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OF GENERAL INTEREST

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CONTINUOUS FRAME ANALYSIS OF FLAT SLABS

BY DEAN PEABODY, JR., MEMBER*

(Presented at a meeting of the Designers Section of the Boston Society of Civil Engineers held on March 8, 1939.)

THE American Codes for reinforced concrete design have contented themselves in the past with recommending for flat slabs that shear forces and bending moments be obtained by methods of analysis that allow for the continuity of the structure. Definite moment coefficients have only been suggested for the case where the successive spans are approximately equal ("Approximately" being defined at times to allow a 10 per cent variation in length).

It would seem that the time has come when more precise methods of moment determination are justified for structures with floor systems whose successive spans are markedly unequal. This is particularly needed for flat slab floors and for 2-way floors.

The mathematicians have worked on solutions for a long time and recently the engineer-mathematicians have tied together theory and tests with a seasoning of practical experience. The German specifications for flat slabs are based on the elastic web analysis of Dr. H. Marcus, which is briefly summarized by Prof. J. A. Wise in the 1928 A. C. I. Proceedings. The American Concrete Institute and Joint Committee moment coefficients are based on the analysis of Dr. Westergaard with a survey of tests by Prof. Slater (1921 A. C. I. Proceedings). Dr. Westergaard submitted his results for practical

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use in the form of floor plans with appropriate moment coefficients for 2-way and flat slabs with equal spans.

It is, however, desirable to have a general method of analysis that can be used by the designer to obtain for himself reasonable coefficients for unusual span ratios. The 1932 German specifications state, "The slab is resolved along the rows of the columns, transverse and longitudinal, with two series of continuous beams, framed into each other with the same degrees of restraint at the columns, as prevail in the slab proper", and the procedure of analysis is left to the designer aided only by a paragraph of suggested approximations.

Similarly, the 1937 Pacific Coast Building Officials Conference Code states for design of flat slabs by Method B, "Flat slabs . . . may be designed by treating such slabs, together with their supporting columns and walls, as elastic frames . . . ", followed by a page of general assumptions. The Code adds "In lieu of the elastic frame analysis . . . any exact method of analysis may be used, subject to approval . . . "

Flat slabs have been designed in Germany since 1932 and in California since 1937 according to these general statements. The facts that the buildings have behaved satisfactorily and that the Joint Committee coefficients for equal spans can be obtained by a general method of elastic frame analysis are justification for its use.

Elastic Frame Analysis

Elastic frame analysis involves the use of slope and deflection equations in some one of the variations in general use. The basic equation may be written in the form

$$M_{AB} = 2EK\ (2\theta_A + \theta_B - 3R)\ \pm F.E.M. \qquad (1)$$

where M_{AB} = the bending moment at the end A of a length AB

E = modulus of elasticity

K = ratio $\frac{I}{l}$

$\theta_A = \theta_B$ = change of slope at sections A and B

R = ratio $\frac{d}{l}$, where d = deflection of B relative to A

$F.E.M.$ = the bending moment at A if sections A and B are fixed.

This basic equation is often employed by the variation known as

Moment Distribution. This is the method that will be used in this discussion. For reinforced concrete design:—

I, the moment of inertia, is taken as the full sectional area with no allowance for the steel.

E is regarded as a constant for elastic loading, which is true for the richer mixes. When the effect of shrinkage, temperature changes, and plastic flow are included, the correct value of E is somewhat problemical and it can best be regarded as an empirical constant based on tests that allow for all these effects. In such cases the symbol E is really the modulus of resistance $R = \dfrac{n}{e + c}$ where:—

n = normal stress intensity

e = elastic strain and c = plastic flow, shrinkage or temperature strains.

Simplifying Assumptions—Flat Slabs or 2-way Slabs

1. All joints of columns and slabs are rigid.
2. There is no change in length of a member due to direct stress.
3. No deflection of a member due to internal shear stress.
4. Span of slabs shall be taken as center to center of columns.
5. Height of columns as center to center of floor slabs.
6. Width of slab equals width of floor bay.
7. Moment of inertia of any section shall be taken as the homogeneous gross section neglecting reinforcement.
8. The structure may be considered divided into a number of bents, each consisting of a row of columns and strips of supported floor slab-systems, each strip bounded laterally by the center line of the panel either side of the row of columns. The bents shall be taken longitudinally and transversely of the building.
9. Each such bent may be analyzed in its entirety, or each floor thereof and the roof may be analyzed separately into its adjacent columns above and below, the columns being assumed fixed at their remote ends. Where slabs are thus analyzed separately in bents more than four panels long, it may be assumed in determining the bending at a given support that the slab is fixed at any support two panels distant therefrom, beyond which the slab continues.
10. Supports of columns shall be assumed free from settlement or movement, unless the amount thereof is determined.

This paper discusses the practical application of continuous frame analysis to flat slabs with unequal spans. Much of the nomenclature and the results are taken from an extended analysis made by Mr. R. L. Bertin, chairman of the A. C. I. sub-committee on flat slabs, while studying the form of a revision of the present chapter 10 of the A. C. I. Code.

Flat Slabs

$\frac{M}{EI}$ *Diagrams*

An essential part of the use of slope-deflection method is the $\frac{M}{EI}$ diagram. In Figure 1, is shown a characteristic flat slab floor

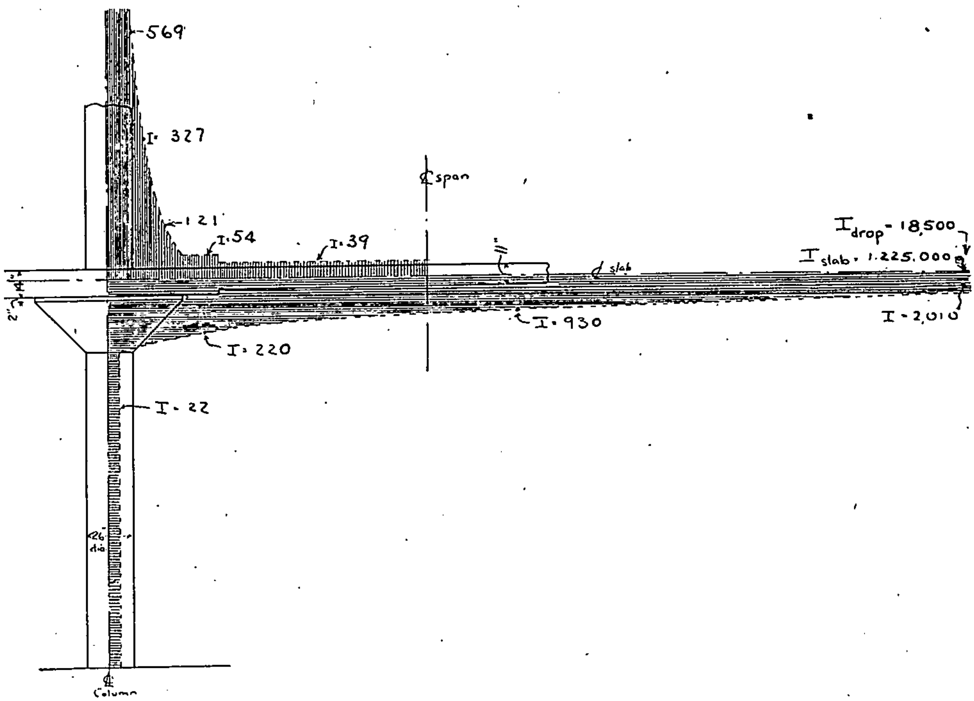
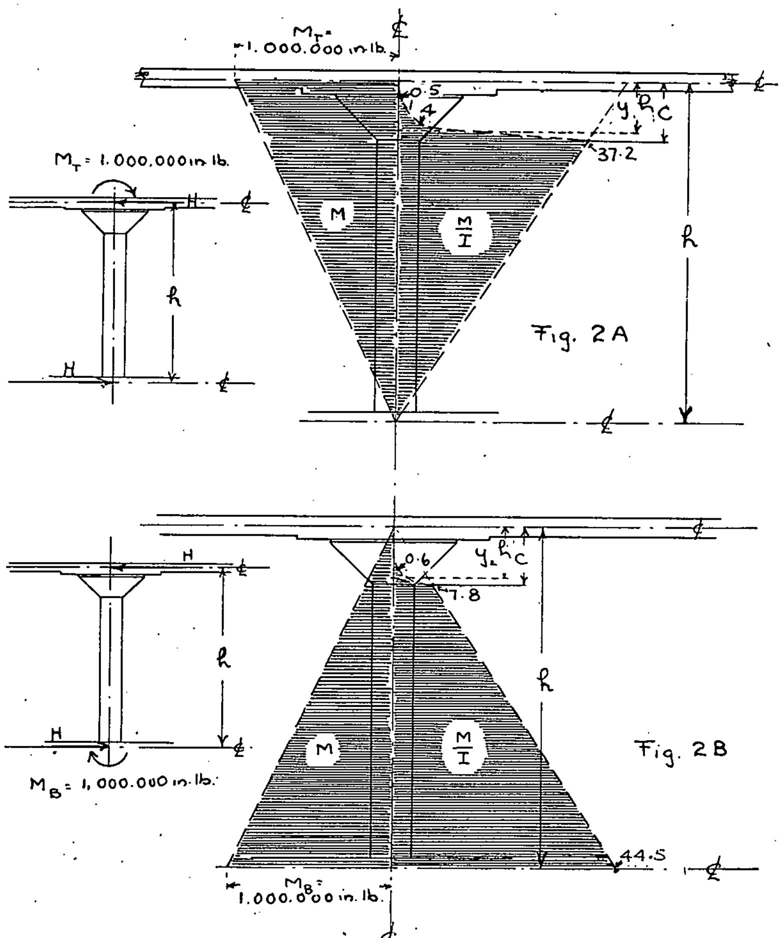


Fig. 1.—Flat Slab Variation of Moment of Inertia in Column and Slab. Column Capital = 80 Inches in Diameter; Dropped Panel = 122 Inches Square

system with the shaded area representing the moment of inertia I of the column and the slab, computed from the gross section with the reinforcement disregarded. These moments of inertia have been computed for the columns taking the sections perpendicular to the center line from the junction with the slab center line to the junction with the slab center line above. Similarly the slab moment of inertia has been figured up to the center line of the column using a width of slab equal to the column spacing laterally. In both cases the moment of inertia increases tremendously as the column-slab junction is approached.

