. The superstructure loads and the weight of the pier are computed and divided by the area of the base giving the unit bearing at the base. Theoretically the design is changed until the most economical dimensions within the bearing power of the soil is obtained. Care is exercised to see that the wall is kept within stable limits.

<u>Bearing of Pier</u>:

Weight of Footing	- 158,156.25
Weight of Wall	- 540,487.50
Superstructure L.L. & D.L.	- 370,200
	1,098,844. lbs.

1,098,844 / 422 = 2610 lb./ft.

The bearing of the pier is 2610 lb./sq.ft. which is well within the bearing power of the soil.

This is the theoretical procedure in the design of the pier and is followed as closely as conditions will permit. In this case the pier is of more massive construction than is absolutely necessary. One reason for this is that the necessary width for the bearing plates must be provided along with the necessary area for bearing. The other reason is that it looks safe and is more pleasing to the eye.

At times it becomes necessary to sacrifice economy for psychological and esthetic factors.

The reinforcing steel in the pier section is mostly for shrinkage, temperature, and the stresses set up by the expansion of the beams. There is also assumed to be a slight bending introduced at the top of the pavement slab by the traction of the moving loads. These stresses are cared for by the use of slightly heavier steel than would be used ordinarily. Dowels of 3/4" ∅ steel were used to bind the wall to the footing. These extended up from the bottom of the footing into the wall a distance of 2'-6". To take any bending introduced in the wall 3/4" ∅ bars were placed vertically up both faces of the wall. The remainder of the wall steel was placed in a horizontal position along the face of the wall, 3/4" ∅ bars being used in the center section and 1/2" ∅ bars in the rounded noses.

The actual design of the structure is complete at this point. The wing walls are merely continuations of the abutment sections and the back wall is cast monolithically with floor slab to the bridge seat, and is intended to keep the backfill from spilling out from between the girders.

The detailed drawings are not taken into consideration in this paper, as they have no bearing on the design features. The detailed drawings are very complete plans of the structure intended for the use of the construction men. They show the placement of the steel, water stop, extent of pours, and so forth.

In addition to actually designing the structure, the engineer is also required to calculate the amounts of wet and dry excavation, quantities of concrete, reinforcing steel, structural steel, railing, field painting, and in fact the quantities of all materials entering into the structure. He is also required to prepare a set of specifications supplemental to the Standard Specifications, specially applying to the bridge in question.

The engineer must also include with the plans an engineer's estimate of cost. A set of the Supplemental Specifications, quantities, and the engineer's estimate of cost actually used in the bidding and construction of this bridge is included in this paper. It should be noted at this point that the authority for all design features is "Specifications for the Design of Highway Bridges as adopted by the Michigan State Highway Department January 1936". This structure was placed under construction and completed during the latter portion of 1939. Below are shown several views of the bridge as seen July 1942. The roadway views show the roadway looking in each direction. Note the expansiveness of the deck and the manner in which the roadway continuity has been preserved across the structure. The traffic capacity of this structure is apparent. The elevation of the bridge is shown from the upstream side. The structure presents a pleasing appearance and this particular picture gives a fine indication of the individual features of the structure. It also indicates the importance of the camber as seen by the horizontal shadow lines at the fascia. The next two pictures show the railings and the beams and diaphragms. In the background of the latter may be seen the large bearing slabs elevating the beams from the piers. The last picture shows one of the bridge plates required on all Federal Aid Projects. Similar plates are usually placed on all State projects.

The structure has given satisfactory service since its construction and it is felt that the cost of replacing the old bridge has been more than justified by the increased capacity and improved appearance of the new structure.

A resume of the material presented in this paper will show that the responsibility of the bridge engineer and designer is no small matter. As has been repeatedly pointed out throughout this paper the problem of the bridge engineer is that of providing a safe structure that is the most economical under the conditions peculiar to a particular structure. The engineer must be able to exercise his ingenuity, keep the cost to a minimum, and at the same time remain on the safe side. A good illustration of this is shown in the placing of the abutment footings at a high level and protecting them by the use of steel sheet piling. The ancient bridge builders did not have this problem to contend with. Cost was of no importance to them and they built the structure as they pleased. If it failed, they merely rebuilt it on a larger, stronger scale. The modern economic structure would not permit this type of construction. Any individual of normal intelligence could construct a safe bridge by using enough material to insure the strength; the duty of the bridge engineer is to scientifically design the same structure on an economic basis.

Location: On County Road in the village of Comstock between stations 5 plus 92.5 and 16 plus 47.0, in Section 19, Town 2 North, Range 10 West, Comstock Township, Kalamazoo County, crossing Kalamazoo River.

