THEESIS.

DMS

A.A. Kennedy, Class '77.
Dance of Worry.

It is hardly necessary to say anything concerning the importance of the use of Dance. The need to which the power of water may be turned is manifest. In manufacturing, particularly in manufacturing, it is so important that its country which has a good water power is considered as especially favored by Providence. The East owes its wealth to its water power. The old proverb "Fire is a good servant but a bad master" applies equally to water. But the invaluable benefit of water is its power. The floods which have been set to limit its action became an exceedingly destructive agent, laying waste perhaps the very fields where tillage had made profitable. Innumerable instances have occurred where an insignificant stream having risen during a time, perhaps, could
making out improvements which had required immense capital and labor to construct.

Dams are of great importance in promoting navigation of rivers, which otherwise would be navigable. It is proposed by the U.S. Engineer to make the Minnesota River and Minnesota navigable by means of a dam. This makes what is called a slack water navigation. Of course no such works the resources of the country in the immediate vicinity of the river have to be taken into consideration.

As the first step towards the improvement of a water power is the building of a dam to give the great importance to a function of constructing, etc., as to give strength and durability to the structure.

The best and most durable, but most expensive dam is made of cut stone. In France water dams are almost unknown.
The French engineers have brought the subject of stone dams and retaining walls to a high degree of perfection.

The first thing to be considered in the discussion of dams are the forces acting.

I. The weight of the dam acting through its center of gravity.

II. The pressure against the dam (in or outside water).

The first may be considered as a constant, as after the dam is built the weight is supposed to remain constant ever after.

The second is variable (generally). This is apparent in the case of stone pumice or which are being filled and emptied frequently.

There is a limit to the height to which a wall or a certain base can be established depending upon the "limit of pressure." This means that if a wall or a given base be established too high it will buckle or its own weight.
The second force on the pressure of the water is resisted simply by the weight of the machinery (current not being taken into account). These two forces can be represented graphically thus:

Fig. 1

[Diagram with vectors P, W, and R forming a parallelogram]

Completing the parallelogram we have P+R as the resultant. From the principles of mechanics that if the wall is inclined to the pressure of the water, that is, if \( P > W \) (and two things, perhaps both, will occur. The wall will either slide along one of the curves 1 or 2, or rest on a line parallel to the surface of the water and in the water face of the wall."

The direction and magnitude of the resultant will determine which motion will occur.

If \( P \) is such that angle \( \phi \) in Fig. 1 is greater than 30°, the dam will slide.
(From the British Surveyors' method we find, that the angle of friction $\phi$ must be at least $82^\circ$. That is, if we have two blocks of stone as $F$ and $B$, and raise the block $F$ at one end till $\phi$ frame $82^\circ$, the block $B$ will begin to slide on $F$. If the result is a fall without the face of the dam rotating, it will occur. In practice, usually, there is not however about a line in the entire surface of the wall (as if would theoretically) the pressure being concentrated at the notch surface at a line through $D$ perpendicular to the figure $I$. Breaks or crumbling the stone thus remaining the area to $D''$.)

It is generally considered that the weight of the dam is the only force overcoming the force of the water.

To depart from our text. Should the dam be curvilinear or straight?
benefit be derived from the curved form. In France preference to the circular forms of the "Turres" the curved form had never been adopted; in Spain they are nearly all of this form. Theoretically it is admitted. That the former acts as an arch against the pressure of the water when they have the curved form, an opinion that is subject to great doubt if we take sufficiently into account the emulsion and the hydraulic friction. But there is another and we think a sufficient reason for giving the preference to the curvilinear form. This reason is derived from the elasticity. It makes the masonry, which at the present day is a proved fact. And if we admit the elasticity, it is obvious that the form which offers the greatest safety is the curved. (It is quite evident from the above that the curved form is an advantage in Masonry Forms, but for our present purpose we will only consider the straight form.)

(1) We will now produce similar for the
dimensions a wall so that it will not be demolished by rivetation. Before attempting to produce the formulae, we will give some of the general principles.

First, Pressure. The force of the water acts in a normal to the sides of the vessel containing it or the surface reflecting it, and the pressure, exerted by the water on any planimeter, is equal to the area of the planimeter \( P \) times the distance of its center of gravity from the surface of the water, \( H \) x the weight of a unit of volume of the water.