In Figure 2 the column is assumed to be supported at the ends



FIGS. 2A AND 2B.—$\frac{M}{I}$ DIAGRAMS FOR COLUMNS and subjected to a couple M applied at the capital (Figure $2A$) or at the base (Figure $2B$). In each case the moment (assumed to be 1,000,000 in. lb.) varies uniformly to zero at the other end. There is also plotted in Figure 2 the values of $\frac{M}{I}$. These vary uniformly as long as the sections are taken in the column but decrease rapidly in the capital. The $\frac{M}{I}$ diagram can be approximated by assuming it to be uniformly varying to a section yh from the upper end. This will give a section near the bottom of the capital but for practical design it is sufficiently accurate to assume the bottom of the capital ($yh = c$). In this case the moment of inertia I is the constant value of the column proper.

Slope at Ends of Column—Simply Supported

If such a simplified $\frac{M}{EI}$ diagram is assumed, the slopes at the column ends can be computed. In Figure $3A$ the conjugate beam is

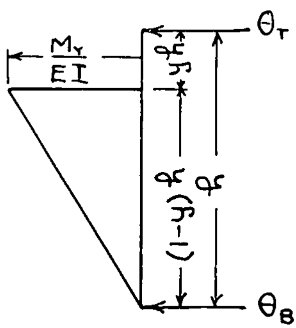


Fig. 3A

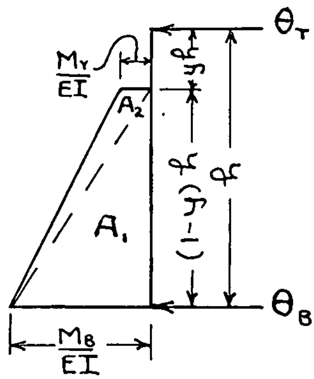


Fig. 3B

shown with a couple applied at the upper end. The supporting forces for the conjugate beam are the slopes at top (θ_T) and bottom (θ_B). Similarly, in Figure $3B$ is shown the conjugate beam for a couple applied at the bottom end of the column.

Couple M_T at Upper End of Column

At a distance yh below the upper support the moment

$$M_y = M_T\ (1-y) \qquad \text{(Fig. 2A)}$$

$$\text{Area of } \frac{M}{EI} \text{ diagram (Fig. 3A)} = \frac{M_y h}{2EI}\ (1-y) = \frac{M_T h}{2EI}\ (1-y)^2$$

$$\therefore\ \theta_T = \frac{M_T h}{2EI}\ (1-y)^2 \left[(1-y)\, \frac{2h}{3} \times \frac{1}{h} \right]$$

$$= \frac{M_T h}{3EI}\ (1-y)^3 = \frac{M_T h}{3EI}\ f_1 \qquad (1)$$

$$\theta_B = \frac{M_T h}{6EI}\ (1-3y^2+2y^3) = \frac{M_T h}{6EI}\ f_2 \qquad (2)$$

Couple M_B at Lower End of Column

At a distance yh below the upper support the moment

$$M_y = M_B y \qquad \text{(Fig. 2B)}$$

$$\text{Area of } \frac{M}{EI} \text{ diagram (Fig. 3B)} = A_1 + A_2$$

$$\therefore\ \theta_T = \frac{M_B h}{2EI}\ (1-y) \left[(1-y)\, \frac{h}{3} \times \frac{1}{h} \right]$$

$$+ \frac{M_B h}{2EI}\, y(1-y) \left[(1-y)\, \frac{2h}{3} \times \frac{1}{h} \right]$$

$$\theta_T = \frac{M_B h}{6EI}\ (1-3y^2+2y^3) = \frac{M_B}{6EI}\ f_2 \qquad (3)$$

$$\theta_B = \frac{M_B h}{3EI}\ (1-y^3) = \frac{M_B h}{3EI}\ f_3 \qquad (4)$$

Couple at One End of Member of Constant Moment of Inertia

$$\theta_{near} = \frac{Mh}{2EI} \left(\frac{2h}{3} \times \frac{1}{h} \right) = \frac{Mh}{3EI} \text{ (Fig. 4)} \qquad (5)$$

$$\theta_{far} = \frac{Mh}{2EI} \left(\frac{h}{3} \times \frac{1}{h} \right) = \frac{Mh}{6EI} \qquad (6)$$

Equations (1) and (4) differ from equation (5) by term f_1 or f_3 Equations (2) and (3) differ from equation (6) by term f_2.

Figure 5 shows variation of the (f) terms with values of (y) varying from $y=0$, when all (f) terms equal unity [see equations (5) and (6)], to $y=0.2$.

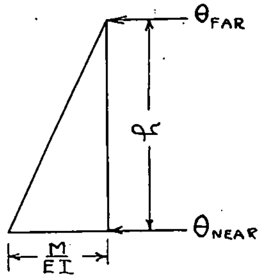


FIG. 4

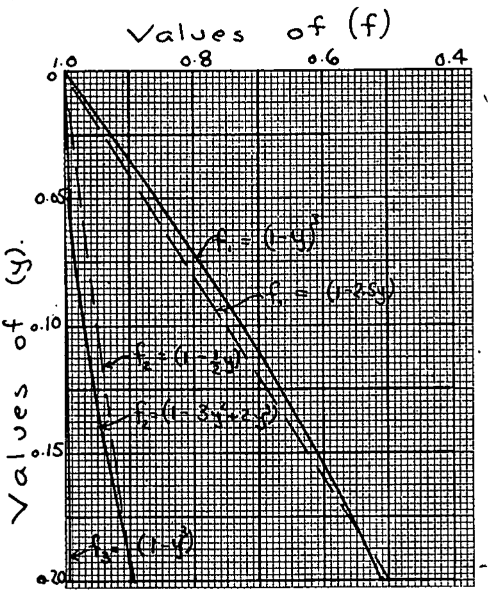


FIG. 5—COLUMN COEFFICIENTS

The dash lines give approximate values of the (f) terms according to the equations:—

$$f_1 = 1 - 2.5y \tag{7}$$

$$f_2 = 1 - 0.5y \tag{8}$$

$$f_3 = 1.0 \tag{9}$$

These values will be used in the succeeding discussion.

Moment at Ends of Column—Far End Fixed

If a couple M_T (Fig. 2A) is applied at the top of the column and the bottom is fixed, a couple M'_B at the bottom causes the slope θ_B to become zero. Equations (2) and (4) must sum up to zero, and:—

$$M'_B = \frac{M_T}{2}\,\frac{f_2}{f_3} = \frac{M_T}{2}\,(1—0.5y) \tag{10}$$

If a couple M_B (Fig. 2B) is applied at the bottom and the top of the column is fixed, a couple M'_T at the top causes the slope θ_T to become zero. Equations (1) and (3) must sum to zero, and:—

$$M'_T = \frac{M_B}{2}\,\frac{f_2}{f_1} = \frac{M_B}{2}\,\frac{(1—0.5y)}{(1—0.5y)} \tag{11}$$

If the member had a constant moment of inertia (Fig. 4), the fixed end moment, M'_{far}, would be:—

$$M'_{far} = \frac{M}{2} \tag{12}$$

Slab—$\dfrac{M}{EI}$ Diagram

The variation of the moment of inertia of the slab is shown in Figure 1. Assuming the slab to be supported at the center line of the columns and that a couple $M = 1{,}000{,}000$ in. lb. is applied at the left support, the $\frac{M}{I'}$ values have been plotted in Figure 6. I' is the actual moment of inertia at each section. This irregular area may be approximated by a uniformly varying diagram of $\frac{M}{I}$ (shown hatched in Figure 6) starting with a value of $\frac{M_x}{I}$ at a distance xl from the left support and ending with a value of $\frac{M'_x}{I}$ at the same distance xl from the right support. The moment of inertia I is that of the slab in the central portion of the span.

