COMPARATIVE DESIGNS OF GRAVITY AND AMBURSEN DAMS

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COMPARATIVE DESIGNS OF GRAVITY AND AMBURSEN DAMS

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FOREWORD

The writers wish to express their thanks to Prof. W. A. Reinert for his suggestions and assistance in the computation of the following work.

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DAM SITE

The site is located at Bow Fort Falls, on the Bow River in the province of Alberta, Canada. This is 15 miles west of the present Ghost Site and 44 miles from the town of Calgary. Bow fort Creek empties into the river about a half a mile above the site and the perpendicular rock cliffs between these two points are about 50 feet high and 385 feet from side to side.

The proposal of hydraulic development at this location was the subject of a thesis written by Mr. W. J. Wignall in 1920. From that thesis was obtained nearly all of the data used in the following designs. The proposed head on the dam is 66 feet and the crest height designed for is 15 feet. To obtain this proposed head continuously a pondage area of 205.2 acres is created in back of the dam. None of the land at the elevation of the pondage surface is at present occupied, nor is it used for agricultural purposes.

The temperature in the drainage area is one of the great factors influencing the discharge of the river, the discharge varying almost directly with the temperature.
The minimum temperature and discharge occur in January, registering -36 degrees and 600 second feet respectively. The maximums occur in July, being 86 degrees and 50,000 second feet. The extreme low water period occurs during January and February, and the first floods appear about May 15th and last through July.

Because of the low temperatures encountered, extreme ice conditions are to be expected and provided for. However, it is anticipated that on account of the depth of the river, sheet ice only will be formed and this will prevent the formation of both fragile and anchor ice.

The general characteristics of the rock at Bow Fort give the impression that there was a fall in the river here at one time the cliff having been cut back until all that remains is a slight drop which entirely disappears at high water. The cause of this drop is a ledge of shale banded with limestone extending across the river: and it is upon this ledge that it has been proposed to place the dam. The shale is of a hard character and is considered capable of a bearing pressure of 8 tons per square foot.

It is recommended that in order to obviate any leakage that might develop through the underlying seams, three inch holes be drilled through
the rock about 2 feet in front of the heel of the
dam, 10 feet apart, and to a depth of 40 feet, and
a thin cement grout forced into them under pressure.
It is also desirable that such drills be made in all
excavation pits which are to accomodate buttress
walls and cut off walls of the proposed reinforced
concrete dam.

The spillway elevation is given as 4010 and
that of the bulkhead as 4030. The riverbed has an
elevation of 3944. The spillway has a length of 250
feet, while the two bulkhead sections have lengths
of 95 feet and 80 feet respectively. The 95 foot length
terminates in a core wall at the river bank while
the 85 foot length terminates in a wing wall, on
the other side of which are located the intakes to
the turbines. These intakes are set flush with the
face of the dam in a bulkhead section of 175 feet
in length which terminates in a core wall at the
river bank similar to the opposite bulkhead section.

The design of the wing walls, abutments, and
intakes is not attempted herein, as it is the author's
desire to present only a comparison of the two types
of dams for this particular dam site.
The proposed plant is one which consists of three units of 500 sec. ft. each, with provision for the installation of two (2) or three (3) additional units, as rapidly as further storage possibilities are worked out.

The power house is to be located 210' down stream from the dam the water being conducted by the three (3), 9' proposed riveted steel penstocks. The power equipment would consist of three (3) Francis turbines set horizontally, of 4400 horsepower each, with 2500 K.W. generators mounted on the shaft.

The tail water elevation will be 3942 and the tail race is to be protected from disturbance by a wing retaining wall running 40' down stream from the power house.

The locations of the power house, gate house, and sluice gates are chosen arbitrarily. They are subject to change upon a more intimate knowledge of the site.

The depths of cut-off walls and footings are also subject to change as the knowledge of actual condition of the river bed is slight. It is impossible to estimate earth excavation in the following:

-4-
NOTATION

The following notation will be observed:

\( f_s \) = tensile unit stress in steel
\( f_c \) = compressive unit stress in concrete
\( M \) = moment of resistance or bending moment in general.
\( A \) = steel area.
\( b \) = breadth of beam or unit width of slab
\( d \) = depth of beam to center of steel.
\( D \) = total depth of beam,
\( k \) = ratio of depth of neutral axis to depth "\( d \)"
\( j \) = ratio of lever arm of resisting couple to depth "\( d \)".
\( p \) = steel ratio = \( \frac{A}{bd} \)
\( V \) = total shear
\( v \) = shearing unit stress, taken as 120 \#/ sq. in.
\( u \) = bond stress per unit area of bar, taken as 100 \# per sq. in.
\( S_o \) = sum of the perimeters of all bars,
\( s \) = horizontal spacing of reinforcing members.
\("l"\) = span of slab in feet.
\( W \) = load in pounds per square foot.
DESIGN

The velocity of approach is figured by assuming that under extreme flood conditions 50000 second feet will pass over the spillway and limited say to an area of 3750 square feet which is obtained from the 250 foot length of spillway and the allowable 15 foot crest height. This gives a velocity of approach of 13.35 feet per second which will probably never be encountered because of the depth of the stream etc.

The spillway is parabolic in shape down to a level 21 feet from the top. The shape is determined from an approximate equation

\[ x^2 = 1.78 \, yh \]

where \( h \) = height of water over the crest of the dam, \( x \) = horizontal abscissae of curve, \( y \) = vertical ordinates of curve.

The height of water in this case because the velocity of approach is over 4 feet per second is found from,

\[ h_1 = h + \frac{V_a}{2g} \left( 0.25(h)^{\frac{3}{2}} + V_a \right) \]

where \( V_a \) is the velocity of approach, and \( h_1 \) the new crest height.

\[ h_1 = 15 + \frac{13.35}{64.4} \left( 0.25 \times 3.88 + 13.35 \right) = 17.975' \]
\[ x^2 = 1.78 \times 17.975y = 32.0y \]

\[ x = 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \]
\[ y = 0.631 \quad 0.125 \quad 0.281 \quad 0.500 \quad 0.78 \quad 1.13 \quad 1.53 \]

\[ x = 8 \quad 9 \quad 10 \quad 11 \quad 12 \quad 13 \]
\[ y = 2.00 \quad 2.53 \quad 3.12 \quad 3.68 \quad 4.50 \quad 5.25 \]

\[ x = 14 \quad 15 \quad 16 \quad 17 \quad 18 \quad 19 \]
\[ y = 6.11 \quad 7.01 \quad 7.98 \quad 9.01 \quad 10.10 \quad 11.28 \]

\[ x = 20 \quad 21 \quad 22 \quad 23 \quad 24 \quad 25 \]
\[ y = 12.50 \quad 13.75 \quad 1.51 \quad 16.50 \quad 18.00 \quad 19.50 \]

\[ x = 26 \quad 27 \]
\[ y = 21.5 \quad 22.75. \]

The spillway slab is then straight until it intersects the curve of the toe which is curved with a radius of \( H/2 \) or \( 33' \).

The deck slab was first figured as an inclined slab supported on parallel buttresses. The angle of inclination, \( \theta \), was taken at \( 48^\circ \) and the distance center to center of buttresses as 20 feet. The thicknesses of slab were determined for pressures at vertical intervals of 10 feet. In the following designs \( f_c \) is taken as 500 and \( f_s \) as 16000. Where possible a balanced steel ratio is obtained, \( p \) being found as in "Lyndon's Hydro-Electric Power," Vol. 1.
The load on the top of the dam is 15 x 62.5 = 940 lb. Required thickness of slab for load, neglecting weight of slab is:

\[ d_t = 18.5 \left( \frac{1143 \times 940}{.00595 \times 16000} \right)^{\frac{1}{3}} = 19.7'' \]

Assume a slab of 24''. Wt. = 300#/sq.ft.

