Civil engineering — Hydraulic engineering

I N V E S T I G A T I O N

OF

R E I N F O R C E D   C O N C R E T E   D A M

ON THE

KALAMAZOO RIVER

AT

OTSEGO, MICH.

---oooOOOooo---

FOR

THESIS B.S.

AT

MICHIGAN STATE COLLEGE

BY

J. J. McDEVITT

J. E. WILCOX

SPRING TERM

...ooo 1927 ooo...

THESIS

INTRODUCTION

In selecting a subject for this thesis it was the intentions of the writers to follow up more extensively and in detail a line of study taught at the Michigan State College.

Reinforced concrete work seemed to satisfy these requirments and after due consideration and consultation with Professor Vedder the "Investigation of the Commonwealth Power Co's. Reinforced Concrete Dam at Corenco, Mich., was chosen as a subject.

The treatment of this subject has been divided into two parts; first, the investigation of the location and plans of the dam; and second, the determination of the stresses throughout the structure of the dam. In the first case it was desired to find out if there were engineering reasons which caused the dam to be located on its present site and in the second to find out if the construction of the dam agreed with modern engineering theory and practise.

Included in this thesis will be found a field note book of the surveys, also four blue prints as follows:

No. 1. Survey of the river and dam.

No. 2. Plan of the dam.

No. 3. A sectional view and plan of the reforming.

No. 4. Chart of the boring.

The last three supplied by Mr. Wm. Fargo, Civil Engineer of Jackson, Mich., to whom the writers are greatly indebted.

Location and Plan

Following that the best possible plan was to take instruments and make a survey of the land along the river and in the neighborhood of the dam site, a party consisting of J. J. Mc Dovitt and J. E. Wilcox, with the following equipment, a transit, level, reading rod, stakes, flag poles, and all accessories, went to Caresso, Michigan, on March 30th, 1900.

The next morning, March 31st, the work was begun on the survey. Owing to the great differences in elevation and distances involved there were only two methods practicable for obtaining the data, i. e. by triangulation and by stadia.

A five hundred foot base line was established on the north and south township line between Marshall and Emmett, to which was tied in the dam and power house by stadia and triangulation. Then it was found out that both shores could not be seen from the ends of the base line A and B, shown on blue print No. 1, or any other intermediate points owing to a curve in the river and the lay of the power house. As no other suitable base line could be obtained and only having one transit, triangulation was uneconomical and impracticable.

The next day a station "C" was established on the pier in the center of the river between the penstock and the Power House and from there the elevations and the stadia reading were taken of the shores of the upper river, with a level, while the angles were turned off at "C" from "B" with a transit.

The elevations of the shore of the river below the dam were also taken. On the day of April 21, the survey was finished by taking the measurments of the dam and power house.

In the first consideration of this subject, the question naturally arose: Why was this location selected for the site of this dam. And from the survey was found that natural conditions prevailed. For on each side of the river the banks are high and steep forming sort of a ridge which follows the river for a considerable distance up stream.

Below the dam the land is low and covered with timber, the ridges which form the river banks of the up stream, here branch off to the southwest and to the north leaving a large area of land between them. Thus making the best possible location of this dam at the neck formed by these ridges.

From the blue print No. 4 of the borings it was seen that good solid rock foundation exists at all points except for a space of thirty feet, beginning about one hundred and fifty feet from the north side. Here sheet-piling was used as shown on the blue print of the borings.

Considering the good foundation and the high banks, this spot made an ideal location for a dam.

Taking up the plans of the dam, on the south side of the river the bed follows a gentle slope downward, while on the north side the bed is quite steep. Therefore, a cove wall was built from the south shore running out into the river one hundred and fifty feet, at the end of which and parallel to the course of the river, is a large and heavy concrete wall. This wall forms the south side of the channell and tail race and acts as a retaining wall for the earthen fill which was made behind the core wall and also as a part of the foundation of the power house.