The slopes at θ_l at the left end and θ_r at the right end can be determined by using the original irregular $\frac{M}{I}$ diagram as the loading of a conjugate beam. The distances xl should be of such value that the

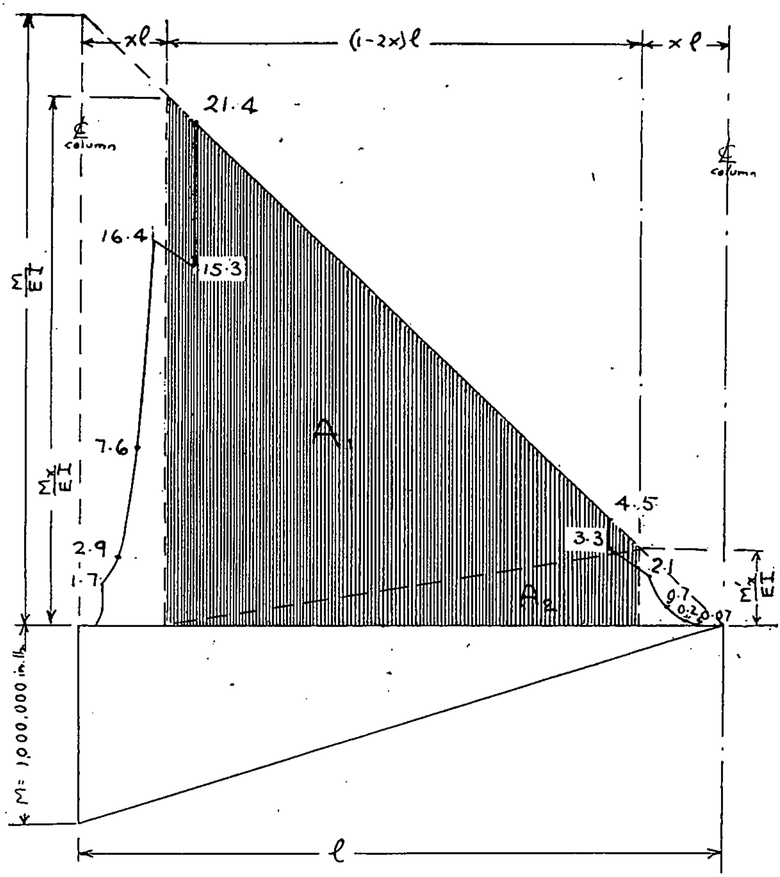


FIG. 6.—$\frac{\text{M}}{\text{I}}$ DIAGRAMS FOR THE SLAB

substitute $\frac{M}{I}$ diagram will give the same end slopes θ_l and θ_r. Mr. Bertin recommends that:—

$$x = b - (b - a)\frac{I}{I_1} \qquad (13)$$

where: a = distance from column center-line to edge of capital.
b = distance from column center-line to edge of dropped panel.
I_1 = moment of inertia of sections through the dropped panel.

I = moment of inertia of sections through slab.

Slab—Couple at One End

If the portion of the $\frac{M}{I}$ diagram within the distance xl of the slab supports be neglected, as in the approximation above, the slopes at the end of a simply supported beam can be determined for a couple applied at one end. In Figure 6 the hatched area will be the $\frac{M}{I}$ diagram for a conjugate beam with a couple M applied at the left end. Dividing this hatched area into two parts A_1 and A_2, the slope θ_{near} at the left end can be found.

at xl from left end: $$M_{xl} = \frac{M}{EI}\left(\frac{l-xl}{l}\right) = \frac{M}{EI}(1-x) \qquad (14)$$

$$A_1 = \frac{M}{EI}(1-x)\left[\frac{(1-2x)\,l}{2}\right] = \frac{Ml}{2EI}(1-x)(1-2x) \qquad (15)$$

at xl from right end: $$M_{(1-x)l} = \frac{M}{EI}\cdot\frac{xl}{l} = \frac{M}{EI}x \qquad (16)$$

$$A_2 = \frac{Mx}{EI}\left[\frac{(1-2x)\,l}{2}\right] = \frac{Ml}{2EI}x(1-2x) \qquad (17)$$

Then:
$$\theta_{near}\,l = \frac{Ml}{2EI}(1-x)(1-2x)\left[xl + \frac{2}{3}(1-2x)l\right] + \frac{Ml}{2EI}x(1-2x)\left[xl + \frac{(1-2x)l}{3}\right]$$

$$\theta_{near} = \frac{Ml}{3EI}(1-3x+3x^2-2x^3) = \frac{Ml}{3EI}f_4 \qquad (18)$$

Similarly:
$$\theta_{far}\,l = \frac{Ml}{2EI}(1-x)(1-2x)\left[xl + \frac{(1-2x)l}{3}\right] + \frac{Ml}{2EI}x(1-2x)\left[xl + \frac{2}{3}(1-2x)l\right]$$

$$\theta_{far} = \frac{Ml}{6EI}(1-6x^2+4x^3) = \frac{Ml}{6EI}f_5 \qquad (19)$$

Slab with Constant Moment of Inertia

For the beam with constant moment of inertia throughout a span of l

$$\theta_{near} = \frac{Ml}{3EI} \qquad \text{(equation 5)}$$

$$\theta_{far} = \frac{Ml}{6EI} \qquad \text{(equation 6)}$$

Slab—Ends Fixed

If the far end is fixed, a couple M' at that end is acting to cause the slope θ_{far} to become zero. By equation 18, M' acting alone would cause a slope of

$$\theta'_{far} = \frac{M'}{3EI} f_4$$

The original couple M produces a slope of

$$\theta_{far} = \frac{M}{6EI} f_5$$

The sum of the two slopes must be zero, so:—

$$M' = \frac{M}{2} \frac{f_5}{f_4} \qquad (20)$$

Slab—Loaded With a Uniformly Distributed Load

If the portion of the $\frac{M}{EI}$ diagram within the distance xl of the slab supports be neglected, the slopes at the ends of a simply supported slab can be determined for a uniformly distributed load on the slab. In Figure 7 is shown the parabola which is the bending

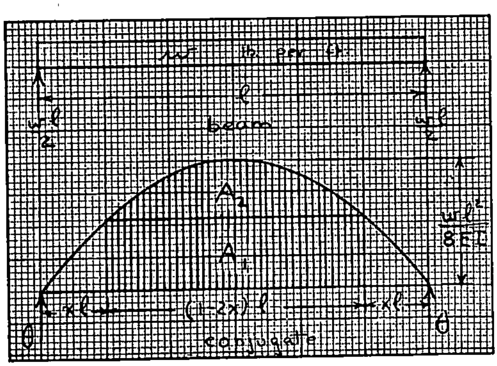


Fig. 7

moment diagram. The hatched portion is to be used in computations. Since the $\frac{M}{EI}$ diagram is symmetrical the two end slopes are equal.

$$M_{xl} = \frac{wl}{2}(xl) - \frac{w}{2}(xl)^2 = \frac{wl^2}{2} x (1-x)$$

$$\text{Area } A_1 = \frac{M_{xl}}{EI}(1-2x)l = \frac{wl^3}{2EI} x (1-x)(1-2x) \tag{21}$$

$$\text{Area } A_2 = \left(\frac{wl^2}{8} - M_{xl}\right)\left[(1-2x)l\right]\frac{2}{3EI}$$

$$= \frac{wl^2}{8EI}(1-4x+4x^2)(1-2x)\frac{2l}{3}$$

$$= \frac{wl^3}{12EI}(1-2x)^3 \tag{22}$$

$$\text{End slope } \theta = \frac{A_1 + A_2}{2}$$

$$= \frac{1}{2EI}\left[\frac{wl^3}{2} x (1-x)(1-2x) + \frac{wl^3}{12}(1-2x)^3\right]$$

$$\theta = \frac{wl^3}{24EI}(1-6x^2+4x^3) = \frac{wl^3}{24EI} f_5 \tag{23}$$

Slab Fixed at Both Ends

If the slab is fixed at both ends and loaded with a uniformly distributed moment, the fixed end moment must produce zero slope at the ends. By equations 18, 19, and 23 this moment M' equals:

$$M' = \frac{wl^2}{4}\left(\frac{f_5}{2f_4 + f_5}\right) \tag{24}$$

Slab Coefficients

Figure 8 shows the variation of the terms f_4 and f_5 with values of x. If $x=0$, there is a uniform moment of inertia and $f_4=f_5=1.0$.

