# Thesis.

## Essex Company's Dam.

## Across the Merrimac River at Lawrence.

May 1875. W. F. Sargent.

The Essex Company was incorporated March 20th. 1845.
The stock of the company was taken up and the company organized in April 1845.
With the following Officers and Directors.
Hon. Abbot Lawrence President,
Messrs. Patrick T. Jackson, William Sturgis, Nathan Appleton, John. A. Lowell, and Ignatius Sargent. Directors.
Charles S. Storrow Esq. Principal Agent, and Chief Engineer. (now Treasurer.)
A careful survey was made, and a general plan formed, under the Chief Engineer, for using the water power, the location and construction of the dam; for the canals mills &c. In the spring of 1846 the services of Capt. Charles H. Bigelow (formerly of the U.S. Engineers) were also obtained for the company.

and under his immediate direction the works of the dam and canal were successfully carried forward to their completion, in accordance with the original designs.

## General History and Description of the Dam and Canals.

The Essex Company — the principal owners of the Water Power and Canals, and the principal owners of the town, have erected the dam and canals. They dispose of the water power to other companies on certain conditions, which are specified with great care and minuteness on the printed proposals for their sale. They define a "mill power" to be thirty cubic feet of water per second, when the head and fall is twenty five feet, which is to be graduated to a greater or less quantity, according as the head and fall is less or greater than twenty five feet.

A mill power is considered to be equal to about 60 or 70 horse power

The excavation for the foundation of the dam was commenced August 1st 1845. The first stone was laid September 19th of the same year, and the dam was completed in 1848.

The whole structure is of solid masonry laid in cement, and the foundation rests on the solid rock bed of the river. Before laying the foundation, all soft and broken material was entirely removed from the site of the dam, and throughout the entire extent, blasting and digging was carried on until the firm solid rock was reached, so that the surface on which the foundation is laid, is exceedingly rough and jagged, and in many places the foundation is bolted to the solid rock bed with iron bolts.

The structure is 1,629 feet in length the overfall is very nearly 900 feet in length the south wing wall is 324 feet in length and the north wing wall is 405 feet in length the latter is constructed to unite with guard locks at the head of the canal.

The dam is 35 feet thick at the base and 12.5 feet thick at the lower end of the coping crest stones. Its greatest height is 40.5 feet, and its average height is 32 feet.

The water falls from 25 to 27 feet giving an effective fall of 28 feet for the whole of the river.

The rock excavation in preparing

the foundation was 1700 cubic yards.
The mass of masonry laid in cement is 29.000 cubic yards, and the hammered granite surface is 148.000 square feet.

The main structure is brought up on the front or down stream side with split granite stone, hammered bed, build and vertical joints, to 3/8 inch joints, and laid in courses of 16 to 24 inches rise. The remainder of the masonry is of rough stones, laid as compactly as it is possible to lay them without hammering, well bonded together, and to the front courses by stones of larger dimensions, the bed joints of the part adjoining the front, being laid to correspond with the front courses.

The whole structure is laid in hydraulic cement, and in such a manner as to form a perfectly compact and impervious mass. The dam is backed with an embankment of earth, sloping 6 to 1. From the end of the overfall, a wing wall, the top of which is 10 feet higher than the crest of the dam, extends on the one shore until it meets the canal, and on the other shore a distance of several hundred feet; as far as was considered necessary for the proper security of the whole work. The ends of these land or wing walls, adjoining the overfall are of split granite stone, similar to that of which the face of the dam is built, down stream for a sufficient distance to protect the banks.

The pond produced by this dam flows back to Hunts falls in Lowell, about 9 miles distant.

Mode of prosecuting the work.

When laying the foundations a portion of the line was enclosed by a coffer dam, and the water pumped out so that the rock might be carefully cleaned of all loose material, such as chips earth &c. and levelled by filling cavities with small stones and cement, and knocking off those portions which rise above the intended level, until such a line had been established as was satisfactory to the Engineer. From one third to one half of the dam was enclosed at one time, and the water suffered to flow over those parts of the dam which were not enclosed, the front courses being in such cases left always higher than the rear and the whole piece of the dam over which the water was allowed

allowed to flow being left with a fair and even face, so as to give as little hold as possible to anything passing out.