Problem: To find what force an equal and horizontal equation of a planimeter will be exerted by the pressure of water on the surface. 

\[ W = \text{weight of water}\]
\[ P = \text{pressure of water}\]

\( W = \text{weight of water} \times H \times \text{planimeter area} \)

\( P = \text{planimeter area} \times \text{weight of a unit of water} \times H \)

\( P = \text{height} \times a, \quad DB = \text{area} = f.\)

Draw the line \( FE \) parallel to \( DB \). Take \( EC = \frac{1}{3} FE \) and from the principles of Mechanics, \( C \) will be the center of gravity.
If the dam. Through $C$ draw $CM$ parallel to $DB$ at the point where it intersects $FB$ will be the "cut-off" pressure $P$ through $\frac{a}{2}$. Direct the origin $D$ from where we have $P \cdot MD = $ the moment of the force tending to overturn the wall and $W \cdot DN = $ the moment of a Still standing to resist this overturning. If $P \cdot MD > W \cdot DN$ the wall overturns, but if $P \cdot MD < W \cdot DN$ the dam will stand.

Considering a unit length of the embankment we have.

\[ P = \frac{a}{2} \cdot \frac{a}{2} - W \]

\[ W = 1 \cdot \frac{a}{3} \cdot W \]

\[ P \cdot MD = \frac{a^2}{2} \cdot W \frac{a^3}{6} = \frac{a^3}{6} W \]

\[ W \cdot DN = \frac{a^3}{3} W \cdot \frac{2}{3} = \frac{a^3}{3} W \]

In a rectangular dam, the problem is again very simple. If $B$ being perpendicular to surf. I value. I the origin $P$.

\[ P \cdot MD = \text{sum of units to overturn the dam} \]

\[ W \cdot DE = \text{sum landing a most overturning} \]
For the trapezoidal form we may apply the last procedure, and we have:

1.挂着 the origin of weights
2. \[ P \cdot XD = \text{mm of water} \]
3. \[ W' - DN + W'' - DF = \text{mm of wall} \]
which is easily carried.

We will now produce the formulae for (I) above (eq. 6).

If we assume a mm one decrease as for solution 1 to height and wish to know the width of the base to sustain a pressure of water to the top of the plane. (For either of the two forms, triangular, rectangular or trapezoidal)

Place the occasion of the wall and water equal to each other, enter the known values, solve the equations for the unknown decrease (at the end of the basin) that with the width of the base where the wall would be just in the point of turning, increasing the drainage to an all for safety and we have the required result.

To illustrate take equations (1) and (2), placing these equal, we have:

\[
\frac{a^3}{b} W = \frac{b^3}{a} W', \quad \frac{a^3}{b} W = \frac{10 \cdot 3^2}{3} W', \quad a = \frac{150 \sqrt{W}}{W'}
\]
with 3 the value gives us (6) the wall will be on the point of overturning hence for safety
\[ \frac{3}{50-0.11} \quad (7) \]
In the same manner we could find the height to which a wall could be carried with the given base to sustain a pressure of water.

If the material employed were of indefinite resisting power, as well as the soil of the foundation, and if there were between them an unlimited degree of adhesion, the only condition of stability to be fulfilled would be that the resultant of the twin forces pass within the base of the dam. For (4) would then be sufficient for the width of the base and a cemented lead of water. But we know in practice that the foundation or the material itself will support only a limited pressure and that without these there be not an unlimited degree of adhesion. Hence the two following conditions of stability:

1. Carry portion of the base with foundation. 
be required to exert only a limited pressure.

II. The course of inclination must not slip on one to
other or the whole damn on the foundation.

From "Egyptian Engineering" we get the follow-
ing solution of the I Case. (There are no cases and
1 damn slipping and thus being detached, when Case I is
fulfilled.