If the approximate value of x be taken as:—

$$x = b - (b-a)\frac{I}{I_1} \qquad \text{(equation 13)}$$

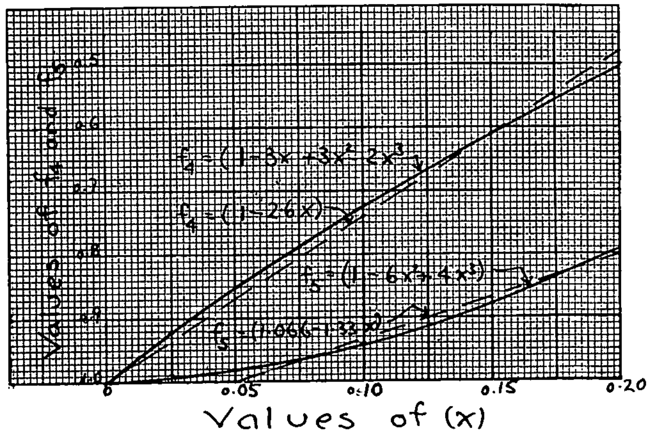


FIG. 8—SLAB COEFFICIENTS

approximate values of f_4 and f_5 are given as:—

$$\left.\begin{aligned} f_4 &= 1 - 2.6x \\ f_5 &= 1.0, \text{ from } x = 0 \text{ to } x = 0.05 \\ f_5 &= 1.066 - 1.33x, \text{ from } x = 0.05 \text{ to } x = 0.2 \end{aligned}\right\} \qquad (25)$$

These values are also plotted in Figure 8.

Distribution of a Moment at a Joint

Let joint A be subjected to an unbalanced couple M brought to the beam AB, (Fig. 9). If all members have constant moments of inertia, the respective resisting moments are:—

$$M_{AB} = 4\frac{EI_1}{l_1}\theta_A = 4EK_1\theta_A$$

$$M_{AC} = 4EK_2\theta_A$$

$$M_{AD} = 4EK_3\theta_A \text{ and } M_{AE} = 4EK_4\theta_A$$

Also $\quad M_{AB} + M_{AC} + M_{AD} + M_{AE} = M$

or $\quad \theta_A = -\dfrac{M}{4E(K_1+K_2+K_3+K_4)} = -\dfrac{M}{4E(\Sigma K)}$

Then $\quad M_{AB} = M\left(1 - \dfrac{K_1}{\Sigma K}\right)$

$$M_{AC} = -M\frac{K_2}{\Sigma K}$$

$$M_{AD} = -M\frac{K_3}{\Sigma K}$$

$$M_{AE} = -M\frac{K_4}{\Sigma K}$$

Moment Distribution at Joint of Flat Slab

If the far end of a flat slab span is fixed, the slope of the joint A for the beam AB (Fig. 9) can be determined using equations (18), (19), and (20):—

$$\theta_A = \frac{M_{AB}\, l}{3EI} f_4 - \frac{M_{BA}\, l}{6EI} f_5 = \frac{M_{AB}\, l}{3EI} f_4 - \frac{M_{AB}\, l}{2\times 6EI} \frac{(f_5)^2}{f_4}$$

$$\theta_A = \frac{M_{AB}\, l}{12EI}\left(\frac{4f_4^2 - f_5^2}{f_4}\right)$$

or $$M_{AB} = \frac{12EI}{l}\, \theta_A \left(\frac{f_4}{4f_4^2 - f_5^2}\right) = 4EK_1'\, \theta_A \qquad (26)$$

where $$K_1' = \frac{I}{l}\left(\frac{3f_4}{4f_4^2 - f_5^2}\right) \qquad (27)$$

then $$M_{AC} = 4EK_2'\, \theta_A$$

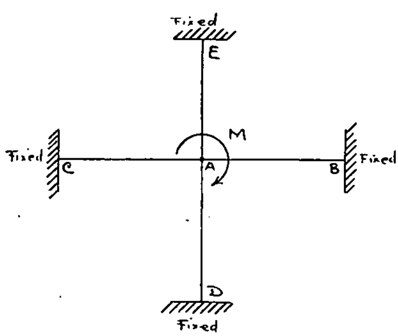


FIG. 9

The columns can be similarly treated. For the lower column AD, using equations (1), (3), and (10):—

$$\theta_A = \frac{M_{AD}\, h}{3EI} f_1 - \frac{M_{DA}\, h}{6EI} f_2 = \frac{M_{AD}\, h}{3EI} f_1 - \frac{M_{AD}\, h}{2\times 6EI} \frac{f_2^2}{f_3}$$

$$\theta_A = \frac{M_{AD}\, h}{12EI}\left(\frac{4\, f_1\, f_3 - f_2^2}{f_3}\right)$$

or $$M_{AD} = \frac{12EI}{h}\, \theta_A \left(\frac{f_3}{4\, f_1\, f_3 - f_2^2}\right) = 4EK_3'\, \theta_A \qquad (28)$$

where $$K_3' = \left(\frac{3\, f_3}{4\, f_1\, f_3 - f_2^2}\right)\frac{I}{h} \qquad (29)$$

The upper column is solved using equations (2), (4), and (11).

to give $$M_{AE} = \frac{12EI}{h} \theta_A \left(\frac{f_1}{4 f_1 f_3 - f_2^2} \right) = 4EK_4' \theta_A \quad (30)$$

where $$K_4' = \left(\frac{3 f_1}{4 f_1 f_3 - f_2^2} \right) \frac{I}{h} \quad (31)$$

Now $M_{AB} + M_{AC} + M_{AD} + M_{AE} = M$

or $$\theta_A = \frac{M}{4E \ (K_1' + K_2' + K_3' + K_4')} = -\frac{M}{4E \ (\Sigma K')}$$

Then $$M_{AB} = M \ (1 - \frac{K_1'}{\Sigma K'})$$

$$M_{AC} = - M \frac{K_2'}{(\Sigma K')}$$

$$M_{AD} = - M \frac{K_3'}{(\Sigma K')}$$

$$M_{AE} = - M \frac{K_4'}{(\Sigma K')}$$

Carry-Over Factor

Beams with constant moment of inertia have a moment at the fixed end equal to one-half the distributed beam moment at the joint which has been released.

The moment at the fixed end for flat slabs will be equal to:—

$$M_{BA} = M_{AB} \left(\frac{1}{2} \cdot \frac{f_5}{f_4} \right) \text{ by equation (20)}$$

In this case the carry-over factor equals $\left(\frac{1}{2} \cdot \frac{f_5}{f_4} \right)$ (32)

The solution of a continuous flat slab system can be made by the usual procedure of the moment distribution method, if the suitable constants for K' and the carry-over factors are computed. These constants enable one to treat each member as though it had constant moment of inertia.

Illustrative Problem

To show the application of this theory a solution is given below for a flat slab system of unequal spans. The procedure includes the determination of the necessary constants and a solution by the moment distribution method. More distributions must be made than for systems of constant moment of inertia because the carry-over factors for the beams are so much larger. Figure 10 shows the center

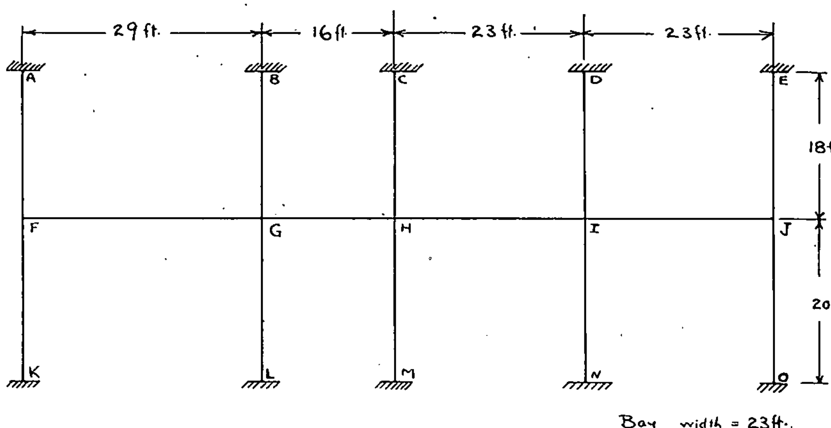


FIG. 10

line spans. Figures 11 and 12 give the necessary computations for the K factors, while Figure 13 shows the moment distributions for a uniformly distributed load of 1 kip per foot of length in span HI.

A similar solution for loads in each successive span enables one to determine the maximum negative moment diagram for each span and also the maximum positive moment diagram. By the use of the derived coefficients the method illustrated above is employed as if the slab had a constant moment inertia. A similar solution can be made for the spans in the perpendicular direction. These solutions cover slabs with or without dropped panels and columns with or without capitals.