Component of wt. normal to deck is:

\[ W = 300 \times \sin \theta = 300 \times .743 = 223 \text{ lb} \]

\[ d_t = 18.5 \left( \frac{1143 \times 1163}{.00595 \times 16000} \right)^{\frac{1}{3}} = 22'' \]

Width of slab:

\[ A = \frac{pb \Delta}{.00595 \times 12 \times 22} = 1.57 \text{ sq. in./ft.} \]

1st 10' Section.

\[ P = (10 + 15) \times 62.5 = 1570 \text{ lb} \]

For load only:

\[ d_{10} = 18.5 \left( \frac{1143 \times 1570}{.00595 \times 16000} \right)^{\frac{1}{3}} = 25.4'' \]

Assume 30''.

\[ W = 30/12 \times 150 = 376 \text{ lb} \]

Normal component = 280 lb

\[ W = 1570 + 280 = 1850 \text{ lb} \]

\[ d_{10} = 18.5 \left( \frac{1143 \times 1850}{.00595 \times 16000} \right)^{\frac{1}{3}} = 27.8'' \]

\[ D_{10} = 30'' \]

Assume 35''.

\[ W = 30/12 \times 150 = 440 \text{ lb} \]

Normal component = 326 lb

\[ W = 326 + 2190 = 2516 \text{ lb} \]

\[ d_{20} = 18.5 \left( \frac{1143 \times 2516}{.00595 \times 16000} \right)^{\frac{1}{3}} = 35'' \]
32.3" \( D_20 = 35" \)

3rd 10' section

\[ P = (30+15) \times 62.5 = 2820\# \] For load only \( d_{30} = 18.5 \left( \frac{1143 \times 2820}{0.00595 \times 16000} \right)^{\frac{1}{3}} = 34" \) Assume 38" Wt. = \( \frac{38 \times 150}{12} = 475\# \) Normal component = 354\# W = 354 + 2820 = 3174\#

\[ d_{30} = 18.5 \left( \frac{1143 \times 3174}{0.00595 \times 16000} \right)^{\frac{1}{3}} = 36.1" \] \( D_{20} = 38" \)

For shear \( D_{30} = \frac{wl}{1440} = \frac{3174 \times 18.5}{1440} = 40.5" \) Make \( D_{30} = 40" \)

4th 10' section

\[ P = (40+15) \times 62.5 = 3440\# \] Shear for load only = 3440 \times 18.5/1440 = 44.2 Assume 48" Wt. = \( \frac{48 \times 150}{12} = 600\# \) Normal component = 446\# W = 446 + 3340 = 3786\#

\[ D_{40} = 3786 \times 18.5/1440 = 48" \] Take \( D_{40} \) as 48"

5th 10' section

\[ P = (50+10) \times 62.5 = 3750\# \] Shear for load only = 3750 \times 18.5/1440 = 48.2 Assume 55" Wt. = \( \frac{55 \times 150}{12} = 686\# \) Normal component = 510\# W = 510

\[ D_{50} = 4260 \times 18.5/1440 = 55" \] Take \( D_{50} \) as 55"

6th 10' section

\[ P = (60+15) \times 62.5 = 4700\# \] Shear for load only = 4700 \times 18.5/1440 = 60.5" Assume 68" Wt. = \( \frac{68 \times 150}{12} = 850\# \) Normal component = 632\# W = 632 + 4700 = 5332\#

\[ D_{60} = 5332 \times 18.5/1440 = 68.2" \] Take \( D_{60} \) as 68".
Base-level section

\[ P = (66+15) \times 62.5 = 5060 \] Shear for load only = 5060 x 18.5/1440 = 65" Assume a slab of 74" Wt. = 74/12 x 150 = 925# Normal component = 690# W. = 690 + 5060 = 5750# \[ D_{66} = 5750 \times 18.5/1440 = 74" \]

Take \( D_{66} \) as 74" \[ A = M/j \text{ and } f_s = 1.2 \times 5750 \times (18.5)^2 = .87 \times 75 \times 16000 = 2.28 \text{ sq.}" 

Use 7/8" rd. rods spaced 3" c.-c.

In computing the steel for the 10' through the 60' sections it was found that 7/8" rd. rods spaced 3" c.-c., with the exception of a 3\( \frac{1}{2} \)" spacing in the 10' section, were necessary.

The above design provides for a slab whose thickness is too great for practical use. Some other design must be made in order that an economical structure may be obtained.

When 6' corbels are placed on each buttress, the clear space between buttresses, used as "1" in the thickness formula, becomes 14! This reduces the thicknesses of the slab to one which varies from 18" at the top to 56" at the bottom for approximately the same steel content. However the difficult character of the form work in-
volved reduces the saving realized in the deck slab to a small amount so that the design is not considered acceptable in this case.

Another method of supporting the deck slab is by the use of longitudinal walls. These intersect the transverse walls or buttresses at right angles, thus forming square or rectangular openings at the slab and permitting the use of reinforcing steel in two directions. Because of the difficulties which would be encountered, the increased cost, and the northern location of the site, this method was not investigated.

However the reinforcing of the slab in two directions was accomplished by the use of longitudinal beams of rectangular shape. The openings at the slab were made square, thus simplifying both calculations and construction. In the following designs it is kept in mind that the fewer the number of buttress walls, the more economical and rapid will be the progress of the work. The distance between centers of the buttresses and the beams is limited however by that distance at which the deck slab becomes excessively thick.
A design was made in which the beams and buttresses were considered as 20' on centers. The slab thickness was determined at each beam. It was decided that in the succeeding works, "1" would be considered as the distance center to center of beams or buttresses rather than the clear space between them. It is believed that a design which more fully represents true conditions will result. The vertical intervals at which the pressures are figured are:

\[ 20 \times \cos \Theta = 20 \times 0.669 = 13.38' \]

It may be well to state here that expansion joints are considered at every other buttress so that the slab acts as a beam partly simple and partly continuous. M is taken at 1.2 Wl. This accounts for the constant .1143 in the thickness formula.

At 1st beam:

\[ P = 15 \times 62.5 = 940'\# \quad W = 940/2 = 470'\# \]

For load only

\[ d = 20 \left( \frac{0.1143 \times 470}{2} \right)^{\frac{1}{2}} = 15" \]

Assume 18" Wt. = 18/12 x .00595 x 16000

150 = 225'# Normal component = 167'# \[ W - (167+940)/2 = 554'\# \]

In the following formula the term .1143/(.00595 x 16000) = .0012. Therefore \[ d = "1" \left( .0012 \times W \right)^{\frac{1}{2}} \]

\[ d = 20 \left( .0012 \times 554 \right)^{\frac{1}{2}} = 16.3 \]

" Take D = 18" A = 12 x 16.3 x .00595 = 1.16 sq." Use 7/8" rd. rods -6" c.-c.
At 2nd beam

\[ P = (15 + 13.38) \times 62.5 = 1780 \# \quad W = 1780/2 = 890\# \]

For load only \( d = 20(0.0012 \times 890)^{1/3} = 20.8\" \) Assume

\[ D = 24\" \quad W_{t} = 24/12 \times 150 = 300\# \quad \text{Normal component} = 223\# \]

\[ W = (223 + 1780)/2 = 1000\# \quad d = 20(0.0012 \times 1000)^{1/3} = 22\" \]

Take \( D \) as 24"

\[ A = 12 \times 22 \times 0.00595 = 1.57 \text{ sq.\"} \]

Use 7/8" rd. rods - 4 1/2" c. to c.

At 3rd beam

\[ P = (15 + 26.67) \times 62.5 = 2610\# \quad W = 2610/2 = 1305\# \]

For load only \( d = 20(0.0012 \times 1305)^{1/3} = 25.2\" \) D for shear = \( W_{t}/2160 \)

for slabs supported on four sides.

\[ D = 2610 \times 20/2160 = 23.2\" \]

Assume 28"

\[ W_{t} = 30/12 \times 150 = 350\# \quad \text{Normal component} = 260\# \]

\[ W = (260 + 2610)/2 = 1435\# \quad d = 20(0.0012 \times 1435)^{1/3} = 26.3\" \]

Take \( D \) as 28"

\[ A = 12 \times 26.3 \times 0.00595 = 1.88 \text{ sq.\"} \]

Use 7/8" rd rods 3 1/2" c. - c.

At 4th beam

\[ P = (15 + 40.05) \times 62.5 = 3440\# \quad W \text{ for shear} = 3440\# \quad W \text{ for bending moment} = 3440/2 = 1720\# \]

\[ d = 20(0.0012 \times 1720)^{1/3} = 29\" \]

\[ D = 3440 \times 20/2160 = 31.8\" \]

Shear begins to govern here so that the greater thickness obtained is the one adopted.

Assume 35"

\[ W_{t} = 35/12 \times 150 = 438\# \quad \text{Normal component} = 325\# \]

\[ W = 325 + 3440 = 3765\# \]

\[ D = 3765 \times 20/2160 = 34.9\" \]

Take \( D \) as 35"

\[ A = 1.2 \times 3765 \times (20)^{2} 
\times 87 \times 33 \times 16000 \]

= 3.93 sq.\" total or 1.97 sq.\" each way.

Use 7/8" rd. rods - 3 1/2" c. - c.
At 5th beam

\[ P = (15 + 53.45) \times 62.5 = 4270 \text{#} \]
\[ D = \frac{4270 \times 20}{2160} = 39.5" \]
Assume 44" Wt. = \( \frac{44}{12} \times 150 = 550 \text{#} \)

Normal component = 410# \( W = 410 + 4270 = 4680 \text{#} \)
\[ D = \frac{4680 \times 20}{2160} = 43.5" \text{ Take D as 44"} \]
\[ A = \frac{1.2 \times 4680 \times 20 \times 20}{.87 \times 42 \times 16000} = 3.84 \text{ sq. in or } 1.92 \text{ sq."} \]
each way. Use 7/8" rd. rods 3\( \frac{1}{2} \) c. - c.

Base level section

\[ P = 5060\# \text{ D} = \frac{5060 \times 20}{2160} = 47" \]
Assume 52" Wt. = \( \frac{52}{12} \times 150 = 650 \text{#} \)
Normal component = 482# \( W = 482 + 5060 = 5542 \text{#} \)
\[ D = \frac{5542 \times 20}{2160} = 51.4" \text{ Take D as 52"} \]
\[ A = \frac{1.2 \times 5542 \times 20 \times 20}{.87 \times 50 \times 16000} = 3.82 \text{ sq. " or } 1.91 \text{ sq. "} \]
each way. Use 7/8" rd. rods - 3\( \frac{1}{2} \)" c.-c.