In the center of the river is a large pear shaped pier, consisting of eighteen inch concrete walls filled in with earth and stone. From the north side of this pier to the further shore lies the reinforced concrete section of the dam, with a thirty foot wall extending into the earth. This section of the dam is one hundred and eighty feet long and is composed of a three foot reinforced concrete deck slab, with a batter on the downstream side of the deck slab of three-quarters of an inch to one foot, and rests on a reinforced concrete apron, thirty-three feet wide. There are six concrete buttresses each twenty-two feet apart supporting this deck slab, then from there to the large central pier is the penstock section of the dam composed of two steel gates each twenty-four feet wide and eight feet high, with a concrete buttress three feet wide between them. Resting on these buttresses is a seven foot reinforced concrete runway or foot walk.

Between the large central pier and the north wall of the embankment are the turbines, inclosed in a reinforced concrete apron fifteen feet wide; from the upstream side of this apron is a concrete dyke wall running down to the rock, while on the downstream side is an eight inch brick wall running to the level of the side walk and backed up every ten feet and nine inches of vertical concrete columns eighteen by twenty-four inches. The bear shed is directly above this, and its dimensions are twenty-eight by sixty-four and one half feet. Adjoining this and situated on the end of the embankment is the Dynamo Room, twenty-one by forty feet.

CALCULATIONS.

Under this head will be included the description of the different parts of the dam as well as the determination of the stresses in them.

According to the Engineering News of November, 1908, this type of dam is called the Ambursen, and consists of a reinforced concrete deck slab of the ordinary gravity dam section, supported at intervals by concrete buttress.

The first thing to be considered in the construction of a dam is its foundation. From blue print number three it was found that the foundation for this type of dam is a reinforced concrete apron thirty-three feet wide and supported at each side. At the upstream side of the apron the concrete is three feet and eight inches thick for six feet, then for eight and one-half feet the thickness tapers from two feet to eighteen inches. The greatest stress comes directly under the wall where the apron is thick. Nineteen feet from the upstream face of the dam the apron drops one foot and ten inches, this necessitates an increase in the thickness of the apron at this point. The rest of the apron is one foot thick until at the end for twenty-six inches it is two feet and one-half thick. At the upstream edge of the base of the apron is a continuation of the concrete downwards till solid foundation is reached. It is twelve inches thick at the base and eighteen inches thick at the top, while on the downstream edge of the apron there are four by eight inches sheet pilings, one and one-half by one and three quarters—tongue and grove.

The Stresses.

Encountered in this apron are:- Crushing of the concrete under the weight of the wall and the load it is holding up; the crushing under the force acting plus the weight of the buttress, which are figured latter; and also the buckling of the apron. Though a dam similar to this one was mentioned in the Engineering News of November, 1908, still no methods of design or computation were shown there or in any other of the books on reinforced concrete. By examining blue print number three it was seen that a very large amount of steel reinforcing was used in the apron.

After the apron the deck slab was next considered. Owing to the fact that an earthen fill had been made on the upper side of the deck slab, it would have been hard to determine the pressure transferred through the earth, but by taking the pressure of the water directly against the wall a safe method is attained. Because the direct pressure is greater than that transferred through the earthen fill.

Computing the pressure on the face of the dam, $P = F \bar{z} y$ which equals 3670# per linear foot, less a force of $P = F'z'y = 500$# which is held by four foot of boards above the deck slab, but these boards are supported by three I-Beams which are imbedded in the concrete deck slab.

This gives a uniform loading of 3170# per linear foot and three concentrated loads of 2200# at five feet out from each buttress and a load of 2225# at the center of the slab. The maximum moment due to the uniform loading equal $\frac{1}{8}$ W l or 168,000 ft. lbs. While the concentrated loads cause a maximum moment of 20,000 ft. lbs. or a total of 188,000 ft. lbs. or 2,270,000 inch lbs. But the practice is to add 50 or 100% for impact of ice and drift. Using 100% and adding to 2,250,000 gives 4,400,000 in. lbs. for the Maximum Moment. This is applied under the load in the center of the span.

The reinforcing bars are three-fourths of an inch square and are twenty-one in number, making the total area of steel 11.81 sq. in.