Description: The proposed work consists of the construction of a bridge structure and the grading and surfacing of the approaches together with incidental work and the removal of the existing structure.

The new bridge substructure consists of two reinforced concrete cantilever type abutments 18'-0" high, measured from crown of roadway to bottom of footings and 2 reinforced concrete piers 24'-0" in height, measure from crown of roadway to bottom of footing.

The new bridge superstructure consists of three 50'-0" rolled beam spans of the deck girder type, with 44'-0" clear roadway with two sidewalks, one 5'-0" in width and the other 2'-6" in width. The structure is on a 90 degree angle of crossing and 0.00% grade.

ITEMIZED BID

ITEMS OF WORK	QUANTITY	UNIT	UNIT PRICE	TOTAL
STRUCTURE				
Removal of Existing Structure		Lump Sum		
Dry Excavation	415	Cu.Yds.		
Wet Excavation	780	Cu.Yds.		
Steel Sheet Piling Left in Place	1774.5	Sq.Ft.		
Concrete Grade A Substructure	732.6	Cu.Yds.		
Concrete Grade A Superstructure	337.6	Cu.Yds.		
Cement	1616.3	Bbls.		
Steel Reinforcement	70240	Lbs.		
Structural Steel Fabrication and Erection	256042	Lbs.		
Railing	382.3	Lin.Ft.		
Field Painting Structural Steel and Railing		Lump Sum		
Rubbed Surface Finish	4452	Sq.Ft.		

ITEM OF WORK	QUANTITY	UNIT	UNIT PRICE	TOTAL
STRUCTURE - (Cont'd)				
Copper Water Stop	446	Lbs.		
1/2" Joint Filler, Soft Asphaltic Felt	36	Sq.Ft.		
1" Joint Filler, Soft Asphaltic Felt	64	Sq.Ft.		
Porous Backfill	94	Cu.Yds.		
Sodding Slopes	325	Sq.Yds.		
APPROACH GRADING				
Earth Excavation	3000	Cu.Yds.		
Gravel Base Course - 5" Compacted	2600	Sq.Yds.		
Gravel Surface Course - 3" Compacted	2600	Sq.Yds.		
4" Concrete Sidewalk	377	Sq.Ft.		
7" Concrete Sidewalk	55	Sq.Ft.		
Concrete Curb	80	Lin.Ft.		
10" Vitrified Tile in Place	106	Lin.Ft.		
Grade A Concrete	0.1	Cu.Yds.		
Inlet 2-Cover D	2	Each		
Removal of Existing C.M.P. and Head Walls		Lump Sum		
Driveway Gravel	10	Cu.Yds.		
Removal of Old Walks	418	Sq.Ft.		
Class A Seeding	0.20	Miles		
Maintaining Traffic		Lump Sum		

TOTAL OF BID $____________

SUPPLEMENTAL SPECIFICATIONS

Maintaining Traffic

Traffic shall be maintained at all times during construction operations. The contractor shall maintain traffic over the existing bridge and roadway until he has completed the west half of the structure and approach grading and surfacing sufficient to maintain 2-way traffic thereon, after which the old bridge shall be dismantled and the structure and approaches completed. The contractor shall then remove the existing bridge and substructure and complete the east half of the structure and approach grading and maintain traffic over the west half of the bridge and roadway. The lump sum item for maintaining traffic shall include the construction of a temporary guard rail on the structure and approaches, complying with the requirements of section 5.03.04 in so far as applicable.

Cofferdams

All cofferdams for the structure shall meet the requirements of Section 5.05 of the Standard Specifications except as follows: No payment will be made to the Contractor for "Cofferdams" as such, but the cost thereof shall be included in the prices submitted by him for the various items of work under this contract.

Removal of Existing Structure

A lump sum bid for the removal of existing structure shall include removal of trusses and floor system, and the substructure to 3' below existing ground line or finished slopes as called for on the plans and any portion thereof that comes within the limits of the construction of the new substructure. Broken concrete shall be disposed of as riprap as directed by the Kalamazoo County Road Commission. The existing trusses and floor system shall become the property of the Contractor and shall be completely removed from the site at the completion of the job.

Forms

In the event that wood liners are used for face forms, backing may be of lumber not less than 3/4" actual thickness, laid without openings and with true and uniform surface on the side to which liners are applied. Studs shall be spaced not more than sixteen times the actual thickness of backing.

Floated Surface Finish

After striking, bridge seats shall be finished with a wooden float to a smooth even surface without any unevenness of more than 1/8 inch showing under a ten foot straight edge or more than 1/16 inch under any bearing plate.