The distance center to center of buttresses was reduced to 18 feet and the slab re-designed.
Vertical distance for figuring pressures is 18x .669=12'

At 1st beam

\[ P = 940\# \text{ W} = 470\# \text{ For load only } d = 18(0.0012 \times 470)^{\frac{1}{2}} = 13.5" \]
Assume 18" Wt. = \( \frac{18}{12} \times 150 = 225\text{#} \)
Normal component = 167# \( W = (167 + 940)/2 = 554\text{#} \)
\[ d = 18(0.0012 \times 554)^{\frac{1}{2}} = 14.7" \text{ Take D as 18", } d_t \text{ as 16", and } d_6 \text{ as 15.13"} \]
\[ A = 12 \times 16 \times 0.00595 = 1.15 \text{ sq."} \]
Use 7/8" rd. rods-6" c.-c. \( f_c = 2M/ jkb \text{d}^2 \)
Values of $j$ and $k$ obtained from curves in "Useful Data" Handbook.

Transverse $f_c = \frac{2 \times 1.2 \times 554 \times 18 \times 18}{.89 \times .34 \times 12 \times 15.13 \times 15.13} = 519$

Longitudinal $f_c = \frac{2 \times 1.2 \times 554 \times 18 \times 18}{.89 \times .34 \times 12 \times 16 \times 16} = 465$

At 2nd beam

$P = (15 + 12) \times 62.5 = 1690\#$  
$W = 845\#$

$d = 18 \times (0.0012 \times 845)^{1/3} = 18.2"$ Assume 22"  
Wt. =  

\[ \frac{22}{12} \times 150 = 276\# \quad \text{Normal component} = 205\# \quad W = (205 + 1690)/2 = 948\# \quad d = 18 \times (0.0012 \times 948)^{1/3} = 19.25" \]

Take $D$ as 22", $d_\perp$ as 20", and $d_t$ as 19.13"  

At 3rd beam

$P = (15 + 24) \times 62.5 = 2440\#$  
$W = 1220\#$

$d = 18 \times (0.0012 \times 1220)^{1/3} = 20.8"$ Assume 26" slab  
Wt. = $\frac{26}{12} \times 150 = 325\#$  

Normal component = 242\#  
$W = (242 + 2440)/2 = 1341\#$  
$d = 18 \times (0.0012 \times 1341)^{1/3} = 23.0"$ Take $D$ as 26", $d_t$ as 23.13", and $d_\perp$ as 24"  

$A = 12 \times 24 \times .00595 = 1.72\text{ sq."}$ Use 7/8" rd. rods 4" c.-c.
Transverse \( f_c = \frac{2 \times 1.2 \times 1341 \times 18 \times 18}{.89 \times .34 \times 12 \times 23.13 \times 23.13} = 534 \)

Longitudinal \( f_c = \frac{2 \times 1.2 \times 1341 \times 18 \times 18}{.89 \times .34 \times 12 \times 24 \times 24} = 498 \)

At 4th beam

\( P = (15 + 36) 62.5 = 3200\# \quad W = 1600\# \quad d = 18(0.0012 \times 1600) = 25" \) Assume 29". Wt. = 29/12 x 150 = 362#. Normal component = 270#. W = 270 + 3200 = 3470#. D = 3470 x 18/2160 = 29" Take D as 29", \( d_1 \) as 27", and \( d_t \) as 26.13".

\( A = \frac{1.2 \times 1635 \times 16 \times 16}{.87 \times 27 \times 16000} = 1.70 \text{sq.} " \) Use 7/8" rd. rods - 4" c.-c. \( p = \frac{180}{12} \times 27 = .0055 \)

Transverse \( f_c = \frac{2 \times 1.2 \times 1635 \times 18 \times 18}{.89 \times .33 \times 12 \times 26.13 \times 26.13} = 530 \)

Longitudinal \( f_c = \frac{2 \times 1.2 \times 1635 \times 18 \times 18}{.89 \times .33 \times 12 \times 27 \times 27} = 496 \)

At 5th beam

\( P = (15 + 48) 62.5 = 3940\# \quad D = 3940 \times 18/2160 = 33" \) Assume 36" Wt. = 36/12 x 150 = 450# Normal component = 335# W = 335 + 3940 = 4275#

\( D = 4275 \times 18/2160 = 35.6" \) Take D as 36", \( d_1 \) as 34", and \( d_t \) as 33.13". \( A = \frac{1.2 \times 2138 \times 18 \times 18}{.87 \times 34 \times 16000} = 1.77 \text{sq."} \) Use 7/8" rd. rods - 4" c.-c.
\[ p = \frac{1.80}{12} \times 34 = 0.044 \quad j = 0.9 \quad k = 0.3 \]

Longitudinal \[ f_c = \frac{2 \times 1.2 \times 2138 \times 18 \times 18}{0.9 \times 0.3 \times 12 \times 34 \times 34} = 444 \]

Transverse \[ f_c = \frac{2 \times 1.2 \times 2138 \times 18 \times 18}{0.9 \times 0.3 \times 12 \times 33.13 \times 33.13} = 468 \]

At 6th beam
\[ P = (15+60) \times 62.5 = 4690 \# \quad D = 4690 \times 18/2160 = 39'' \]
Assume 45'' Wt. - 43/12 \times 150 = 575\# Normal component = 428\# W = 428 + 4690 = 5118\#
\[ D = 5118 \times 18/2160 = 42.6'' \]
Take D as 43'', \( d_1 \) as 41'', and \( d_t \) as 40.13''.
\[ A = \frac{1.2 \times 2545 \times 18 \times 18}{0.87 \times 41 \times 16000} = 1.74 \text{ sq.}'' \]
Use 7/8'' 7/8'' rd. rods - 4'' c.-c. Area = 1.80 sq."
\[ P = 1.80/12 \times 41 = 0.0366 \quad j = 0.91 \quad k = 0.28 \]

Longitudinal \[ f_c = \frac{2 \times 1.2 \times 2545 \times 18 \times 18}{0.91 \times 0.28 \times 12 \times 41 \times 41} = 386 \]

Transverse \[ f_c = \frac{2 \times 1.2 \times 2545 \times 18 \times 18}{0.91 \times 0.28 \times 12 \times 40.13 \times 40.13} = 402 \]

\[ f_s = \frac{M/A \times d}{1.80 \times 0.91 \times 41} = 14700 \]

Base-level section
\[ P = 5060 \# \quad D = 5060 \times 18/2160 = 44.5'' \]
Assume 46''
\[ Wt. = 46/12 \times 150 = 575\# \]
Normal component = 428\# W = 428 + 5060 = 5488\#
\[ D = 5488 \times 18/2160 = 45.8'' \]
\[ A = \frac{1.2 \times (18)^2 \times 5488}{0.87 \times 44 \times 16000} = 3.48 \text{ sq.}'' \]

total or 1.78 sq."

use 7/8'' rd. rods - 4'' c.-c.
Area of steel used = 1.80 sq." $p = \frac{1.80}{12} \times 44 = .0054 \quad j = .91 \quad k = .28$

Transverse $f_c = \frac{2 \times 1.2 \times 18 \times 18 \times 2744}{.91 \times .28 \times 12 \times (43.13)^2} = 375$

Longitudinal $f_c = \frac{2 \times 1.2 \times 18 \times 18 \times 2744}{.91 \times .28 \times 12 \times 44 \times 44} = 360$

**Longitudinal Beams**

**Beam #1**

$W =$ load on the beam $= \text{load/sq.ft.} \times \text{the area of the load triangles}$.

$W = 1107 \times 18 \times 9/2 = 89800 \#$

Assume a beam weighing 850\#/

$M$ for external loads $= M_e = 1.2 \times 850 \times (18)^2 = 1940000\#$

$M$ for load of beam itself $= M_d = 1.2 \times 850 \times (18)^2 = 332000\#$

Total $M = M_e + M_d = 1940000 + 332000 = 2272000\#$

$V = 89800/2 + 850 \times 18/2 = 44900 + 7650 = 52550\#$

$bd = 52550/Vj = 52550/120 \times .87 = 504 \text{ sq.}"$

Take $D = 40", b = 20",$ and $d = 38"$.

$A = \frac{2272000}{.87 \times 38 \times 16000} = 4.3 \text{ sq."}$

$8-\frac{3}{4}\text{"sq.rods have an area of 4.5 sq."}$

$10-\frac{3}{4}\text{"sq.rods have an area of 10 x .5625 = 5.625sq."}$

$p = 5.625/20 \times 38 = .0074 \quad j = .87 \quad k = .37$

$S_o = 52550/100 \times .87 \times 38 = 15.9" \quad 6-\frac{3}{4}\text{"sq.rods have a } S_o \text{ of 5 x 3.00 = 15.0". Thus 6 rods will be run straight through at the supports and 4 rods will be bent up at or near the quarter point.}$
\[ V = \frac{52550}{.87 \times 20 \times 38} = 79.5\# \] Shear at the middle is taken at zero.

\[ f_c = \frac{2 \times 227200}{.87 \times .37 \times 20 \times (38)^2} = 467 \]

\[ f_s = \frac{227200}{5.625 \times .87 \times 38} = 12200 \]

Stirrups-use 3/8"rd. single loop stirrups.