The theory of the reinforced concrete beam used is taken from Church's Mechanics, Chapter V on Reinforced Concrete Beams, page 332. It is that a composite beam can be formed of concrete by imbedding steel in the side of the beam that is to take tension and this beam is cheaper than a beam of equal strength composed entirely of concrete or one composed entirely of steel. The area of the steel to the area of concrete is given by Church as one percent. It has been worked out by Thacker in the book on Reinforced Concrete by Buel and Hill that with proportions of 1:2:4 concrete and six months old, that area of steel is to area of concrete as one to one hundred.

In such beams the steel takes all the tension stress and the concrete above the neutral axis, the compression, so it becomes necessary to find out the distance the neutral axis is from the top.

F'p' = total tensile stress and F' the area of the steel and p' the unit stress in the steel rods. p is the unit compression stress in the fibre of the concrete at the only fibre. Now again where the steel rods are elongated a distance and the concrete fibre has been shortened an amount d t so that d t : d t' :: e : h-e.

But for the Free Body method of taking the beam

$$\frac{z}{e}\, p\, d\, F - F'\, p' = 0 \qquad \text{Put } \frac{p}{e} = \text{a constant and } dF = b\, d\, z$$

and $p\, b/e \quad \int z\, d\, z = pb/e \cdot e^2/2$ Therefore $\frac{pbe}{2} = F'p'$

Again $\quad E = \frac{p}{\text{relative elongation}} \quad \& \; E' = \frac{p'}{d\, t / dx}$

Then $d\, t \div d\, t' = p\, E' \times p'E$ - equation

$$e \div h-e = p\, E'\, \div\, p'E \quad \text{where } N \div E \div E' = 20$$

Then

$$e = \frac{F'n}{b}\left(\sqrt{\frac{2\, bh}{F'n} + 1} \;\; - 1\right)$$

$$= \frac{11.21 \times 20}{3.035 \times 12}\left(\sqrt{\frac{2 \times 2.73' \times 12 \times 3.035 \times 12}{11.21 \times 20} + 1} \;\; - 1\right)$$

$$e = 11.05''$$

Having located the neutral axis and returning to the free body, it is seen that the resultant compression in the concrete between the upper surface of the deck-slab and the neutral axis is 1/2 pxbe lbs. and is equal to the total tension F'p lbs., in the steel rods at that section, and that these forces are parallel. Consequently they form a couple whose Moment is equal to the product of one of these forces, say F'p, by the perpendicular distance, a", between the steel and the center of pressure of the concrete above the neutral axis.

For equilibrium the shear I and the two forces, V the reaction and P, the load, must be an equal and opposite moment to that of the stress couple. Call this moment M, it is the bending moment of the section at the center and is equal to, $M = Rx - P.(x-x_1)$ where R = reaction x distance out to section and x_1 distance out to load. P, being the concentrated load. M = 4,460,000# which is the larger and which will be used.

Therefore $M = F'p'\left(a - \frac{1}{3}e\right)$ or $p' = \dfrac{M}{F'\left(a - \frac{1}{3}e\right)}$

Substituting the values in this equation and get p' equal to 13,195# which shows that a factor of safety of 64,000# ÷ 13.195 = 4.87 was used or which is more likely that in the design of this dam that a factor of safety of five was used.

But since the resultant compression $\frac{1}{2}$ p. b e, is equal to the resultant tension F'p', then $M = \frac{1}{2}p.be\left(a - \frac{1}{3}e\right)$ and therefore $p = \dfrac{2M}{be\left(a - \frac{1}{3}e\right)}$. Substituting in this equation the values, p = 341# per sq. in. which is the unit crushing stress and is within the limits of 700 lbs. per sq. in. and gives an additional factor of safety of 2.05.