The top of the work over which the water was allowed to flow during its construction, was covered with a sheathing of suitable material, such as boards or planks, to prevent the action of the water upon it, and before carrying up such portions, the top of the unfinished work was carefully examined; and replaced if necessary. The deepest part of the river was first enclosed, and the foundations of the dam there brought up to the level of the rest of the bed. Before the dam was brought up to its full height, the water was let into the canal, which relieved the dam and facilitated the closing of the work

The dam cost $250.000. including the cost of coffer dams, and all incidental expenses.

The water is taken from the pond by an artificial canal 5,330 feet in length, 100 feet in width at the upper end and 60 feet in width at the lower end, and measuring at the surface of the water; 12 feet in depth at the middle, and 4 feet in depth at the side walls. At the head of the canal are six sluice ways 12 feet deep and 9 feet wide; and a lock for navigation 95 feet long and 26 feet wide, all built of hammered granite, laid in cement. At the lower end of the canal are three locks of 9 or 10 feet lift each, which are about 100 feet long and 20 feet wide; and a large waste weir of masonry.

The earth excavated for this canal was 266.000 cubic yards. The side walls are of granite masonry, laid in cement, and contain 12.000 cubic yards. The canal is about 400 feet from and nearly parallel to the river, and in this space, between the canal and the river, are the sites for the mills. The water is prevented from oozing into the adjoining sandy soil, by plank or sheet piling. The canal and structures connected with it cost about $200,000.

## Details of the Dam and Canal.

### Masonry.

The lower front course of stone resting upon the rock is composed entirely of headers, none of which are less than 18 inches deep and 8 feet long.

they are let into the rock, their full depth, so that it is impossible for them to slide. They project one foot beyond the face of the dam, and are laid in level stretches lengthwise of the dam, as far as the uneven surface of the rock will permit, that is to say, 30, 40 or 50 feet, or more running lengthwise of the dam are laid at the same level and then a step is made if necessary, and another level stretch carried on. The whole front of the dam is built of split stone laid in regular courses, with joints of not over 3/8 of an inch, and hammered to a fair bed for two feet from the face of the dam. The joints are at right angles to the face, which has a batter of 1 foot in 12 feet. The headers run back four feet from the face, and are laid as often as once in eight feet in length of course, and breaking joints from one another.

The crest of the dam is composed entirely of headers, none of which are less than two feet deep and nine feet long, they are hammered to 3/8 inch joints, and project one foot beyond the face of the dam. These headers slope backward from the face at the rate of one foot in three feet. and every stone is bolted to the stone underneath its lower end by an iron bolt 1½ inches in diameter, and set in brimstone. The stones in the rear of the headers, on the crest of the dam, are laid as stretchers, none of them are less than five feet in length, and the headers are secured to these by iron clamps.

The interior work of the dam is what Rankine calls "Common Rubble masonry" it being composed of rough stones, large and small, laid in hydraulic cement, and without any attempt to lay them in regular courses, they are well bonded together however, and to the front courses, by stones of larger dimensions. The bed joints are laid to correspond with the joints of the split stone of the face of the dam, that is to say, half the thickness is laid sloping to the rear and the rest horizontal, the lower course is well fitted to the rock, and wherever is was deemed necessary, is bolted to it.

The whole structure both split stone and rough stone, is laid in such a manner as to form one mass perfectly compact and impervious to water.

The ends of the land or wing walls, where they join the crest of the dam, consist of heavy split granite stones, similar to those of the face of the dam. The remainder of these walls, are laid up with rough stone in cement, most of the wall being coursed rubble masonry but some large stones being used, broke up the regular courses, in some places so that a part of the wall is common rubble masonry. These walls are backed with a tight-joint or wall of hard brick, one foot thick laid in cement.

## Embankment.

The embankment behind the dam has a slope of 6 at base to 1 in height. The surface to the distance of 20 feet behind the front of the dam is covered with heavy ballast. The part of the embankment which lies next to the dam, for a thickness of 5 feet throughout the whole height was selected with care in order to place there the most solid and impervious material, and for that purpose, gravel of a satisfactory kind was made use of. The remainder of the embankment consists of earth excavated from the foundation of the dam, the adjoining wing walls, and a large amount which was brought from some point further up the river, besides the earth used in the construction of the coffer dams. Waste stones and chips were also thrown in with the embankment, wherever their presence, would not facilitate the passage of the water through it.