Spacing:

At support \( s_1 = \frac{2 \times .11 \times 12000}{39.5 \times 20} = 3.34" \)

At 1/4 pt. \( s_2 = 3.34 \times \frac{39.5}{29.6} = 4.45" \)

At 1/3 pt. \( s_3 = 2 \times 3.34 \times 6.68" \)

At 3/4 pt. \( s_4 = 4 \times 3.34 = 13.36" \)

Use:

6 @ 3"---------15"

3 @ 4"---------12"

3 @ 6"---------18"

1 @ 13"---------13"

13 stirrups-----58"

Beam #2

\[ W = 1895 \times 18 \times 9/2 = 154000\# \quad M_0 = 1.2 \times 154000 \times 18 = 3310000"\# \quad M_0 = 154000/2 + 1200 \times 18/2 = 77000 + 10800 = 87800\# \quad b_d = 87800/120 \times .87 = 830 sq." \]

Take \( b = 24" \), \( d = 46" \), and \( D = 48" \). Wt. = \( (24 \times 48/144) \times 150 = 1200\#/' \)

\[ A = \frac{3777000}{.87 \times 46 \times 16000} = 5.58 sq." \]

area of 7.78 sq." \( p = 7.78/24 \times 46 = .00715 \quad j = .88 \)

\[ k = .36 \quad S_0 = 87800/100 \times .88 \times 46 = 21.6" \] 8-3/4"sq.rods have a \( S_0 \) of 24". Thus 8 rods will be run through
Shear Diagram for Beam #2

Carried By Concrete

\[ \frac{1}{2} \text{ single loop stirrups} \]

6 - \( \frac{3}{4} \) in. bars
8 - \( \frac{3}{4} \) in. bars

6@3" = 20'
8@3" = 21'

b = 24"
d = 46"
D = 48"
and 6 bent up. \( v = \frac{87800}{0.88 \times 24 \times 46} = 90.5\)#

\[
f_c = \frac{2 \times 3777000}{0.88 \times 0.36 \times 24 \times (48)^2} = 432
\]

\[
f_s = \frac{3777000}{7.78 \times 0.88 \times 46} = 11800
\]

Stirrups—use \( \frac{1}{2}\)"rd. single loop stirrups.

Spacing-

At support \( s_1 = \frac{2 \times 0.196 \times 12000}{50.5 \times 24} = 3.88" \)

At \( \frac{1}{4} \) pt. \( s_2 = 3.88 \times 50.5/37.9 = 5.17" \)

At \( \frac{1}{3} \) pt. \( s_3 = 2 \times 3.88 = 7.76" \)

At \( \frac{3}{4} \) pt. \( s_4 = 4 \times 3.88 = 15.52" \)

Use:

\[
\begin{array}{c}
6 @ 3" \quad \text{---} \\
2 @ 5" \quad \text{---} \\
3 @ 7" \quad \text{---} \\
1 @ 15" \quad \text{---} \\
12 \text{ stirrups} \quad \text{---} \\
\end{array}
\]

Beam #3

\( W = 2682 \times 18 \times 9/2 = 217000\) # \( M_w = 1.2 \times 217000 \times 18 = 4700000\) # Assume a beam weighing 1560#/'

\( M_d = 1.2 \times 1560 \times (18)^2 = 605000\) # \( M_t = 605000 + 470000 = 5305000\) # \( V = 217000/2 + 1560 \times 18/2 = 108500 + 14040 = 122540\) # \( b_d = 122540/(120 \times 0.87) = 1170\) sq."

Take \( b = 30", \quad d = 48", \) and \( D = 50". \)

\( A = \frac{5305000}{0.87 \times 48 \times 16000} = 7.95 \) sq." 17-\( \frac{3}{8}\)" sq. rods have an area of 9.56 sq."\( p = 9.56/30 \times 48 = 0.00665 \)

\( j = 0.88 \quad k = 0.36 \quad S_0 = 122540/(100 \times 0.88 \times 46) = 29". \)

10-\( \frac{3}{8}\)" sq. rods have a \( S_0 \) of 30.0". Thus 10 rods will be run through and 7 rods bent up.
Shear Diagram for Beam #3

Carried by Concrete

\[ d = 48" \]
\[ D = 50" \]
\[ b = 30" \]

-20a-
v = \frac{122540}{(0.88 \times 30 \times 48)} = 96.7\# \\
\frac{f_c}{2 \times 5305000} = 485 \\
\frac{f_s}{5305000} = 13200 \\
\cdot 88 \times 9.56 \times 48 \\

Stirrups—use \frac{1}{2}"rd. single loop stirrups.

Spacing—
At support \( s_1 = \frac{2 \times 0.196 \times 12000}{56.7 \times 30} = 2.78" \)
At \frac{1}{4} pt. \( s_2 = 2.78 \times 56.7/42.5 = 3.72" \)
At \frac{1}{2} pt. \( s_3 = 2 \times 2.78 = 5.56" \)
At \frac{3}{4} pt. \( s_4 = 4 \times 2.78 = 11.12" \)

Use:

\[
\begin{align*}
12 @ 3" & \quad \quad \quad 33" \\
4 @ 5" & \quad \quad \quad 20" \\
1 @ 11" & \quad \quad \quad 11" \\
17 \text{ stirrups} & \quad \quad \quad 64"
\end{align*}
\]

Beam #4

\( W = 3470 \times 18 \times 9/2 = 281000\# \quad M_d = 1.2 \times 281000 \times 18 = 6060000"\# \quad \text{Assume a beam weighing 1750\#/ft.} \)
\( M_d = 1.2 \times 1750 \times (18)^2 = 680000"\# \quad M_t = 680000 + 6060000 = 6740000"\# \quad V = 281000/2 + 1750 \times 18/2 = 140500 + 15750 = 166250\# \quad bd = 156250/120 \times .87 = 1500 sq." \)

Take \( b = 30", d = 54", \text{and } D = 56". \quad A = \frac{6740000}{.87 \times 54 \times 16000} = 8.98 sq." \quad 16-\frac{3}{4}" \text{sq. rods have an area of } 9.00 \text{sq."} \)

19-\frac{3}{4}" \text{sq. rods have an area of } 10.70 \text{ sq."} \)

\( p = 10.70/30 \times 54 = .00066 \quad j = .88 \quad k = .36 \)

\( S_o = 156250/100 \times .88 \times 54 = 32.95" \quad 11-\frac{3}{4}" \text{sq. rods have a } S_o \text{ of 33.00". Thus 11 rods will be run} \)
Shear Diagram for Beam

Carried by Concrete

8 @ 4" @ 12" 11-1/2" bars
8-3/16" bars
8 @ 4" single loop stirrups

d = 54"
D = 56"

b = 30"
11 @ 21/2" = 23
8 @ 3" = 24

# 6 @ 7 = 12
# 6 5 = 104
# 801 = 12

-21a-
through at the supports and 8 rods bent up.
\[ v = \frac{156250}{.88 \times 30 \times 54} = 109\] 
\[ f_c = \frac{2 \times 6740000}{.88 \times .36 \times 30 \times (54)^2} = 486 \] 
\[ f_s = \frac{6740000}{10.70 \times .88 \times 54} = 13300 \]

Stirrups—use 3/8"rd. double loop stirrups.
Spacing—
At support \[ s_1 = \frac{4 \times .11 \times 12000}{59 \times 30} = 2.98" \]
At 1/4 pt. \[ s_2 = 2.98 \times 59/44.5 = 3.95" \]
At 1/2 pt. \[ s_3 = 2 \times 2.98 = 5.96" \]
At 3/4 pt. \[ s_4 = 4 \times 2.98 = 11.92" \]

Use:
7 @ 3"—————-18"
4 @ 4"—————-16"
4 @ 6"—————-24"
1 @ 12"—————-12"
16 stirrups——-70"

Beam #5
\[ W = 4275 \times 18 \times 9/2 = 346000 \] 
\[ M_0 = 1.2 \times 346000 \times 18 = 7470000 \] 
Assume a beam weighing 2250#/'
\[ M_d = 1.2 \times 2250 \times (18)^2 = 876000 \] 
\[ M_t = 876000 + 7470000 = 8346000 \] 
\[ V = 346000/2 + 2250 \times 18/2 = 173000 + 20250 = 193250\] 
\[ h_d = 193250/120 \times .87 = 1850 sq." \] 
Take \( b = 36", d = 58", \) and \( D = 60". \) 
\[ Wt_2 = (36 \times 60/144) \times 150 = 2250\] 
\[ \frac{346000}{.87 \times 58 \times 16000} = 10.03 sq." \] 
21-3/4"sq.rods have an area of 11.8 sq." p=11.8/
Shear Diagram for Beam #5