\[ \theta = \frac{\text{FB}}{\text{AD}} \quad \text{and} \quad \theta = \frac{38}{7} \]

\[ \text{FB} \text{CD} \text{ring the profile I damn, any section a unit the length,}
\]

\[ \text{may be considered as acting upon}
\]

\[ \text{by till force one the vertical em-
}\]

\[ \text{p} = \text{F} = \text{resultant} \text{ at } \theta \text{ of these}
\]

\[ \text{and vertical thrust of water on face}
\]

\[ \text{DF} \text{ and the horizontal em-
}\]

\[ \text{p} \text{ the pressure of the water}
\]

\[ \text{emphatic the parallelogram we}
\]

\[ \text{have the resultant } \text{F} \text{ coordinate}
\]

\[ \text{F} \text{ as acting at } \theta \text{.}
\]

\[ \text{F tends to slide the damn on its}
\]

\[ \text{foundation. } \text{F} \text{ the vertical force pushes itself upwards}
\]

\[ \text{till from its extremity } \text{B which is nearest to}
\]
From O'Brien in his "Essential Elements of Practical Mechanics" end which apply to a homogeneous rectangle pressed by a force acting along one of the symmetrical axes. In these formulae

\[ N = \text{load} = P \]
\[ A = \text{area of the force} \]
\[ W = \frac{L}{2} - 2w \] ~

Thus we have

\[ \rho' = \frac{P}{2} \left( 1 + \frac{32 - 8w}{7} \right) = 2 \left( 2 - \frac{3w}{2} \right) \frac{P}{2} \] ~
\[ \rho' = \frac{P}{2} \left( \frac{4}{2} - \frac{2w}{2} \right) = \frac{2}{2} \frac{P}{2} \] ~

For (\text{a}) is applicable only when \( w < \frac{1}{3} \). For (\text{b}) is applicable when

\[ \frac{2 - 2w}{2} < \frac{1}{3} \text{ or } w > \frac{3}{2} \]

For (\text{b}) is applicable when \( w > \frac{3}{2} \).
The stability of the dam requires that each unit area shall receive a burst pressure that is less than the bursting point of the material.

Letting \( R' \) = burst pressure. The pressure at the point \( P \) must therefore be less than \( R' \), and we shall have from (a) and (b) according as

\[
\frac{2 - \frac{5}{4} \frac{P}{2}}{2} < R' \quad (\text{or}) \quad \frac{1}{3} \frac{P}{2} < R' \quad (\text{d})
\]

These conditions must be fulfilled in order to stability. These formulae would be modified if we took into account the maximum height to which a wall could be carried without losing the pressure on the face exceed the burst - \( R' \).

The formulae to ensure against slipping are very rarely used.

\[
LH = \frac{1}{6} CD \quad (pg 14) \text{ reduces the curve section of a wall or dam,}
\]

\[ P = \text{pressure on unit area face } BD \text{ (normal to surface).} \]
$P'$ and $P'' = \text{res. of the vertical and horizontal components of } P$.

$x = \text{any PE } P'P'' \text{ of } C$.

$P'' = 2 \text{ erc } x \text{ and } P' = P \text{ erc } x$.

The pressure upon any surface will be vertical in magnitude = the area of the surface \times \text{distance from curb. Pressure to curate to earth 7 gravity of curb instead = weight of a unit of volume}$.

Let $h$ = height of dam = $BF$.

$a = \text{horizontal projection of profile, consider a unit length of dam}$.

$P = \frac{1}{2} h \cdot C \quad (C = 62.5 \text{ lbs. per ft. at 12 ft. depth})$

$P'' = \frac{1}{2} h \cdot C \left( \frac{\tan \alpha}{\sqrt{h^2 + a^2}} \right) = \frac{1}{2} h^2 \cdot C$

$P' = \frac{1}{2} h \cdot C \left( \frac{\tan \alpha}{\sqrt{h^2 + a^2}} \right) = \frac{1}{2} a^2 h \cdot C$

letting $D = \text{breadth of dam}$

$a' = \frac{\tan \alpha}{h} \cdot D \cdot C$

$c' = \text{width of facet for foundation.}$
Area \( A B C D = \left( b + \frac{a \cdot d}{2} \right) h \) = cut. contact of a unit depth.

\[ \text{upt.} = \left( b + \frac{a \cdot d}{2} \right) h \cdot C' \]

The whole pressure in the base will \( h = \text{upt.} + \text{dam} + 2 \), which is

\[ \frac{1}{2} a \cdot h \cdot C + \left( b + \frac{a \cdot d}{2} \right) h \cdot C' \]