The embankment was carried up simultaneously with the dam.

Details of Mortar and Beton used in the construction of the Dam.

1st Hydraulic

Principally, { Lawrence's Rosendale Cement from Roundout N.Y. of excellent quality
{ White's Rosendale Cement, from Roundout N.Y. of good quality

Incidentally i.e. when the above could not be procured
Cornell's Rosendale, Van Waggener's, New York, Newark, New Jersey.
Hoffmans American Cement.

2nd Lime.

Thomaston (Me) lime, one cask affording 8 cu. ft of stiff lime paste

3rd Sand.

Pit sand, obtained in Lawrence, of excellent quality

4th Broken Stone
Principally, mica slate, from the ledges on the south side of the river.

## Proportions of Mortars and Betons

### 1st Cement Mortar.

Cement 300 lbs
Sand 6 cu. ft.

### 2nd Lime and Cement Mortar

Cement 1 cask = about 350 lbs
Lime paste 2 cu. ft.
Sand $10\frac{1}{2}$ cu. ft. or according to strength of lime

### 3rd Cement Beton

Cement 1 cask = 4½ cu. ft. nearly
Sand 4½ " "
Broken Stone 9 to 12 " "

### 4th Lime and Cement Beton

Cement 4 casks or 18 cu. ft., nearly
Lime paste 1 cask or 8 " " "
Sand 48 " "
Broken Stone from 96 to 126 " "

July 10th. A change was made in the Lime and Cement Mortar as follows.

Cement 1 cask
Lime paste 2 cu. ft.
Sand 4½ " ".

Lime and Cement Beton for North wing wall

May 4th 1847. Cement 1⅓ casks
Lime Paste 3 cu. ft.
Sand 15 " "
Broken Stone 36 " "

5th

A mortar of the consistency of thin cream, composed of cement and water only, was used to brush over the surfaces of the stones where Beton was to be laid, to insure cohesion between the Beton and the stone work of the dam.

## Preparation of the above kinds of Mortar and Beton

### 1st Lime Paste

This was made by slaking lime to the consistency of thin cream, and then allowing it to run off into a vat to cool, when cool it was of the consistency of stiff paste

### 2nd Sand.

The sand was screened when used in mortar for hammered joints.

### 3rd Cement Mortar.

The proper quantities of sand and cement were first mixed dry, and the whole was then wet up to a proper stiffness, no more being prepared at one time than was wanted for immediate use.

### 4th Lime and Cement Mortar

The lime paste was measured into the mortar box, together with the sand, water was then added and the whole worked, until all lumps completely disappeared from the lime paste. The cement was then added in suitable quantities at a time, and thoroughly worked in, more water being added if necessary.

5th Cement Beton

The broken stone was measured out and the cement mortar being prepared as above, a layer of broken stone was placed upon the beton bed and upon that a layer of mortar, then another layer of stone, succeeded by one of mortar, and so on, until the materials were exhausted, the pile being when finished, about 1 ft. thick. It was then shovelled over, each shovel full as it was thrown down being well rubbed into the bed, and this process was repeated until each piece of stone was covered with a coating of mortar.

6th Lime and Cement Beton.
This was prepared in the same way as the Cement Beton, except that Lime and Cement Mortar was used instead of Cement Mortar

Application of the different kinds of Mortar and Beton.
Cement Mortar was used in setting the Foundation Headers, and for the distance of 8 feet back from the front of the dam. In the rear part of the dam for a distance of 5 feet back On top of dam for depth of several feet and in wet places in the dam Lime and Cement Mortar, was used in all cases where Cement Mortar was not employed.

Cement Beton. Used behind the granite face of the dam for several feet back, and in wet places in the body of the dam, and to fill up spaces between rubble masonry

Lime and Cement Beton.

Used in all cases where Cement Beton was not used i.e. to fill up interstices between blocks of rubble masonry of the dam. In order to diminish the expense of Beton, when the space to be filled was large, blocks of stone were put into the middle of the space and Beton packed in around them.