CORRECTION FOR TWO-WAY SLAB SYSTEM

The analyses made above do not allow for the fact that these continuous frames are not one-way slabs. Each slab will act like a plate and deflect laterally as well as longitudinally. Accurate mathematical analyses, such as Dr. Westergaard's, allow for this and the moment coefficients are lower than those given by a one-way analysis. In the case of square slabs and equal spans this reduction amounts to about 28% of the one-way analysis. The accurate analyses are too

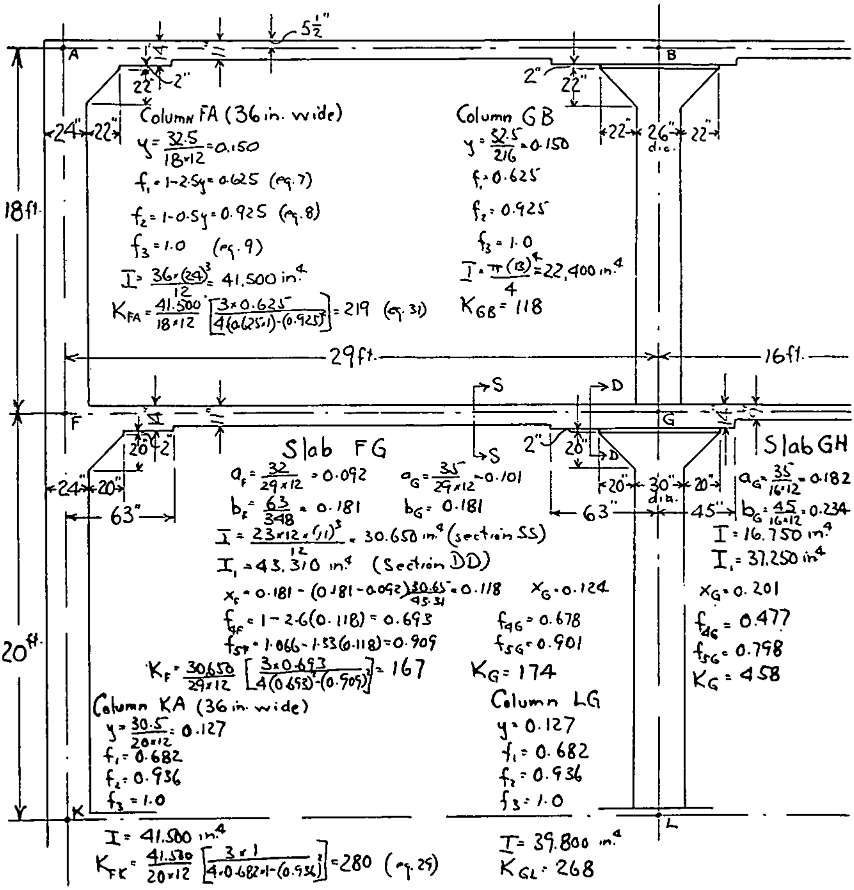


FIG. 11—SLAB AND COLUMN CONSTANTS FOR SPAN FG

difficult for use by the ordinary designer, especially with unequal spans.

Mr. Bertin suggests that this reduction can be found by assuming the critical negative moment be taken at some empirical distance out from the center line of the columns, much as we are accustomed to take the critical negative moment for beams fixed at the ends at the face of the column rather than at the center line of the support.

The present A. C. I. and Joint Committee codes only recommend moment coefficients for the case of equal spans with uniformly distributed loads. These coefficients have been used for a number of years and are reasonable values. If this case of equal spans and

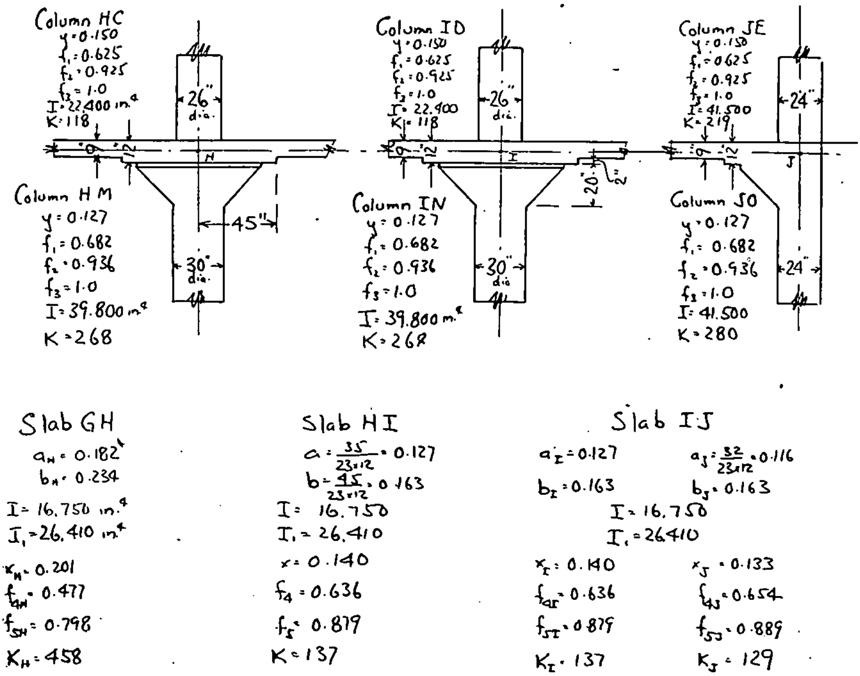


FIG. 12—SLAB AND COLUMN CONSTANTS

uniform load be applied to the equations derived above, the negative moment at the center line of each support can be found as illustrated above. Then a moment equation can be written for any section a distance (ml) out from the support. If this equation be equated to the recommended Joint Committee moments, the distance (ml) at which the moment equals the Joint Committee value can be determined. Mr. Bertin finds that this distance is given by the equation:—

$$m = 0.50 - \sqrt{0.183 - 0.45a} \qquad (32)$$

where al = distance from column center line to the edge of the capital, or to the face of the column if there is no capital. This critical section at which the reduced moment equals the Joint Committee value is usually located in the dropped panel somewhat beyond the capital. This equation gives negative moments varying less than 5% from the Joint Committee values.

The maximum positive moment can be taken as found in the original analysis. These values agree closely with those of the Joint Committee for dropped panel slabs but may be as much as 10 to 20%

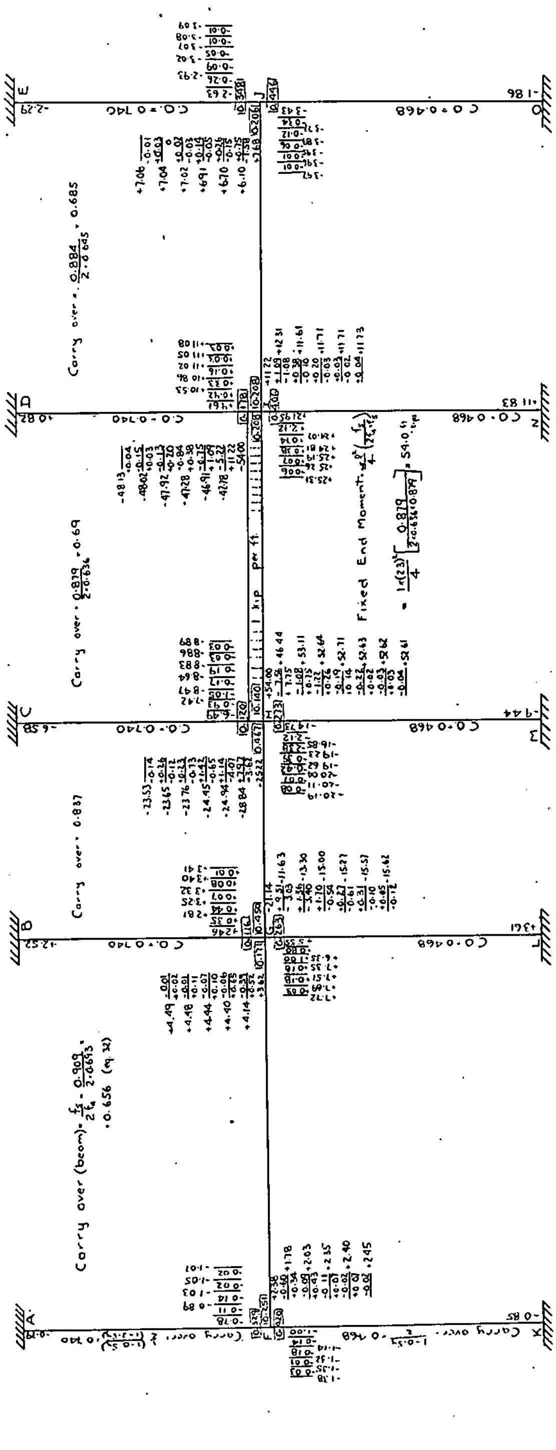


FIG. 13—MOMENT DISTRIBUTION FOR FLAT SLAB

in excess if there is no drop. The greater excess occurs with small capitals.

Neither the A. C. I. or Joint Committee give definite procedure, at present, for unequal spans. Without tests it is problematical whether the approximation of equation 32 can be used to locate the critical negative moment. Until some better *easily applied approximation* is justified, one can *tentatively* use equation 32 to locate the critical section, even though it was derived for the case of fixed ends (zero slope).