Carried By Concrete

$\frac{1}{2}$" double loop stirrups

8-4" bars

13-3\(\frac{3}{4}\)" bars

5@4" 4@5" 2@8" 1@16

b=36"
d=58"
D=60"

8@4.28
13@2.33

LYN-PETERSEN.
<table>
<thead>
<tr>
<th>m</th>
<th>12</th>
<th>12</th>
<th>12</th>
<th>88</th>
</tr>
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<tbody>
<tr>
<td>6</td>
<td>16</td>
<td>16</td>
<td>6</td>
<td>16</td>
</tr>
</tbody>
</table>

\[
16.26 = 80.6 \times 4 = 7.4
\]
\[
16.6 = 6.9 \times 4 = 2.8
\]
\[
16.6 = 5.6 \times 4 = 2.0
\]
\[
16.6 = 4.4 \times 4 = 1.6
\]

\[
\frac{64 \times 0.8}{4} = 15.999 \times 12000 \times 4 = 1262400
\]

Pipes should be chosen. It was decided to use the floor beams. All the values are very close, and the material for the beams was 22.5.
Beam #6

\[ W = 5020 \times 18 \times 9/2 = 412000 \text{#} \]

*Assume a beam weighing 2400#/ft.*

\[ M = 1.2 \times 412000 \times 18 = 8900000 \text{#} \]

\[ M_d = 1.2 \times 2400 \times (18)^2 = 935000 \text{#} \]

\[ v = 412000/2 = 206000 + 21600 = 227600 \text{#} \]

\[ \text{bd} = 227600/120 \times .87 = 2180 \text{ sq.}" \]

Take \( b = 36", d = 62", \) and \( D = 64" \)

\[ A = \frac{9835000}{.87 \times 62 \times 16000} = 11.4 \text{ sq."} \]

24-\( \frac{3}{4} \)" sq. rods have an area of 12.4 sq." 24-\( \frac{3}{4} \)" sq. rods have an area of 13.5 sq." \( p = 13.5/36 \times 62 = .006 \)

\[ j = .88 \quad k = .35 \quad s_o = 227600/100 \times .88 \times 62 = 41.8" \]

13-\( \frac{3}{4} \)" sq. rods have a \( s_o \) of 42". Thus 13 rods will be run straight through at the supports and 11 rods bent up. \( v = 227600/.88 \times 36 \times 62 = 116" \)

\[ f = \frac{2 \times 9835000}{.88 \times .36 \times 36 \times (62)^2} = 462 \]

\[ f_s \times \frac{6 \times 9835000}{.88 \times 14.1 \times 16000} = 12800 \]

Stirrups-use \( \frac{1}{2} " \) rd. double loop stirrups.

**Spacing**

At support \( s_1 = \frac{4 \times .196 \times 12000}{76 \times 36} = 3.44" \)

At \( \frac{1}{2} \) pt. \( \quad s_2 = 3.44 \times 76/57 = 4.55" \)

At \( \frac{1}{2} \) pt. \( \quad s_3 = 2 \times 3.44 = 6.88" \)

At \( \frac{3}{4} \) pt. \( \quad s_4 = 4 \times 3.44 = 13.76" \)

Use:

| 7 @ 3" | 13" |
| 4 @ 4" | 13" |
| 4 @ 6" | 16" |

16 stirrups------71"
The thickness of the crest was fixed arbitrarily at 24" and that of the spillway deck at 18". The reinforcement in the crest is composed of 7/8" rd. rods -8" c. - c. The spillway reinforcing is of 1/2 " rd. rods 10" c.-c.

The Toe

There is a heavy pressure existent at the toe due to the deflection of the falling water from an inclined to a horizontal position. This may be computed from the formula

\[ T = \frac{222 \times F \cdot V^2}{r \sin \frac{\alpha}{2}} \]

where \( T \) = pressure against curved portion of the toe in pounds per sq. ft., and normal to the surface at every point.

\( \alpha \) = angle thru which water is deflected

\( \alpha \) = angle subtended between radii at ends of curve.

\( r \) = radius of curvature, usually \( H/2 \)

\( V \) = velocity of water flowing over toe

\[ 8.025 \left( \frac{h + h/2}{V} \right)^{1/3}, \] in which \( h \) = height from crest of dam to middle point of curvature of toe, and \( h \) = depth over crest.

\[ F = \text{depth of water at toe} = \frac{3.33}{V} \frac{h}{2} \]

\[ T = \frac{740 \ h^{3/2} \ V \ sin \frac{\alpha}{2}}{r \alpha} \]
In determining the quantity of reinforcing steel necessary, it is sufficiently accurate, and good practice, to take the whole toe and treat it as if it were of a uniform thickness, equal to its average thickness.

Horizontal length of toe = 11.0'

Average thickness of toe = 48"

Average wt. of toe / sq. ft. = 4 x 150 = 600#

\[ h^2 = 57.2 \quad h/2 = 7.5 \quad h = 53.0 \]

\[ V = 8.025 (53.0 + 7.5)^{1/2} = 62.5 \text{ '/sec.} \]

\[ \alpha = 56^\circ \quad \sin \frac{\alpha}{2} = 0.4695 \]

\[ T = \frac{740 \times 57.2 \times 62.5 \times 0.4695}{33 \times 56} = 672\# /\text{sq. ft.} \]

Total stress / sq. ft = 600 + 672 = 1272#

\[ A = \frac{1.2 \times 1272 \times (18)^2}{0.87 \times 46 \times 16000} = 0.77 \text{ sq. " /ft. of width.} \]

7/8" rd. rods. - 9" c.-c. give an area of 0.80 sq." /ft of width and will be used.

Resultant of Forces and Center of Gravity - Spillway

The centers of gravity of both the spillway and bulkhead sections are determined analytically by the method of moments. Dimensions and lever arms are scaled from Plate VIII.

-27-
The line of action of the resultant forces is determined graphically and is also shown on Plate VII.

The spillway slab is divided up into a number of sections of short lengths and the moments for these sections determined.

**Moments - Spillway Section**

Longitudinal dimension length from buttress to buttress 18' c.-c. measurements.

On right of Y-Y axis.

Area of toe from point of tangency " t" to end = 95 sq. ft.

Volume = 99 x 18 = 1780 cu.ft.

Lever arm = 44.0 ft.

Moment = 1780 x 44 = 78500 Vol.ft.

Area of spillway section " a " = 30.8 sq. ft.

Volume = 30.8 x 18 = 552 cu. ft.

Lever arm = 30.5 ft.

Moment = 552 x 30.5 = 16800 vol. ft.

Area of section " b" = 15 sq. ft.

Volume = 15 x 18 = 270 cu. ft.

Lever arm = 23.5 ft.

Moment = 270 x 23.5 = 6340 vol. ft.

-28-
Area of section "c" = 11.3 sq. ft
Volume = 11.3 x 18 = 203 cu. ft.
Lever arm = 19 ft.
Moment = 203 x 19 = 3860 vol. ft.

Area of section "d" = 15 sq. ft.
Volume = 15 x 18 = 270 cu. ft.
Lever arm = 12 ft.
Moment = 270 x 12 = 3240 vol. ft.

Area of section "e" = 10 sq. ft.
Volume = 10 x 18 = 180 cu. ft.
Lever arm = 6.5 ft.
Moment = 180 x 6.5 = 1170 vol. ft.

Area of sections "f" = 7 sq. ft.
Volume = 7 x 18 = 126 cu. ft.
Lever arm = 2.0 ft.
Moment = 2 x 126 = 252 vol. ft.

Area of buttress wall from crest down to line A B = 1547 sq. ft. Thickness taken as 2 ft.
Volume = 1547 x 2 = 3094 cu. ft
Lever arm = 15.5 ft.
Moment = 3094 x 15.5 = 48000 vol. ft.
Area of buttress wall below line A B = 376 sq. ft.
Volume = 376 x 2 = 752 cu. ft.
Lever arm = 28.5 ft
Moment = 752 x 28.5 = 21450 vol. ft.

Beam # 1 Volume = 20 x 40 x 18 /144 = 100 cu. ft.
Lever arm = 0.5 ft.
Moment = 100 x 0.5 = 50 vol. ft.

On left of Y-Y axis.
Area of upstream deck = 256 sq. ft.
Volume = 256 x 18 = 4620 cu. ft.
Moment = 4620 x 38.8 = 179000 vol. ft.

Area of buttress wall = 2160 sq. ft.
Volume = 2160 x 2 = 4320 cu. ft.
Lever arm = 23.0 ft.
Moment = 4320 x 23 = 99500 vol. ft.

Beam # 2 Vol. = 48 x 24 x 18 /144 = 144 cu. ft.
Lever arm = 9.5 ft.
Moment = 144 x 9.5 = 1380 vol. ft.

Beam # 3 Vol. = 30 x 50 x 18/144 = 188 cu. ft.
Lever arm = 22 ft.
Moment = 188 x 22 = 4140 vol. ft.
Beam # 4  Vol. = 30 x 56 x 18/144 = 210 cu. ft.
Lever arm = 34.5 ft.
Moment = 210 x 34.5 = 7250 vol.ft.