When concrete was used to fill up interstices, the stones were smeared with mortar to insure cohesion between them and the concrete

The sand used was washed and screened if necessary, to free it thoroughly from loam gravel or any improper matter.

# Description of Plates

Fig. 1. represents a plan of the dam, the south, river and wing walls, the north, river and wing walls, the piers and guard lock. Since the dam was built, a certain space from the north wing wall, up stream, has been filled in, so that the ordinary height of the water in the pond does not cover it.

Fig. 2. represents a section of the dam, with that portion of the embankment which is immediately over and upon the dam. the rear part of the dam has a batter of 45° and is laid up in steps as shown in the fig. excepting for a distance of 7½ feet at the lower back edge, which is vertical, as shown. The stones in the interior of the dam are a sort of quartzite, of a dark slate color. The foundation headers, front course and coping crest stones are of granite.

Fig. 3. represents the crest stones, in both

plan and elevation. The stretchers which rest against the lower ends of the crest stones are also shown, and the manner in which the two are held together. The round iron bolts shown in the fig. are put into holes in the joints, to keep the stone from sliding past each other. The crest stones are dovelled to the stretchers underneath them, with iron dowels. The course under the crest stones consists entirely of stretchers, and they are doweled to the course below them. In each one of 5 feet or more in length there are two dowels, and but one, in those of a less length. The two paraleel rows of holes in the crest stones, are to hold the ends of iron pins, which keep the flash boards in place. Fig 4. represents the manner in which the common headers and stretchers are arranged, the headers being dovetailed into the stretchers. Fig. 5. represents a section, taken through the foundation headers and the trench in which they lie. The course resting immediately upon the foundation headers consists entirely of stretchers, they are let into the foundation headers a little as shown, and doweled to them, each stretcher, of 5 feet or more in length, having two dowels, and those of less than 5 feet in length having but one. All surface dowels, like those in Fig. 3. were set in sulphur, all others, like those in this fig. were set in the ordinary cement of the dam. Fig. 6. represents a side elevation of one of the long piers, and a section of the gate house. The foundation of the piers like that of the dam rests upon the solid rock, a level foundation of rubble masonry was first laid, and on that was built the granite piers to a height of about 15 feet, on top of the granite were built two walls of rubble masonry, as shown in the fig. between these walls is a layer of Beton, 2 feet thick. and above that, to the top of the walls, is ordinary earth. There are 4 gates in each set. each gate being 9'9" wide and 3'3" high. they are raised by means of a rack and pinion, worked by a worm shaft, which is operated by men. The Essex Company thought of using water power for raising their gates, but concluded that the interest on the investment would be more than what they paid the French Canadians, for working the machinery now employed in raising them.

Fig. 11. represents the iron support for the worm shaft, there are two of them.
Fig. 12 represents the iron hooks for the starts, their use will be described in connection with Fig. 14.
Fig. 13 represents a front view of one of the gates, which is 24 feet long 9'9" wide 3'3" high and 8" thick. it is composed of 4 pieces of timber, and braced to the upright or shaft; each end of the gate is shod with a thick strip of iron, which fits into the grooves in which the gate moves up and down
Fig. 14. represents the uprights or shafts of the gates, to the first of which is fastened the rack, 12 feet long. at the lower end of this upright is seen on the back side, the hook, when this gate has been raised its height; i.e. until the bottom of it is on a level with the bottom of the gate next to it