Applying equation 32 to span *HI* of the illustrative problem of Figure 10 the critical negative moments are found at a distance:

$$m = 0.50 - \sqrt{0.183 - 0.45 \times 0.127} = 0.146$$

$$ml = 0.146 \times 23 = 3.36 \text{ ft.}$$

Figure 14 shows the loads and bending moments obtained from

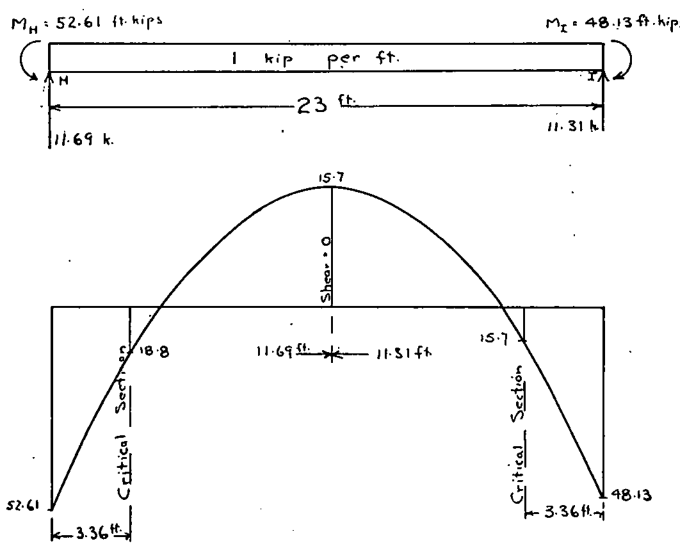


FIG. 14—MOMENT DIAGRAM FOR SPAN HI

the moment distributions. At the critical section near the columns at *H* the negative moment equals:

$$M_H = 18.8 \text{ ft. kips} = 0.0356\ wl^2$$

At the critical section at 3.36 ft. from the column centers at *I* the negative moment equals:

$$M_I = 15.7 \text{ ft. kips} = 0.297\ wl^2$$

The positive moment at section of zero shear equals 15.7 ft. kips. These values are all larger than would be used for design since the dead loads in the other spans would reduce the moments in span *HI*.

Distribution of Moment Across Width of Slab

It has been general practice to divide the slab width into two bands, the column and mid strips, and to assume the maximum moments to be constant in each of these strips. The Joint Committee recommends the per cent of the maximum negative or maximum positive moment to be taken by each strip, if the slabs have equal spans. No method is given for distribution if the slabs have unequal spans. The 1925 German Code recommends for all cases a distribution of 75% of the maximum negative moment to the column strip and 25% to the mid strip, while 55% and 45% respectively is the distribution at the section of maximum positive moment.

Accurate mathematical analyses are too complicated to apply to ordinary designs. However, in certain irregular spans it may well be desirable to ascertain a reasonable distribution. Such a distribution should ensure that the deflection is the same for north-south or east-west strips.

The area of slab supported by any column is bounded by the sections of zero shear. From the bending moment diagrams (Figure

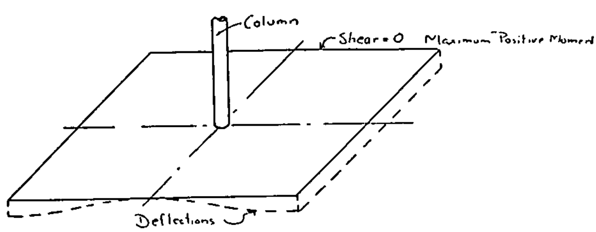


FIG. 15A—EAST-WEST DEFLECTION

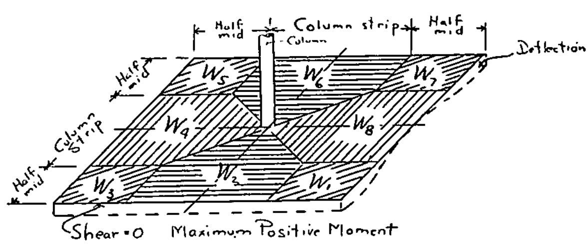


FIG. 15B—NORTH-SOUTH DEFLECTION

14) one can determine the sections of zero shear and divide the floor into rectangles, each assigned to a column.

The actual deformation can be visualized as an independent bending of the slab in the east-west direction (Fig. 15*a*) superposed on an independent bending on the north-south direction (Fig. 15*b*).

The deflection: at $0 = 0$ (Fig. 16) (33)

at $A = v_1$ (34)

at $B = v_2$ (35)

at $C = v_1 + v_6 = v_2 + v_7$ (36)

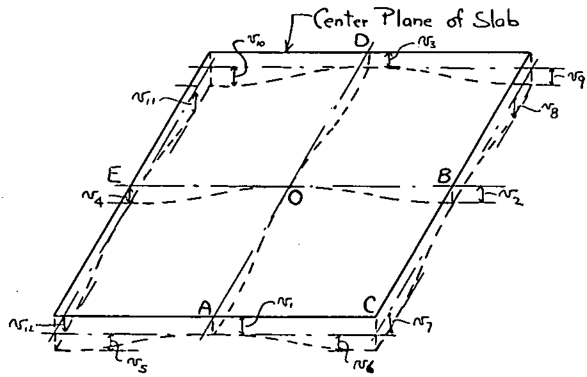


FIG. 16—COMBINED DEFLECTIONS

At each of the other corners equations similar to equation 36 can be written. In place of the accurate solution which requires that the deflection of any part of the slab shall be the same for the north-south strips as for the east-west strips, an approximate solution can be made by equating the deflections at the four corner points (equation 36). Mr. Bertin made such a solution dividing the loads on the slab as shown in Figure 15b.

Loads W_2 and W_6 are wholly carried by the north-south column strip.

Loads W_4 and W_8 are carried by the east-west column strip.

Part of the loads W_1, W_3, W_5, and W_7 are carried by the east-west mid strips to the north-south column strip. The remainder is carried by the north-south mid strips to the east-west column strip. The solution involved the additional assumptions:

1. The slope along the column center lines is the same for the column and mid strips and equals that found by the elastic analysis.
2. The bending moment on the section along the column center

lines is constant in the column strip and a different constant value in the mid strip. These moments are respectively proportional to the load carried by the mid and column strips.

3. The column strip loads are regarded as concentrated on an equivalent beam on the center line of the columns and the mid strip loads are concentrated on an equivalent beam on the section of zero shear.

4. The loads on these equivalent beams are assumed uniformly distributed.

Using these assumptions, it is possible to express the deflections v of the equivalent beams at the sections of zero shear in terms of:

$$v = k \frac{Wl^3}{EI}$$

where: the span l, and modulus of elasticity E are known. The moment of inertia I will be that of the slab in the column or mid strip respectively. The factor k can be determined for a uniformly distributed load on the span l with end slopes θ given by the previous elastic analysis. The only unknowns will be the per cent of the loads W_1, W_3, W_5 and W_7 carried by east-west or north-south strips. In other words, there are four unknowns for each column area. Using the deflection equality of equation 36 for the four corners these unknowns can be determined. Mr. Bertin solved by determinants and the final equations are as long as those of the accurate mathematical solutions. It is very doubtful if the designer would take time to use them, since they are so involved and based on so many assumptions.

Therefore, until some simpler solution of the moment distribution is found, it would seem wise to adopt an arbitrary division, such as is used in the German Code.

Summary

Adopting a width of one bay, it is possible to solve a flat slab of unequal spans as an elastic frame, obtaining the negative moments on the column center lines. The complete bending moment diagram for the loads adopted can then be constructed. The same procedure can be followed for the spans in the perpendicular direction.

Some combination of live and dead loads will give the maximum positive bending moment for the width of a bay. This moment can be used for design. The combination of live and dead loads which give the maximum negative moment at each column center line can also be determined. These maxima values are too large but the value to be used for design can be obtained from the moment diagram at some critical section beyond the column capital.

The critical moments, positive or negative, are distributed over a width of a bay. It is customary to assume constant moments in each of the two divisions of the bay, the column and mid strips. There is, as yet, no simple method of division for unequal spans and an arbitrary division seems desirable for the time being.

The method of elastic analysis outlined above can also be applied to continuous slabs supported on all four edges by beams or girders. The solution is much easier as the sections of one bay width have constant moments of inertia up to the face of the supporting beam and the columns usually have no capitals or brackets. There is the same problem of the distribution of the critical positive or negative moment between the column and mid strips.

THE COST OF COLLECTION AND INCINERATION OF REFUSE AT NEW BEDFORD, MASS.

By A. M. Thresher*

(Presented at a meeting of the Sanitary Section, Boston Society of Civil Engineers, held on March 1, 1939)

The City of New Bedford, with an estimated population of 111,642 in 1938, covers an area of 19.4 square miles, of which a built-up section of about 10 square miles is furnished with refuse collection service.

For some years previous to 1923, the city operated a garbage reduction plant which involved high operating costs and gave more or less trouble from odors. In 1923 the reduction plant was destroyed by fire and for 3 years thereafter makeshift methods, employing what was left of the reduction plant, were used for the disposal of garbage.

Shortly after the fire in 1923, engineering studies were made to determine upon the best method of disposal of the city's refuse. As a result of careful study it was decided to construct an incinerator plant. Specifications were prepared for a plant having a capacity of 100 tons in 24 hours. Proposals were invited and a total of 8 bids were received, ranging from $60,000 to $280,000. Following an analysis of the plants proposed by the several bidders, a contract for the construction of the plant was awarded to the Superior Incinerator Company of Dallas, Texas, at a cost of $99,500. This plant was completed and accepted in December 1926.