Beam # 5  Vol. = 36 x 60 x 18/144 = 270 cu. ft.
Lever arm = 46.8 ft.
Moment = 270 x 46.8 = 12600 vol.ft.

Beam # 6  Vol. = 36 x 64 x 18/144 = 288 cu. ft.
Lever arm = 59 ft.
Moment = 288 x 59 = 17000 vol.ft.

Total of volumes on right of Y-Y = 7201 cu.ft.
Total of volumes of left of Y-Y = 10040 cu.ft.
Volume total = 17241 cu.ft.

Total of moments on left of Y-Y = 320870 Vol.ft.
Total of moments on right of Y-Y = 179410 Vol. ft.
Difference = 141460 Vol. ft.

Thus the center of gravity lies to the left of the axis, and is a distance away from it =
141460/17241 = 8.2 ft.

The total volume of an 18 ft. length of dam, including one buttress wall, has been found =
17241 cu. ft. or 958 cu. ft. / ft of length. Wt. per ft. of length of dam = W = 958 x 150 = 144000 #.
The total water pressure acting on the deck is
\[ P = \frac{6H}{2 \cos \theta} (H+2h) \approx \frac{66(66+30) \cdot 62.5}{2 \times 0.669} \]
\[ = 296000\# \text{ (approx)} \]
Height of center of pressure above base is \[ \frac{66}{3} \left( \frac{66+45}{66+30} \right) = 25.4\text{ ft.} \]

The total pressure acting vertically on one buttress wall footing \( = (P \sin \theta + W) \) lb, \( P \) and \( W \) being the water and structure weights per ft. of length, respectively.
\[ P \sin \theta = P_v = 296000 \times 0.743 = 220000\# \]
\[ W = 144000\# \]
Total pressure/ft. of length = 364000#
Weight one buttress wall \( = 364000 \times 18 = 6550000\# \)

If the wall footing were 1 ft. thick, the average weight, per sq. ft. would be \( (P_v + W) / 1 \)
\[ 6550000 / 127.5 = 51400\# \]

The greatest pressure would be at the upstream side and equal to \( S = 51400 (1 + \frac{6(127.5/2-56.5)}{127.5}) \)
\[ = 69000\#/\text{sq. ft.} \]

The safe limiting pressure for the hard shale type of foundation found at the site is taken as 8 tons / sq. ft. Width of footings = 69000 / 16000
\[ = 4.3' \text{ theoretically.} \]

-32-
The footings will be spread out to a width of 5' and will be carried 1.5' into the rock. This width of 5 feet will be maintained to a height of 1.5 feet above the rock where the footing will be stepped in to meet the required thickness of the buttress wall.

For direct compression the limiting value is taken at one-fifth of the ultimate strength of the concrete or 400 # / sq. in. This is used as 50000# / sq. ft.

The thickness of the buttress wall at the bottom = 69000/ 50000 = 1.38 ' or 16" theoretically. The following thicknesses of buttress walls for the spillway section were decided upon:

- Top to 20' level = 12 "
- 20' to 40' level = 16"
- 40' to 66' level = 20"

Corbels 18" wide shall be placed at the upstream deck side of those buttresses at which expansion joints occur. Expansion joints shall be located at every other buttress wall, that is, every 36 feet. The tongue type of expansion joint will be used, the special iron plates being ½ "x 8" in size. The use of this size of plate shall be universal in expansion joints throughout the rest of structure.
Factor of Safety.

Overturning moment = $P \times \text{lever arm} = 296000 \times \frac{25.4}{25.4} = 5040000$ (Lb-ft)

Resisting moment = $144000 \times \frac{62.5}{18.5} \times P = 296000 \times \frac{743}{18.5} = 2200000$ (Lb-ft)

$144000 \times 62.5 = 9000000$

$220000 \times 18.5 = 4070000$

$13070000 / 5040000 = 2.6$ factor of safety.

Bulkhead Section

The upstream deck is continued at the same angle as in the spillway section to Elev. 4030 to form the deck of the bulkhead section. The thickness of the deck from Elev. 4010 to 4030 is maintained at 18". The top deck of the bulkhead section is 8' wide and 12" thick. 7/8" rod. 8" c.-c. constitute the reinforcing in both the deck above the spillway and in the top.

The buttress wall at the downstream side is dropped vertically to Elev. 4010 and thence inclined outward with a batter of 1 in 4 to Elev. 3944.

Determination of Resultant of Forces and Center of Gravity.

Moment on left of Y-Y axis

Buttress wall Area = 2160 sq. ft.
Volume = 2160 x 2 = 4320 cu.ft.
Lever arm = 23 ft.
Moment = 4320 x 23 = 99500 vol.ft.

Deck slab - Volume = 4620 cu.ft.
Moment = 179000 vol.ft.

Beam #1 Volume = 100 cu.ft.
Moment = 50 vol.ft.

On right of Y-Y axis
Deck slab - Area = 21 x 1.5 = 31.5 sq. ft.
Volume = 31.5 x 18 = 568 cu.ft.
Lever arm = 9 ft.
Moment = 568 x 9 = 5100 vol.ft.

Top - Area = 10 sq.ft.
Volume = 10 x 18 = 180 cu.ft.
Lever arm = 19.5 ft.
Moment = 180 x 19.5 = 3500 vol.ft.

Upper part of buttress wall - Area = 203 sq.ft.
Volume = 203 x 1.5 = 304 cu.ft.
Lever arm = 16 ft.
Moment = 304 x 16 = 4880 vol.ft.
Lower parallelogram part of buttress wall - Area = 1584 sq. ft. Volume=1584 x 1.5=2380 cu. ft. 
Lever arm=12 ft. 
Moment=2380 x 12= 28600 vol.ft. 

Lower triangular part of buttress wall - Area = 126 sq. ft. Volume=726 x 15= 1009 cu.ft. 
Lever arm=31 ft. 
Moment=1009 x 31= 34100 vol.ft. 

Beam #2,3,4,5, & 6. 
Volumes = 1100 cu.ft. 
Moments = 42370 vol.ft. 

Total of volumes on right of Y-Y=4440 cu.ft. 
Total of volumes on left of Y-Y=10040 cu.ft. 
Volume total = 14480 cu.ft. 

Total of moments on left of Y-Y=320870 vol.ft. 
Total of moments on right of Y-Y=76230 vol.ft. 
Difference = 244640 vol.ft. 

Thus the center of gravity lies to the left of the Y-Y axis and a distance away from it = 
244640/14480=16.9'. 
Volume=14480 cu.ft. /18 ft. section or 803 cu.ft. /
ft. of length. W=803 x 150=120500#. 

-36-
Resultant for bulkhead cuts base 53 ft. from heel of dam. \( P \sin \theta = 220000 \)

\[ w = 120500 \]

\[ 340500\# = \text{total wt./ft. of length.} \]

Weight on one buttress wall = 340500 \( \times \) 18

6210000\#.

If the wall footing were 1 ft. thick the average wt. / sq.ft. would be \( \frac{6210000}{119} = 52200\#. \)

The greatest pressure would be at the upstream side and equal to \( S = 52200 \left(1 + \frac{6(119/2 - 53)}{119}\right) = 69250\# / \text{sq.ft.} \)

Width of footing = \( \frac{69250}{16000} = 4.32' \) theoretically. Use the same width of footing as in the spillway section.

Thickness of buttress wall at bottom = \( \frac{69250}{50000} = 1.38' \) or 16". Use the same buttress walls as previously designed.

**Factor of Safety**

Overturning moment = 5040000 \#\)

Resisting moment = 120500 \( \times \) 71 = 8550000\#

\[ 220000 \times 18.5 = 4070000\# \]

Total = 12620000\#

\[ \frac{12620000}{5040000} = 2.5 \text{ factor of safety.} \]
Flash Boards

It was decided that because of the extreme ice conditions to be expected at the site, flash boards, rather than crest gates would be adopted. The hollow space in the dam permits the use of a very satisfactory form of flash board. Instead of a wooden stanchion to break off, or a light iron rod to bend over, a pipe sleeve is set in concrete through which a stiff steel rod loosely passes. Leakage is prevented by a lightly packed stuffing box. When it is desired to release the flash boards, the rod is turned halfway around and pulled down until the hook rests in a socket formed in the crest. The flash boards then drift away and are recovered while the rod is out of the way of ice and logs, and can be raised into position the following year. See the accompanying plate.

Sluice Gates.

Two 8' x 8' sluice gates are to be used, and are to be operated by hydraulic power. The deck is recessed in two bays to such a depth as to allow of the gate on the outside with the stem passing in thru a stuffing box. See detail on plans. It is to be especially noted that this form of gate
Flash Board Up

Flash Board Down
Detail of Sluice Gates

Ambursen Dam
goes directly under the deck, instead of requiring a bulkhead to protect and operate it, hence the length of the deck is not reduced no matter how many gates are required. Obviously the gate mechanism is entirely out of the way of ice.

**Estimates**

Concrete

Spillway---240000 cu.ft. or 8900 cu. yds.
Bulkhead---281000 cu.ft. or 10040 cu.yds.
Total 18940 cu.yds.