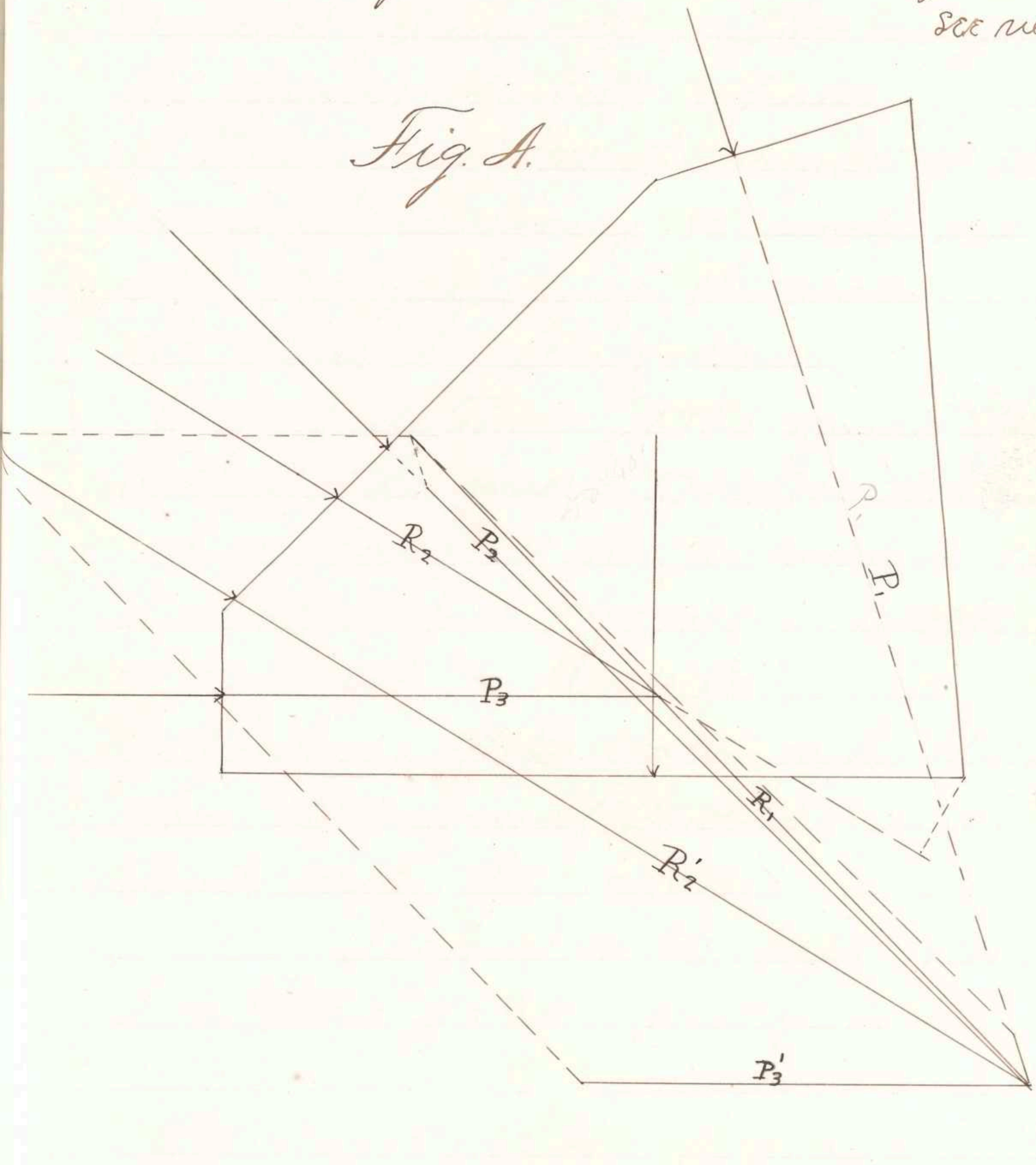
the hook comes in contact with the knob on the next gate, and then the two rise together until the hook on the second gate comes against the knob on the third gate then the 3 rise together, and so with the fourth and last gate. The hook shown dotted in fig. 6. is used in the same way as there, for pulling the gates down if for any reason it is necessary. Fig. 7. represents the guard lock at the upper end of the canal. it measures 95 feet from mitre to mitre and is 26 feet wide. It is built of granite, laid in regular courses. Fig. 7' represents a plan of the piers, there are five in all, two long and three short ones. The recesses near the ends are to receive the ends of stop planks, in case it is necessary to repair the gates. The long piers are

34 feet long and 2 feet wide.
The short piers are 29½ feet long and 2 feet wide
Fig. 8. represents a section of the lower locks, showing the side walls of masonry, the lining of plank, and the floors.
Fig. 9. represents a section of the canal, the sections of the canal differ considerably at different points, on account of the silting in of earthy matters in some places and in others the walls have been strengthened, thereby changing the section of the canal there.
Fig 10. represents a plan and elevation of the lower locks. The floors of the 1st and 2nd are 100 feet long. and the floor of the 3rd is 129 feet long.
Two rows of short pieces of timber 2 feet long and 1 foot square, are placed between the stone walls, and the wooden lining These blocks are placed from 4½ to 6 feet apart.