The plant has 4 furnaces, each furnace having 3 cells and a grate area of 156 square feet. There are two 100-ft. chimneys, each with an inside diameter of 5 ft. 6 inches. A stoking aisle passes through the center of the building. There are two furnaces on each side of the aisle, each pair of furnaces being served by separate chimneys which are located on opposite sides of the building.

Relatively little mechanical equipment is used in connection with the operation of the plant. Refuse trucks rise to the charging floor on a ramp, passing over a platform scale where they are weighed, and their contents are discharged directly into the furnaces. Electric chain hoists are provided to raise and lower the heavy fire-brick lined,

*Superintendent, Department of Garbage Disposal, New Bedford, Mass.

charging-trunk covers. The furnaces are of the sprung-arch type. Ashes are removed from the furnaces directly onto the stoking floor and are there shoveled by hand into ash trucks. The ashes are used to fill in low land at the rear of the plant. Forced draft equipment consists of two 5½ foot Sirocco blowers, each driven by a 15 H.P. electric motor. It has been impracticable to use these blowers with the method employed in charging the furnaces.

The incinerator was put into operation in January, 1927, and has operated successfully for the past 12 years. Operating costs since the plant was first started have varied considerably owing chiefly to the methods employed in the collection of refuse. For a time, garbage and rubbish were collected separately, the former being collected by contract, while the latter was collected by the Department of Public Works. The efficiency of operation of the furnaces with separate collections of garbage and rubbish was considerably less than when these materials were collected together. Separate collections prevailed from January, 1927, to June, 1929, during which period the cost of incineration averaged well above $2 per ton. Collection costs were also excessive, averaging above $5 per ton.

In July, 1929, the city entered into a 5-year contract for the collection of combined garbage and combustible rubbish. As a result, both the costs of collection and incineration were substantially reduced. The cost of collection since 1929 has been as low as $3.50 per ton and the cost of incineration as low as 89 cents per ton.

The following data on the collection and incineration of rubbish and garbage are for the year 1938:

Collection data — 1938

Rubbish	7,884 tons	27,39 tons per day	141 lbs. per capita
Garbage	12,874 "	44.95 " " "	231 " " "
Total	20,758 "	72.34 " " "	372 " " "
Cost of collection for 1938			$83,364.59
" " " per ton			4.19
" " " per capita			0.746

Operation of incinerator — 1938

Supervision and labor	$19,861.92	$0.956 per ton
Other than personnel	2,881.73	0.138 " "
Workmen's compensation & medical	500.13	0.024 " "
Outlay	214.46	0.01 " "
Total	$23,458.24	$1.128 " "
		0.21 per capita

Combined costs of collection and operation — 1938

	Annual	Cost per ton	Cost per capita
Collection	$83,364.59	$4.19	$0.746
Incineration	23,458.24	1.128	0.21
Total	$106,822.83	$5.318	$0.956

Costs of collection and incineration for the 12 years ending December 31, 1938 are shown on the following tabulation:

Collection data for 12 years ending Dec. 31, 1938

Rubbish	85,180 tons	
Garbage	145,147 "	
Total	230,327 "	Equivalent to 19,194 tons per year
Average cost of collection		$82,613.99 per year
" " " "		$4.42 per ton

Operation of incinerator for 12 years ending Dec. 31, 1938

Supervision and labor	$284,379.13	$1.238 per ton
Other than personnel	57,683.47	0.25 " "
Workmen's compensation and medical	2,946.71	0.012 " "
Outlay	11,253.49	0.048 " "
Total for 12 years	$356,262.80	$1.548 " "

Combined cost of collection and operation — 12 years ending Dec. 31, 1938

	Average cost per yr.	Cost per ton
Collection	$82,613.99	$4.42
Incineration	29,688.57	1.548
Total	$112,302.56	$5,968

The New Bedford incinerator has been in constant operation for 12 years. The cost of repairs to the furnaces during this period has amounted to $10,342.16 or an average of $861.85 per year. On the basis of the total tonnage handled, the cost of repairs amounts to 4.44 cents per ton. Approximately 85% of the cost of operating the incinerator is for labor, since the plant contains practically no mechanical equipment.

The experience of 12 years operation of the New Bedford incinerator attests to the success of this method of refuse disposal. The plant has served its purpose effectively and efficiently. The value of keeping complete and detailed operating records in a plant of this kind has been demonstrated beyond all doubt. Without such records there is nothing to guide a plant superintendent in his efforts to improve operation and reduce operating costs.

MECHANICAL EQUIPMENT FOR REFUSE INCINERATORS

By Charles E. Greene*

(Presented at a Meeting of the Sanitary Section of the Boston Society of Civil Engineers Held on March 1, 1939)

The purpose of this paper is to discuss the mechanical equipment of refuse incineration plants. Such equipment is selected on a basis of experience with equipment that has been in similar service with consideration of new developments that appear to be desirable. This selection involves certain general considerations which are stated briefly at this point.

General Considerations

The general nature of the incineration process involves getting the material to the top of the plant by driving the collection vehicles up a ramp or lifting the dumped materials with a crane or hoist, or by dividing the lift between the trucks and cranes making use of the natural contours around the plant. From the top of the plant the material generally moves by gravity in batches or "charges" through the furnaces to the ash pits whence the non-combustible portion is trucked away to a dump.

To give an idea of the scale of the operations, a 100 ton per 24 hour unit involves handling anywhere between 900 cubic yards of rubbish and 250 cubic yards of mixed refuse (garbage and rubbish). Usual city plants have more than 100-ton 24-hour capacity, 150 to 200 tons per day being a common capacity in smaller plants. 400-ton to 500-ton plants are frequently installed in cities where the production of large quantities of refuse in a limited area is found. Where the total collections are not the determining factor, the size of plant is based on balancing the cost of trucking the material farther against the cost of building and operating more smaller plants compared with the more economical, larger plants.

Practical sizes of crane buckets, furnaces, and charging arrangements tend to determine the size of batches or "charges" going through the plant at about 1½ cubic yards to 2 cubic yards. This is partly

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dependent on the size of the opening all through the process to admit the largest objects commonly found in refuse. The general practice now requires openings into the furnaces that will admit an object of 30 inches largest dimension. Oblong openings giving a somewhat larger dimension in one direction are often desirable.

With allowance for the excess rubbish that a bucket will pick up and the underload buckets when the bin is nearly empty, the crane must make about 320 to 400 round trips per day for a hundred ton unit, or one every four minutes.

Some charging device will have to operate once every four minutes or allowing three to a one hundred ton furnace, each charging device must operate once every twelve to fifteen minutes.

With rubbish, the material is reduced roughly to about 1/8 of its volume and to 40% to 50% of its weight. If the ash hoppers average 6 cubic yards to a 100 ton unit, they have to be emptied 16 times in 24 hours, or with 3 to a unit, 48 operations of one ash gate or another on each 100 ton unit.

If the units are smaller than one hundred ton, the charging and ash-removing devices are usually smaller and operate about as frequently. The dumping mechanisms of the grate might have to be operated two or two and a half times as often as the corresponding ash gates.

About 40 or 50 tons of ashes would have to be hauled away requiring at least 12 trips of the ash truck or roughly, once every two hours.

The whole schedule must be maintained 24 hours per day for 5½ or 6 days depending on the collection system.

This scale of operations would vary from city to city and even in different parts of the same city. It is fairly typical for rubbish, but only roughly representative of mixed refuse and only broadly suggestive of the corresponding figures for garbage.

Obviously everything has to "click" and ruggedness and dependability are prime requirements.

Wooden objects in the refuse tend to be broken down starting at the dumping process, helped along by the crane bucket and being finally consumed in the furnace.

The natural cussedness of steel wires, springs, chains, pipes, and structural shapes, and an infinite variety of metal objects has to be reckoned with at every step.

On account of the generally vertical movement of the material in the plant, the vertical height of every element is given careful consideration and vertical clearances are reckoned down to inches to economize on building costs and cost of lifting the material.

At most plants, the refuse arrives at the plant by automotive trucks. Most of these vehicles discharge their load by dumping, usually by elevating the front end of the body. Occasionally, the collection vehicles require other means of unloading such as moveable containers which are hoisted bodily into the plant and arrangements for pulling the load off the truck.

Weighing

The best practice is to weigh all refuse material arriving at the plant. Weighing is not universal, but is of such value that it should be encouraged. The weight records give an obviously valuable control over the work of the collection department, and the operation of the incinerator and are of assistance in preparing the annual department budget and forecasting future needs both of collection and disposal equipment.

The weighing is done on the truck in every instance with which I am acquainted. Platform scales are used, generally having a 20 ft. by 10 ft. platform and 10 ton capacity. Recent improvements have been in the use of dials for reading the weight more rapidly. There is some interest in scales which automatically print the weight on a record and on a driver's ticket. There does not appear to be any corresponding saving in operating cost to justify the extra first cost with current methods of superintendence of the collection department and the disposal plant.

At most plants a man is required to answer telephone calls of the public regarding collections during hours of collection and can be of assistance to the department head in charge of collection in a number of ways. These duties fit in with his location at the scales on account of his frequent contact with the truck drivers, so that the time of a weigh clerk is usually well spent. Sometimes his duties can be combined with those of the plant superintendent, but at some sacrifice of his effectiveness in every direction.