But the force tending to counteract the push of the water and we exchange the stability as to slipping difficulty is equal to \( \text{upt.} + \text{dam} + 2 \) increased by the pressure of the stage. By cutting the earth at the point \( P \) (picture) picture \( A-B \) if we have for the force to hold the dam the ice pressure

\[ \left( \frac{1}{2} a \cdot h \cdot C + \left( b + \frac{a \cdot d}{2} \right) h \cdot C' \right) f' \]

and when \( P'' \) is on the joint \( f \) displacing the dam.

\[ \frac{1}{2} h^2 \cdot C = \left[ \frac{1}{2} a \cdot h \cdot C + \left( b + \frac{a \cdot d}{2} \right) h \cdot C \right] f' - 2 \]

\[ h = \left[ a + \left( b + \frac{a \cdot d}{2} \right) \frac{2 \text{C}}{C'} \right] f' - \quad - \quad (C) \]

Hence for stability against slipping.
for \( \delta \) and find the limiting value for \( \delta \).

The discussion I hope to file to give to a wall having its end right side to impact is quite interesting but foreign to our subject. A few remarks will perhaps be in order.

We can find no easy escape. What is the maximum height for a wall with vertical face? If we wish to carry the wall beyond this height the base must be made larger so that the limit of pressure on a unit of area shall not exceed \( \frac{H}{\delta} \).

To illustrate \( FCD \) represents the wall height to which the wall \( F \delta CD \) can be carried with vertical face. If we carry it higher the base must be widened, as to \( C'D' \) so that the limit of pressure in a unit of area shall be less than \( H \).
To determine the profile of equal resistance.

This is theoretically an unsolved problem, as the integrations have not yet been fully made (only partial) so the method of procedure is possible.

The water is supposed to press on the face $OX$.

$\rho = \text{pressure on element whose area} = (\Delta x \cdot \text{tang of depth})$

$\rho = cy \text{ where } c = \text{pressure unit force that acts with a leverage of } x, x$ so that the differential moment $- (cx \Delta x)(x - \xi) \text{ and the whole moment } = c \int_{x}^{x} (x \Delta x \Delta x - x \Delta x)$, moment formula equals $m \int_{1}^{4} (y - \frac{y}{2}) \Delta x \text{ where } m = wyt + \text{fret, H. of centering placing the sum. Small end moment of pressure equals each other, and that if the integration could be performed we would get the equation for } C X$. 

Practically known it would be no account as this would give a well shaped figure with a top.

In constructing a dam, the face towards the river should have the same profile as a wall having to one way to support the water. The anti face should be such that the conditions of stability as previously stated should be satisfied.

Few remarks on the laying of stones in dam:

1. The building of the dam: The character of the inner filling.

2. The present plan to avoid laying the stones in strata, these being less stable. Essentially if the dam is to resist great pressure and to hold water, the stones should be laid in every possible direction.

To illustrate:

As a dam to resist pressure in the direction of 3, 4, 5, could not lay the stones in one direction.

As 10, 11, 12, 13, 14, could not lay the stones in one direction.
but rather as in II reason is very apparent. The face of the dam must be the same as the embankment, (so that the water has a downward pressure as well as a horizontal) but II is not so necessary. The filling should not be due to different character from the facing. The filling consisting of cut stone filled in with mortar is apt to crack and at time to be destroyed. This is illustrated in the case of canal boats, made of earth and stone, the buth cutting past so that the facing becomes detached, water penetrating, where too late with the first frost the facing will be detached.

"A good filling is that made by large rough blocks, struck so at regular intervals apart. (The distance increasing as the fill is approached) and the earth thrown in with mortar of the same quality, a method we believe, lately adopted in the construction of one of the Ordino dams in this state (N.Y.) but perhaps to get better one is to replace the latter.
by the French mixture known as kton lurgick. But these fillings known are and as that will sum-
ted the from a close extration with the fear all nae "A dirty away activity with pinto of any kind ") (Hochat)

We intiuded when we chose this subject to make a study of corridor dam as we had the good fortune of working with an engineer while mak-
ing the place & estimates for a tunnel look the dam. But pressure of other duties the num ber and importance of which were but the exan of the spring term knew I will not 
permit.

Finis.

1877.