The surface of the floor slab which will be subject to highway traffic shall be finished as specified for Surface Courses and Pavement, Article 4.01.03 (p and q) of the Standard Specifications in so far as applicable. The Contractor shall furnish a 10 foot straight edge for the purpose of testing surfaces thus finished. Tops of walks shall be finished as specified under Article 7.07.03 (h) of the Standard Specifications in so far as applicable.

Structural Steel

The requirements for Mill inspection is hereby waived. Shop inspection will be required and will be paid for by the Kalamazoo County Road Commission. The Contractor will be notified of inspection arrangements immediately upon receipt of information from him as to source of materials.

Railing

The superstructure railing will be measured in lineal feet and will be paid for at the contract unit price per lineal foot, exclusive of cement and steel reinforcement, but inclusive of structural steel, concrete and surface finish.

Rubbed Surface Finish

Rubbed Surface Finish shall be in accordance with Article 5.10.03 (h) of the Standard Specifications except as follows: In lines 12 and 14 of the first paragraph, change 1 foot to 2 feet.

Shop Painting of Structural Steel

The first and second paragraphs of Article 5.13.03 (g) 5 of the Standard Specifications shall be superseded by the following: All paint for shop coat shall be Michigan State Highway Department Painting Mixture No. 1.

When fabrication is complete and the work has been accepted, all steel shall be given one complete coat of paint.

Field Painting of Structural Steel and Railing

The fourth paragraph of Article 5.13.03 (g) 6 of the Standard Specifications shall read as follows: Surfaces to be riveted in contact shall not be painted. Surfaces which will be inaccessible after erection, except surfaces to be in contact with concrete, shall be painted with such field coats as are called for on the plans or authorized.

After the completion of all concrete work which is supported by steel work, all exposed surfaces shall be thoroughly cleaned and the Contractor shall apply one complete coat of Painting Mixtures No. 2 and 5A to the steel of the new structure, including the railing. All paint is to be furnished by the Contractor.

The lump sum bid for "Field Painting-Structural Steel" shall be payment in full for all items of cost necessary to complete the work as specified.

Handpicking of Coarse Aggregates

Coarse Aggregates for railing posts shall be handpicked of objectionable particles to the satisfaction of the Engineer. No additional payment will be made for this work and cost of same shall be included in contract unit price bid for Railing.

Earth Excavation

This work consists of all excavation, other than foundation excavation necessary to complete the approaches as called for on the plans, or as otherwise directed by the Engineer. All work shall be done in accordance with the provisions of the Division 2 of the Standard Specifications except as follows: The Contractor shall secure his own borrow pit, or borrow pits and right of way for obtaining same, and no allowance will be made for overhaul in connection with this classification of work. Borrow pits can be secured approximately one-half mile from the job site.

Rounding Slopes

Where trees or other restrictions do not interfere, the top of backslopes and the bottom of fill slopes shall be rounded on a vertical curve varying from four foot in length in case of cuts or fills less than four foot to an approximate maximum of ten feet in length in case of cuts or fills greater than sixteen feet. All transitions in length of vertical curves shall be gradual and so executed as to present a uniform and attractive appearance.

Guard Rail

The placing and furnishing of cable guard rail is not a part of this contract. All cable guard rail as called for on the plans will be furnished and placed by the Kalamazoo County Road Commission on the completion of this contract.

Public Utilities

All public utilities interfering with the work will be moved by others.

Removal of Existing Guard Rail

The cable guard rail at the ends of existing bridge shall be removed by the Contractor and stored at the job site for salvage by the Kalamazoo County Road Commission, and the costs thereof shall be included in the lump sum bid for removal of existing structure.

Removal of Rubbish

The Contractor shall remove all rubbish at the south end of the proposed structure prior to making the approach grade and shall be considered as incidental to the items of work as specified in the itemized bid.

Right of Way

The right of way required for this project has been secured as shown on the plans.

Steel Sheeting Left in Place

Sheet piling left in place as specified on the plans may be used sheeting in good condition. It shall be of the interlocking type and of a section weighing not less than 22.0 lbs. per square foot. It shall be driven to the depths below bottom of footing as shown on the plans and with tops driven to or cut off at the elevation specified.

Removal of Wood Piling in River

The Contractor shall cut off at bed of stream and pull all old wood piling under existing bridge and in abandoned railroad trestle immediately west of the existing structure, and the cost of cutting off or removing the piling shall be considered as incidental to the items of "Removal of Existing Structure" as specified in the "Itemized Bid".

Progress Schedule

The progress schedule shall provide for the completion of the following units:

Substructure, West half, July 15, 1939.