Horizontal Shear in this case is along the base and the two ends but since this deck-slab was used as supported only at each end, the shear will be figured on the ends and if it holds then it is safe to assume the whole slab to hold. But first the horizontal shearing stress will be determined for any section along the reinforcing steel bars, as follows: Taking any differential section dx, along the beam as a free body. The forces acting consist of the tension F'p" on the left-hand of the steel, the tension on the right hand end of these rods:

the resultant compression being 1/2 be$_1$p, in concrete on the left; and that, 1/2 be(p+dp) on the right; and, finally, the two vertical shears, J and J'. Here p is the unit compression stress in (lb. per sq. in.) in the outer fiber of concrete at the left hand extremity of this section, while p+dp expresses the unit compressive stress in the same outer fiber compressive at the right hand section.

Evidently the difference between the total tensile stresses at the extremities of the steel rods will give the total horizontal shearing stress on the sides of those rods and this may be written $p_s' l_o$ d x(lbs). Where p's equal unit shearing stress between the steel and the concrete, and l_o = the aggregate perimeter of the steel rods (and lodx the total area of the outside surface of rods in this section we took of length dx.)

Then $p's\ l_o\ dx = F'(p'+dp') - F'p'$

But if, for the free body Σ mon. = 0 about the point G, which is the point of application of the center of pressure of the concrete above the neutral axis and is a distance 1/3e from the upper fiber, then

$$Jdx = \left[F'\ (p+dp') - F'p\right]\ (a-1/3e)$$

or $p'_s = J \div lo\ (a-1/3e)$ and substituting we get

J= 37,750#; a = 32.4"; e = 11.05" ;

F'= 11.81□"; l_o = 63"

and p's = 20.3 lbs. per sq. in. unit shearing stress between steel and concrete and is within the allowable stress of 64 lbs. per sq. in. with a factor of safety of three.

Showing the shearing stress across section, say at the piers, let ps denote the unit shearing stress or tendency to slide along the horizontal surface, the total amount is psbdx. Σ hor. comp. = 0 we find F'(p+dp') − F'p' = psbdx. or that $ps = \frac{J}{b(s-1/3s)}$ = 15 lbs. per sq. in. which gives a factor of safety of four.

Investigating the piers that hold up these deckslabs, to see if they are safe for crushing, then the apron under them which is strongly reinforced is also safe for crushing. Also the pier must be safe against overturning.

The dimensions of the six uniform piers are, width eighteen inches, height fourteen and one-half feet to top of runway from top of apron, and seven feet long for the upper seven and sixty-seven hundredth feet and sloping from there to eighteen feet along at the base. The total weight of the buttress at one hundred and fifty lbs. for concrete, = 31,500 lbs. Added to this is the weight of the runway and railing slabs and resting on the buttress which amounts to 15,500 lbs. per section, making a total weight of 47,000 lbs. on each buttress. The force of the water acting on the buttress is 20,710 lbs. acting one third the distance up or 3.31 ft. making an overturning moment of [illegible],000 lbs. and the resisting moment is 300,000 lbs. Therefore the buttress is safe against overturning.

The resultant of these forces passes through the middle third and close to ten ft. from the toe of the buttress giving a surface of 10 ft. by 1-1/2 ft. or 15 sq. ft. bearing surface. The crushing strength of concrete is 50,000 lbs. per sq. ft. so that 50,000 x 15 = 750,000 lbs. which is safe for these buttresses.

Therefore the buttresses are safe against crushing and overturning and it is unnecessary to figure shearing as we figured the same pressure over on a smaller amount of concrete.

In Purl and Hills' book on Reinforced Concrete, there are empirical formulas worked out by Thacker and on substituting in these formulas, as the amount of steel required was found to be 12.5 sq. in. for a beam eighty-two inches wide, and d, the depth was figured to be twenty-two inches.

The deck slab of this dam, which is the beam under consideration, is thirty-twp inches deep and has 11.81 sq. in. of steel. This gave a deficiency of .7 sq. in. of steel and a surplus of 820 sq. in. of concrete. This shows the beam to be strong enough.

Conclusion.

In the matter of reinforced concrete work it was found that a great deal has been written but very few formulas derived and those that there are, differ greatly. The formulas from Church's Mechanics were used on account of their simplicity and clearness.

These formulas gave very good results throughout, showing that this dam followed close to the theory advanced by Church.

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