Calculations as to the stability of the dam
First as regards sliding on its foundation.

See next page.

Fig. A.



In these calculations I took a portion of the dam, included between two vertical planes at right angles to the dam; 10 feet apart.
I then calculated the weight of the mass of masonry so included, and also the pressure of the water upon the same. As follows.
Area of section = 778.5 square feet
Contents of the mass = 778.5×10 = 7785 cu. ft.
wt. of 1 cu. ft. of the masonry = 135 lbs.
∴ wt. of mass = 7785×135 = 1050975 lbs.
= 525.5 tons.

## Case 1st

Pressure of the water on the dam when the surface of the water is on a level with the crest.

Pressure on the crest stones

$$P = \frac{62.4 x_1^2 y \sin\theta}{2} \qquad x_1 = 13' \; y = 10' \; \sin\theta = \frac{4}{13} \; \cos\theta = \frac{12.4}{13}$$

$$\therefore P_1 = \frac{62.4 \times 13^2 \times 10 \times \frac{4}{13}}{2} = 16224 \text{ lbs} = 8.1 \text{ tons}$$

Vertical component of $P_1$ =
$16224 \times \frac{12.4}{13} = 15475$ lbs = 7.7 tons

Horizontal component of $P_1$ =
$16224 \times \frac{4}{13} = 4992$ lbs = 2.5 tons

Pressure on the part sloping at 45°.
$x_1 = 34'$  $x_2 = 5'$  $y = 10$  $\sin\theta = \cos\theta = .70711$

$$P_2 = \frac{62.4(x_1^2 - x_2^2)\,y \sin\theta}{2} = \frac{62.4(34^2 - 5^2)\,10 \times .70711}{2}$$

= 249519 lbs = 124.76 tons
Vertical component of $P_2$ = 249519 × .70711 = 176432 lbs.
Horizontal " " " = " " = "

Pressure on vertical part at lower back edge.
$x_1 = 32$  $x_2 = 24.5$  $y = 10$  $\sin\theta = \cos\theta = 1$

$$P_3 = \frac{62.4(32^2 - 24.5^2)\,16 \times 1}{2} = 132210 \text{ lbs} = 66.1 \text{ tons}$$

Vertical component = 0  Horizontal component = $P_3$

Distance of "centres of pressure" of $P_1, P_2, P_3$, from surface of water measured along the slope. $P_1, x_0 = 8\frac{2}{3}$ ft. $P_2, x_0 = 23$ ft. $P_3, x_0 = 28.4$

See Fig. A.

Combining $P_1$ with $P_2$ we get $R_1$ then combining $R_1$ with $P_3'$ we get $R_2'$ which is thus given in direction and magnitude, i.e. it makes an angle of about 58°40' with the vertical, and is equal to a pressure in that direction of 365000 lbs, now moving $P_3'$ to $P_3$ and $R_2'$ to $R_2$ we have the latter in magnitude, direction and point of application, as shown in the fig.

The angle of repose of stone varies from 31° to 35° so we see that the dam has a <u>tendency</u> to slide on its foundation.

But the total Vertical pressure is equal to weight of masonry plus the vertical pressure of the water that is equal to

1050975 + 191912 = 1242887 lbs.
coefficient of friction of dry masonry = .6
1242887 × .6 = 745732.2
Total Horizontal pressure = 313619 lbs
∴ the factor of safety is about 2.3
that is supposing the foundation of the dam to be smoothe and level, and the dam held in its place by the vertical pressure of its weight combined with that of the water. but in reality the foundation of the dam is very rough and numerous precautions beside were taken to prevent its sliding, ∴ the real factor of safety is considerable higher.

Stability of the dam with reference to overturning.
Taking moments around the lower front edge.
The wt. of the dam acting through the centre of gravity has an arm

of 14.6' in length. and the moment is = 1050975 × 14.6' = 15344235. lbs

The pressure of the water acts with an arm of 4.2' and the moment is = 365.000 × 4.2' = 1553000 lbs

Both act towards the left hand or towards the up stream side of the dam ∴ it cannot be overturned by the force of the water. ∴ we conclude that the dam will give way neither by sliding or overturning.