Superstructure, West half, August 1, 1939, including traffic provision.

Substructure complete, September 15, 1939.

Job complete including approach grading and surfacing, November 1, 1939.

Shrubbery

Shrubbery interfering with or in the way of approach fill slopes at the Northeast quadrant shall be removed and reset in a satisfactory manner and any losses shall be replaced with good live stock of the same variety. Such work shall be considered as included in the price bid for "Earth Excavation".

ENGINEERS ESTIMATE OF COST

Bridge File No. B1 of 39-5-21 Date February 23, 1939
Location In the Village of Comstock Kalamazoo County

Overall Length 150'-0" Roadway 44'-0" Spans 3 @ 50'-0"
Overall Width 53'-11" Walks 1 @ 2'-6" & 1 @5'-0" Grade 0.0%
Angle of Crossing 90° Type of Superstructure Steel Girder
Type of Abutments Cantilever Height 18'-0"
Type of Piers Concrete Height 24'-0"

STRUCTURE

Removal of Existing Structure - Lump Sum	$ 1,000.00
Dry Excavation - 415 Cu.Yds. @ .50	207.50
Wet Excavation - 780 Cu.Yds. @ 3.00	2,340.00
Steel Sheet Piling Left in Place - 1774.5 Sq.Ft. @ .80	1,419.60
Concrete Grade A Substructure - 732.6 Cu.Yds. @ 16.00 includes cofferdam and pumping	11,721.60
Concrete Grade A Superstructure - 337.6 Cu.Yds. @ 12.00	4,051.20
Cement - 1616.3 Bbls. @ 2.00	3,232.60
Steel Reinforcement - 70,240 Lbs. @ .04	2,809.60
Structural Steel - Fabrication and Erection - 256,042 Lbs. @ .045	11,621.89
Railing - 382.3 Lin.Ft. @ 5.00	1,911.50
Field Painting Structural Steel and Railing - Lump Sum	600.00
Rubbed Surface Finish - 4452 Sq.Ft. @ .10	445.20
Copper Water Stop - 446 Lbs. @ .40	178.40
1/2" Joint Filler - Soft Asphaltic Felt - 36 Sq.Ft. @ .50	18.00
1" Joint Filler - Soft Asphaltic Felt - 64 Sq.Ft. @ .70	44.80
Porous Backfill - 94 Cu.Yds. @ 1.00	94.00
Sodding Slopes - 325 Sq.Yds. @ .25	81.25
Structure =	$41,777.14

(Estimate Continued)

APPROACH GRADING

Earth Excavation - 3,000 Cu.Yds. @ .40	$ 1,200.00
Gravel Base Course-5" Comp. - 2,600 Sq.Yds. @ .50	1,300.00
Gravel Surface Course-3" Comp. - 2,600 Sq.Yds. @ .35	930.00
4" Concrete Sidewalk - 377 Sq.Ft. @ .20	75.40
7" Concrete Sidewalk - 55 Sq.Ft. @ .30	16.50
10" Vitrified Tile in Place - 106 Lin.Ft. @ 1.00	106.00
Concrete Grade A - 0.1 Cu.Yds. @ 20.00	2.00
Inlets - 2 each @ 65.00	130.00
Removal Existing C.M.P. and Headwalls - Lump Sum	25.00
Driveway Gravel - 10 Cu.Yds. @ 2.00	20.00
Removal Old Walks - 418 Sq.Ft. @ .10	41.80
Class A Seeding - 0.20 Miles @ 100.00	20.00
Maintaining Traffic - Lump Sum	600.00
Concrete Curb - 80 Lin.Ft. @ .80	64.00
Approach Grading =	$ 4,530.70

Total Estimated Contract	=	$ 46,307.84
Engineering and Contingencies 10%	=	4,630.78
Total Estimated Cost		$ 50,938.62

Roadway Looking North
Toward U. S. 12

Roadway Looking South
Toward Comstock

Elevation Looking Downstream

Railings

Girders and Piers Showing
Intermediate Diaphragms

Bridge Plate

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Bridges in History and Legend
Watson, Wilbur J.

Bridges
Whitney, Charles Smith

Portland Cement Bulletin

Specifications for the Design of Highway Bridges as Adopted by the Michigan State Highway Department, January 1936

Note: A great deal of the material used in this thesis has been obtained from practical experience and personal interviews with the persons mentioned in the introduction.

Pocket has:
2 Blueprints &

EST HOLE #1
STONY SANDY GRAVEL
TEST HOLE #2
TEST HOLE #3
TEST HOLE #4