18940 cu. yds. of concrete are equivalent to:

28000 bbls. of Portland cement.
8540 cu. yds of Sand
17060 cu.yds. of Stone.

Steel estimates on accompanying plates.

Rock excavation:

Spillway footings--496 cu. yds
Bulkhead footings--637 cu. yds.
Cutoff wall -----377 cu. yds.
Total 1510 cu. yds.
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Total Poundage - St. Rods - 1,603,940
### STEEL

**BENT RODS ONLY**

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**Total Poundage - Bent Rods - 640,900**

### STIRRUPS ONLY

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**Total Poundage - Stirrups - 1004**
DESIGN OF GRAVITY DAM.

This dam is to be of rubble concrete, of the vertical back type, spillway section.
Length of spillway = 250 ft.
Discharge = 47600 cu. ft/sec. However a maximum of 50000 sec. ft. will be provided for.
H = height of crest above foundation = 66 ft.
h = maximum height of water over spillway = 15 ft.
\( v_a \) = velocity of approach = \( Q/A \)
where \( Q \) is the quantity of water flowing over the spillway, and \( A \) the area of spillway section. Therefore \( v_a \) is equal to 13.35'/sec.
as for the Ambursen dam.
Resultant of forces to fall at end of middle third. Factor of Safety = 2
Material - Rubble concrete.
\( w \) = weight, per cubic ft., of material = 150 lbs. per cu.ft.
\( s \) = specific gravity of material = 150/62.5 = 2.40
Total pressure acting on dam, / ft. of length =
\[ P = 62.5H(H/2+h) \]
\[ P = \frac{62.5 \times 66(66+30)}{2} = 198000 \text{# acting at a distance vertically upward from the base of} \]
\[ p = \frac{H}{3} \left( \frac{H+3h}{H+2H} \right) = \frac{66}{3} \left( \frac{66+45}{66+30} \right) = 25.4 \text{ ft.} \]

**Spillway**

The spillway is parabolic in shape down to the 20' level and is determined from the equation \( x^2 = 1.78 \) hy which is the same as used for the hollow dam. The values previously computed will be used. (See page ). First round off the upper, upstream corner, so that the highest point of the spillway is 3.75 ft. back from the face of the dam at "a". This rounding should begin 22 " below level of "a" as indicated. The vertex of the parabola is at the highest point on the crest, and the \( x \) values are measured horizontally in a downstream direction, while the \( y \) values are measured vertically downward from the horizontal line at the elevation of the highest point of the crest. The computed values of \( x \) and \( y \) are plotted on the figure beginning at the point \( a \) which is the vertex of the parabola and resulting in the curve abc as shown.
At a depth 10 feet below the crest, the thickness through the dam is 21.65 ft., which is the thickness fixed by the parabolic curve. The thickness required to cause the resultant of all the forces to fall within the middle third of the section whose base line is 10 ft. below the crest:

\[ l'' = \frac{H_e}{1.08(s)^{\frac{1}{2}}} \]

\[ H_e = (H^3 + 3H^2h)^{\frac{1}{3}} \]

where \( H \) is the height above base line and \( h \) is the height above crest.

\[ s = \text{specific gravity} = 2.40 \quad l'' = 0.598 \ H_e \]

\[ H_e = \left( 1000 + 300 \times 15 \right)^{\frac{1}{3}} = 17.65 \text{ ft.} \]

\[ l'' = 0.598 \times 17.65 = 10.55 \text{ ft.} \]

Hence the dam is 21.65 - 10.55 ft. = 11.10 ft. thicker at 10 ft. level than strength requires. This however is not a loss of concrete. The extra weight helps to produce a higher gravity moment for the whole dam, and will therefore, permit the concrete to be of a more slender section at some lower level.

The thickness through the bottom section at the foundation base line may now be approximated. \[ l'' = 0.598 \ H \quad H = \left( 4356 + 3 \times 66 \times 15 \right)^{\frac{2}{3}} = 78.5 \]

\[ l'' = 0.598 \times 78.5 = 47.0 \text{ ft.} \]
The above design is for a dam without uplift acting and without considering ice pressure. Furthermore it is only approximate. A more exact determination is as follows:

\[ \text{"1"} = \left( \frac{A+B+0.096p}{C} + \frac{D}{2C} \right)^{\frac{3}{2}} - \frac{D}{2C} \]

where

1. \( \text{"1"} \) is the thickness of the section, \( A = \frac{H(H+3h)}{66} = 66(66+45) = 7340 \)
2. \( B = sa^2 \) where \( s \) = specific gravity and \( a \) is the thickness of crest. \( s = 150/62.5 = 2.40 \)
3. \( a = 14 \) ' \( B = 196 \times 2.4 = 470 \)
4. \( C = s - \phi \) where \( \phi \) per cent of total area of base under which it is assumed water can penetrate. \( \phi \) in this instance is taken at 0 because of the hard shale foundation. \( C = 2.4 \)
5. \( D = s(2.4 - 14 = 33.6 \)
6. \( p = \text{force due to ice pressure. Taken at 0 because of spillway section.} \)

\[ \text{"1"} = \left( \frac{7340+470+0}{2.4} + \left( \frac{33.6}{4.8} \right)^2 \right)^{\frac{3}{2}} - \frac{33.6}{4.8} = 50.2' \]

This value works out well graphically as also does 50'. 50' is the final length adopted, and the resultant of the forces cuts the base just inside the middle third.

This length is laid out to scale on
a horizontal line and from the end of the base line thus formed, at point d, a straight line is drawn to point c, at which the parabolic section is stopped. Usually it is carried down until it is tangent to the curve of the toe. However for this type of dam \( x=1.6h \) is usually a sufficient distance to extend the parabolic curve.

**Area of cross-section**

Area \( abcfa \) \( \frac{2}{3} xy \) where \( x \) 20 and \( y \) 12.50

Area 167 sq.ft.

Area \( afej \) \( 3.75 \times 12.5=46.9 \) sq.ft.

Total area down to line \( ce \) \( 167+46.9=213.9 \) sq.ft.

Area below line \( ce \) \( (23.75 \times 50) \times \frac{53.5}{2}=1975 \) sq.ft.

Total area of cross-section \( 1975+213.9=2188.9 \) sq.ft.

Total weight for a one foot section \( 2188.9 \times 150=329000 \) #.

**Center of gravity**

Taking the first parabolic section included in the curve abc and its coordinates, af and ak, the center of gravity is \( 60/8=7.77 \) ft.

horizontally from axis of parabola and \( 37.5/5=7.50 \) feet vertically, from upper horizontal ak, and lies at g. Considering afei as a parallelogram, its center of gravity lies at \( g \) its geometrical center.

-44-
Area, parabolic section = 167.0
Area, rectangular section = 46.9
Length line $g_0g = 9.70$ by scale.
Then $g_0$ the center of gravity of all that portion lying above the line ce, lines on line $g_0g$ and at distance, $x$, from $g_0$ such that
\[ 167.0 \times 46.9 \times (9.70 - x) \quad x = 2.130 \]
which locates $g_0$.

Center of gravity of trapezoidal one is found graphically. It lies at $G_1$. The center of gravity, $G$, of the whole dam lies on the line joining $G_1$ and $g_0$.
Length of Line $G_1g_0$, from scale = 36.4
Area, upper portion = 213.9
Area, trapezoidal portion = 1975
Distance of $G$ from $g_0$ = $x$
\[ 213.9 \times 1975 \times (36.4 - x) \quad x = 32.82 \text{ ft.} \]
which locates $G$.

Combining the water and gravity forces, the resultant is found, and it cuts the base just inside the middle third. For this type of dam with only the water and gravity forces acting, any further analysis is unnecessary because the topmost section has been found thicker than necessary and the bottom, or whole
section, as heavy as the middle third requirement demands. The whole section, from the top down to the base, being bounded by straight lines, it is obvious that each section will show an excess thickness, this excess increasing with the height above the base.

The total resistance to over-turning is: $329000 \times 32.0 = 10500000 \text{"#}$. 32.0 being the horizontal distance from the center of gravity of the section to the downstream end of the base.

The over-turning moment is: $62.5 \times (66)^2 \times \left(\frac{66}{6} + \frac{15}{2}\right) = 5037000 \text{"#}$.

Factor of safety $= \frac{10500000}{5037000} = 2.08$ which is 4 per cent. greater than the factor of safety required.

It is to be noted that where the resultant falls just at the end of the middle third, the factor of safety against over-turning, neglecting the effect to the toe is about 2. While it is customary to neglect the effect of the toe, it, unquestionably, adds considerably to the strength against over-turning. Although its cross-section is small, and it will break through under a comparatively small force the brak will not occur
at the exact face of the dam, but at some distance downstream from it, so that it add to the lever arm of the gravity force and increases the moment against overturning.

The total thickness thru the dam at the base measures 84 feet from the heel to the end of the toe. The total cross-sectional area is then 2350 sq.ft.

An 8' x 9' tunnel running the length of the dam is to be constructed at Elevation 3968 with a .01% grade, and a 10'x10' stair-well built near the gate house which will provide access to the tunnel and permit regular inspection.