## Case 2nd

Pressure of water on the dam when the surface of the water is 10 feet higher than the crest of the dam

### Pressure on the crest stones

$P_1$ = 62.4 × 13 × 10 × 12 = 97344 lbs  { $x_1' = 14$, $x_2 = 10$ or depth of C of G = 12 }
Vert. Component of $P_1$ = 92851 "
Horiztal " " " = 29952 "

### Pressure on the part sloping at 45°

$P_2$ = 62.4 × 29 × 10 × 24.25 = 438828 lbs   $x = 24.25$
Vert. Component = 310300 "
Horizontal " = 310300 "

Pressure on the rear, vertical part.

$P_3 = 62.4 \times 7.5 \times 10 \times 38.25 = 179010$ lbs $x = 38.25$

Vert. compt. = 0 Horizontal compt. = $P_3$

When the water is 10 feet deep on the crest of the dam it is 26 feet in the river in front of the dam, so that there is a pressure of water on that side, and normal to the battered face. And this pressure resists to a certain extent the pressure of water above the dam.

Pressure of water on the face of the dam.

$P_4 = 62.4 \times 26 \times 10 \times 29 = 470496$ lbs. $x = 29$

Vert. component of $P_4$ = 39087 "

Horizontal " " " = 461448 "

Distance of the "centres of pressure" of $P_1$ $P_2$ $P_3$ + $P_4$, from the surface of the water measured vertically are

$P_1$ $x_0 = 12.1'$ $P_2$, $x_0 = 26.3'$ $P_3 x_0 = 38.3'$

$P_4 x_0 = 30.9'$

Combining the forces as before we find that the resultant pressure of the water makes an angle of about 75° with the vertical. hence we see that there is a tendency to slide. But summing up the vertical pressures we find the total vertical pressure is = 1493213 lbs. multiplying this by f = .6 we get
1493213 × .6 = 895927.8
Summing up the horizontal pressures on the back of the dam, we find their total to be = 519262 lbs. But there is a horizontal pressure of 461448 lbs. opposed to this, due to the water pressing against the face of the dam. hence the pressure tending to slide the dam down stream is = 519262 − 461448 = 57814 lbs
Now 895927.8 ÷ 57814 = 15.5 nearly, so that we see the dam cannot slide, and the coefficient of safety is even larger than in case 1.

Stability of the dam with reference to overturning.

Taking moments around the lower front edge.

The weight of the dam acting through the centre of gravity has an arm of 14.6' and its moment is =
1050975 × 14.6' = 15344235. lbs.
The resultant pressure of the water acts with an arm of 1' and its moment is = 1720000 × 1 = 1720000 lbs.
Both act towards the left hand as in Case 1st therefore we conclude that the dam cannot be overturned by the water. And as it will neither slide nor be overturned, in both the cases considered, we conclude that the dam is perfectly stable.

# Quantity of water passing over the dam at different heights, as calculated by Francis formula

$$Q = 3.012\, l\, h^{1.53}$$

| Heights | Cubic feet per second | Heights. | Cubic feet per second. |
|---|---|---|---|
| 0.5 feet | 933 | 5.5 feet | 36810 |
| 1. " | 2725 | 6. " | 42010 |
| 1.5 " | 5045 | 6.5 " | 47550 |
| 2. " | 7833 | 7. " | 53235 |
| 2.5 " | 11033 | 7.5 " | 59145 |
| 3. " | 14060 | 8. " | 65250 |
| 3.5 " | 18420 | 8.5 " | 71610 |
| 4. " | 22560 | 9. " | 78150 |
| 4.5 " | 27120 | 9.5 " | 84950 |
| 5. " | 31800 | 10. " | 91900 |

The Essex Company estimate their total water power to be equal to about 15000 horse power which is equal to about 230 "mill powers".
They don't intend to ever sell more than 12000 horse power, in order to provide for all contingencies,
and they have already sold a large part of the 12000 horse power, hence it is probable that in a few years all the available power will be in use.

P.S. I should have stated before that the dam crosses the river in an oblique direction, and also that it has a slight curvature up-stream, the offset at the centre from a line joining the ends of the dam being 14.97 feet, offsets were taken from this line at every 50 feet.