The gate house is to be built on the bulwark directly over the intakes which are to be set flush with the face of the dam.

Two 8' x 8' sluice gates are to be provided to insure safety against floods and which will aid materially in passing off excess water at the time of construction. These sluice gates are to be made of heavy cast iron slabs, strengthened and supported by ribs and arranged to slide in a strong iron frame on the upstream face of
Hydraulic Ram

ELEV. ft 3956

SECTION AT SLUICE GATE
FOR GRAVITY DAM
LYON-PETERSEN

SCALE - 0.12345 FEET
Section At Intake

Scale - 23468/10 Feet

For Gravity Dam.
Lyon - Petersen.
the dam. The sliding surfaces being faced with bronze strips. These gates are to be operated by a hydraulic ram system placed above them on the face of the dam.

The volume of the spillway section is \(250 \times 2350 = 588000 \text{ cu.ft.} \) or \(21800 \text{ cu.yds.}\)

The volume of the bulkhead sections is estimated at \(690000 \text{ cu.ft.} \) or \(26500 \text{ cu. yds.}\)

Total volume = \(21800 + 26500 = 48300 \text{ cu.yds.}\)

Thus:

- 71500 \(\text{ bbls. of cement}\)
- 21900 \(\text{ cu. yds. of sand}\)
- 43500 \(\text{ cu.yds. of broken rock}\) would be required.

It is estimated that 2140 \(\text{ cu.yds of rock}\) will need to be excavated for the foundation. The rest of the rock for the rubble must be either excavated from the sides of the river or imported from other sources.

The specifications for this dam will read the same as those that follow with the exception that instead of broken stone, broken rock excavated mainly at the site and of a size up to "nigger-heads" shall be used. No steel of course is necessary in this dam.
SPECIFICATIONS.

1. Extent of Contract: These specifications include the furnishing of all material and all labor necessary for the construction and completion, in final and acceptable form, of a concrete dam across the Bow River at Bow Fort Falls, Alberta, Canada, of section as shown on the plans, and of a length of about 600 ft. The work shall include the following:

(A) The construction and removal of all necessary cofferdams.

(B) All necessary excavation, and all work preparatory to placing of concrete.

(C) All necessary timber for use in form, bracing, crest of dam, etc.

(D) All concrete work.

(E) Furnishing and placing of all bolts, nails, reinforcing bars, etc., which may be needed in temporary structures of the complete work.

2. Location: The proposed location of the dam is shown on plans in the thesis of Mr. Wignall. It shall occupy essentially the position as indicated on those plans, the exact location to be
3. **Foundation:** The dam will be founded upon rock throughout its entire length. Any earth or unsound and disintegrated rock shall be removed and the surface shall be thoroughly cleaned and prepared for the pouring of concrete, to the full satisfaction of the Engineer.

4. **Cofferdams and Pumping:** The contractor shall furnish all material and labor necessary to construct and pump out cofferdams sufficiently tight to admit of the placing of concrete without sacrifice of quality, and sufficiently substantial to protect the work from injury due to overflow. The contractor shall be held responsible for any damage caused by the failure of said cofferdams, and shall tear out and replace or repair any work injured previous to the completion and acceptance of the work. Upon completion of the work, the cofferdams or such portions of same as the Engineer may direct, shall be removed and cleared away.

5. **Concrete Work:** All concrete shall conform to the following specifications:
(a) Aggregate, etc. Concrete shall consist of one (1) part of cement, two (2) parts of sand, and four (4) parts of broken stone, all ingredients being determined by volume. In determining the above proportions, one (1) barrel of cement shall be taken as constituting four (4) cubic feet. If desirable, a good well graded, clean water or bank gravel may be substituted for broken stone in which case the proportion of cement, sand, and gravel will be changed, if necessary, by the Engineer, to obtain a satisfactory mixture.

(b) Cement: The cement shall be of the best quality of portland cement, conforming in every particular, to the standard specifications of the American Society of Civil Engineers. The contractor shall provide a storage warehouse with a floor to keep the cement from the ground and sufficiently tight throughout to thoroughly protect the cement from the weather. All cement shall be delivered at least fourteen (14) days before needed for the work, to allow time for testing. Cement injured in storage or rejected cement shall be removed within three (3) days after notice to the contractor of its rejection.
(c) **Sand**  All sand used for concrete or for mortar shall be clean, sharp, coarse and free from dirt or other foreign matter, and shall be screened and washed whenever necessary. Broken stone shall be of sound hard limestone crushed to a maximum size which will pass a two inch (2") ring.

(d) **Mixing Concrete:** All concrete shall be thoroughly mixed to the satisfaction of the Engineer, in a approved concrete mixer and wetted as directed by the Engineer, to obtain a medium wet concrete, which will flow to an approximate level without tamping.

(e) **Placing of Concrete:** The dam shall be built in sections approximately fifty four (54) feet long, each section being completed from foundation to crest by as nearly continuous pouring of concrete as practicable.

The concrete shall be well worked with a spade along the forms and elsewhere if necessary, to remove air bubbles, thoroughly consolidate the material.

Reinforcing rods shall be placed as design indicates.
When fresh concrete is to be placed against a surface of concrete already set or upon the stone foundation, said surface shall be carefully washed and then carefully and completely covered with a coating of neat cement mortar, applied with a broom immediately before the new concrete is poured.

Any depressions in finished surfaces shall be filled with 1 to 2\(\frac{1}{2}\) mortar immediately upon removal of the form. On all exposed surfaces there shall be spread, immediately upon removal of the forms, a wash of neat cement mortar, as thick as practicable, laid on with a broom.

Any cement mortar or concrete which has thickened, due to the process of setting before being used so that, in the opinion of the Engineer, it is unsatisfactory for use, shall be removed and not used in the work. Retempering will not be allowed.

All concrete shall be kept thoroughly moistened for at least three (3) days after removal of the forms.

6. **Timber Work.** The contractor shall furnish and set the timbers on the crest of the dam as shown on the plans, said timbers
to be anchored with one (1) inch bolts provided with brass nuts as indicated; said bolts to be spaced four (4) feet apart.

All of the above timber work shall be of a good quality of southern pine, free from knots, wind shakes, or other defects which would impair their strength or durability, and suitable for the purpose intended.

7. **Construction Plant**: The contractor shall furnish all necessary tools and construction equipment and a boat for use of the Engineer inspecting the work, for soundings etc.

8. **Removal of Waste Material, Rubbish, etc.**

All unused material, and all rubbish of any kind, must be removed and deposited in a place satisfactory to the Engineer. The work shall be left in a neat, clean and orderly condition.

9. **Price and Measurement**: (a) **Concrete Work**: All concrete work heretofore specified shall be paid for on the cubic yard basis at the price named by the contractor in his proposal for the work; said price shall include the cost of all material such as sand, stone,
cement, lumber for forms, etc., and all labor of every kind for mixing and depositing the same. Said price shall also include all steel reinforcement and timber work as shown on the plans.

(b) Excavation: All excavation shall be paid for on the cubic yard basis at the price named by the contractor in his proposal, said price to include all cleaning of surface and all work necessary to properly prepare the bottom for the concrete work to be placed thereon.

(c) The contractor shall name in his proposal a lump sum price for all cofferdam work, said price to include the cost of all pumping, bailing or other work necessary to properly unwater the site.

(d) Extra Steel: The contractor shall name in his proposal a price per pound to be paid for any extra steel reinforcement that may be ordered placed by the Engineer.

(e) Extra Work: Any extra work not included in these specifications and ordered by the Engineer shall be paid for on the basis of cost plus ten per cent (10%).
CONCLUSION

From a comparison of the preceding designs it was decided that the reinforced concrete of Ambursen dam would be the most satisfactory type to be built under the conditions prevailing at this particular site. The design of the Ambursen dam shows that every part of the structure has a definite known strength as against the design of the gravity dam which demands a certain thickness thru a given section. No part of the gravity dam is designed to take tension, while in the Ambursen dam steel is provided for that purpose. The hollow dam practically eliminates sliding and over-turning which are the main factors in the design of the gravity dam. The quantity of rock necessary to be excavated is less. As this work is one of the most difficult parts in dam construction, this is a deciding factor.

The Ambursen dam permits of regular inspection and conditions which may develop to
cause failure may be readily discovered and remedied.

Another and probably the most important factor in choosing the dam is time of construction. With the Ambursen dam it is possible to get into the river and out of it during the same period of low water. Thus cofferdams are cheaper (they sometimes may even be of the sand-bag type); the cost of handling the water is less; and the losses due to frequent washings out of the cofferdam are practically eliminated. By means of construction tunnels built thru the dam, and of a nature similar to the inspection tunnel but on a lower level, men and materials may be gotten easily to work which is located in mid-stream.

Furthermore the plant would be in operation and paying for itself before the construction of the gravity dam would be completed.
PLAN AND ELEVATION
Bow Fort Power Plant
Bow Fort Falls
Alberta, Canada
Lynn - Peterlee
Spillway Section

Gravity Dam

Scale: 1:1250 Feet

Lyon - Petersen.