Doors

Enclosure of the dumping space, which is desirable to avoid nuisance around the plant, requires several large doors. The steel roll-up type seems to be favored over the overhead sliding or hinged and folding doors. The roll-up doors get more completely out of the way and lend themselves to motor operation in large plants, although they do not look as well and are less convenient to operate. They are probably safer.

CRANES

Where cranes are used they are usually of the four motor type in order to travel along the building, move the bucket across the building, and with one motor to raise and lower the bucket, and one to open and close the bucket. On account of the operating schedule described above, the speeds of each of these motions requires careful study, with the consideration of all motions and allowances for lost time included. The hoist motors will be 20 h.p. or 30 h.p. and the others, 3 h.p., 5 h.p., or 7½ h.p. These motors should be totally enclosed because of the exposure to dust. The crane brakes are a fertile source of trouble not only directly in themselves, but in their effect on other equipment. Careful attention must be given to suitability of rating, spring mounting or other shock-absorbing features and ease of adjustment and repair.

Roller bearings are available and generally used throughout the crane. The completeness of enclosure must be studied, especially for gears and brakes.

Direct current is by far the best for crane operation, but is seldom available in incinerator plants with a purchased electric power supply. On alternating current, the interconnection of the brakes with the motor control is important. Counter torque braking is being applied as superior to dynamic braking, the power being applied to the bucket in the hoisting direction of insufficient torque to overcome the weight and momentum of the dropping bucket but giving a smooth control of the rate of downward travel. Limit switches are always installed for both directions of bridge travel and for upward travel of the bucket. These devices have to be rugged and foolproof and their motions and adjustments require study to develop the full use of the building and furnaces with safety to equipment and personnel. The most obvious recent improvements in cranes for incinerators have been better safety devices and enclosure of contactors in the operator's cab, improved brakes, better mounting and enclosure of gears and brakes, and improved visibility and convenience for the crane operator.

More convenient access to the crane should be provided for emergencies, such as accidents and fires.

It can be seen from the outline of operations given above that approximately 200 tons of furnace capacity is the limit for a single crane. Larger plants usually require a second crane. This is dependent on building arrangement, height of lift, and character of material.

It must be borne in mind that when the crane breaks down, usually the plant stops operating. However, many plants with a single crane operate continuously with only minor shut-downs and all repairs made on week-ends. Next to the brakes, the cables are the most serious cause of interruption and upkeep expense. Everything affecting the cables should be carefully scrutinized.

Crane buckets are important. They are affected by the more direct and continual contact with the materials being handled. Their construction has been developed on a basis of handling the heavier, harder, and more abrasive materials found in other services so that they give little trouble. The principal considerations involve clearances as mentioned previously and a selection between lever-arm, power-wheel, and multiple-sheave operation with their effect on clearances, bucket swinging, and the tendency of the bucket to twist. The preference is generally in the order given above.

Charging Devices

When the material starts into the furnaces, it should come under the control of the stokers through some charging device. This control may be direct or through signals. The former leads to faster and better incineration. A variety of systems are being used. The crudest method has operators with hand tools or a bull-dozer push the material toward the charging inlets or even by direct dumping from the collection vehicles. Probably the most widely accepted method is to have the material dumped in hoppers leading by gravity flow of the material into "trunks" or containers, each of such size as to give a fairly uniform charge when admitted to the furnace. Some projection of the hoppers above the floor is desirable in preventing workmen from falling into the charging containers.

An ideal charging device should close the charging opening smoke-tight, resist exposure to the fire, and protect the incoming material from being ignited before entering the furnace. It must be capable of intermittently admitting charges of predetermined volume under control of the stoker, the frequency of operation being determined by the quantity and characteristics of the material.

Solutions of this problem have evolved into a horizontally moving truck or gate carrying a refractory-lined cover which is dropped onto the charging opening at the end of travel in the closing direction Above and insulated from this is a plate for closing the bottom of the charging container, thus supporting the material ready for the next charge out of contact with hot metal or brick. When the plate and cover move away from the charging opening, a short duct or trunk comes under the charging trunk and permits the material to drop into the furnace, at the same time, preventing spilling of it on top of the furnace. Gates on the bottom of the trunk may be used instead of the plate on the truck. The whole mechanism must be supported over the top of the furnace and resist the impact of large and heavy objects that may be dropped on it by the crane bucket. In many plants these charging gates are power operated, the generally accepted means being compressed air, from a central supply tank, acting on a piston under the control of the stoker. Direct electric power has been applied successfully. Hand operation through a chain and wheel is frequently used as a cheaper substitute for power operation. The forces involved must be carefully studied to provide sufficient power smoothly and yet not be destructive of the mechanism, if an obstruction is encountered.

Dumping Grate Mechanisms

After combustion is completed, the non-combustibles must be discharged to the ash pit from the grates. This is usually accomplished by hoeing or raking the non-combustible residue to a section of the grate that can be opened into the ash pit. Various arrangements have been tried to develop a movable section of grate that will resist exposure to heat and sudden changes of temperature without being interfered with by any of the troublesome materials frequently encountered. The tendency is toward one or two hinged sections of grate with a system of links to bring the operation to some mechanism outside the furnace. Most of the simple mechanisms such as lever, pulley, cam, screw, and wedge have been applied. Counterweights are frequently introduced and attempts to apply compressed air and electric power have been made. There are many successful arrangements, but few are outstanding. Any design that is submitted should be scrutinized for ruggedness, resistance to heat, moisture, ashes, and mechanical shock. A general rule requires about twenty inches to twenty-four inches clear opening for large objects and clinker.

Travelling grates have been used to solve in one mechanism the feeding and discharging problem. They are subject to injury and are not conducive to uniform combustion because of the non-uniformity of the refuse.

Ash Pits

An ash pit should provide storage, resistance to heat and moisture, air tightness up to the pressure required for forced draft (usually not over one inch of water) quenching the ashes and discharge at a level below the stoking floor.

These requirements have resulted in a steel or cast iron hopper as large as the grate at the top and thirty inches to thirty-six inches square at the bottom with a vitrified shale brick lining and a horizontal sliding ash-gate below. Direct discharge to the ash-handling truck is desirable and commonly used even at the expense of considerable added height to the building. The quenching is provided by sprays inside the hopper, the construction of which must provide for drainage of the quenching water.

Radial gates and clam shell gates tend to be deficient in air tightness, and size of opening. Hinged doors do not lend themselves to free discharge and drainage. Vertical or inclined sliding gates require more complicated and less rugged operating mechanisms.

The horizontal gates usually operate on rollers capable of adjustment for vertical clearance. These gates can be operated by hydraulic cylinders or by hand-powered gearing. The hydraulic cylinders are commonly used to economize on labor when more than six gates are in a single plant. Oil under pressure from a pump is the preferred means of applying the hydraulic power. Compressed air tends to irregular motion or jumping by the sudden expansion of the compressed air. The jumping causes jamming, which is the most troublesome feature of any ash gate mechanism. Water requires protection from freezing, especially during the week-end shut-downs in winter.

The ash tunnel must be effectively ventilated because of the steam and ashes liberated and because of the presence of gasolene powered vehicles. This is usually easy of accomplishment by the draft of the chimney on all spaces connected to it, but requires some study to be effective under all conditions.

Returning to the furnace, we find several auxiliaries commonly used:

Dampers

A main damper is always required to regulate the pressure in the furnace and velocity of the gases. The damper is required to close a duct opening 4, 5, or 6 ft. wide by 6 to 8 ft. high and must be able to travel from completely closed to wide open and further for occasional complete removal. The exposure may involve temperatures above 2000 degrees F. and considerable abrasion.

Various arrangements of firebrick supported in a steel frame have been tried, and light weight temperature-resistant alloys have been considered. A curtain of short sections of chains closely spaced has been used with moderate success. The most satisfactory construction for rubbish seems to be a boiler-plate shell filled with water and with overhead suspension by steel cables to a counterweight and winch. This requires a constant flow of water to be supplied and discharged through armored hose. The discharge is, for safety, usually without valves through a funnel for observation of temperature and rate of flow. This arrangement can waste much money in the form of water if not carefully controlled. Thermostatic regulation of the water flow appears practicable but has not been used so far as I know. There is opportunity for economy of water and recovery of some heat at this point.

The large flat surfaces exposed require bracing to prevent warping but this is usually easily provided in connection with the welded construction commonly used.

Other dampers, where the gasses are cooler or the exposure less subject to variation, are commonly used and resemble power boiler practice. They are usually pivoted at the center and of more or less corrosion-resistant and temperature-resistant alloys, depending on the exposure expected.

Fans

Forced draft fans are simple in nature, the air being clean and the required pressures seldom exceeding two or three inches. They are usually motor driven unless waste heat recovery makes steam available. They can and should be arranged to handle the air as cold as possible for economy of power. In the larger sizes, these fans are equipped with devices to make them efficient over a considerable range of volume and pressure. This method of control has recently superseded variable speed drive and plain dampers. Each section of the grate must have separate damper control arranged to be convenient to the stoker.

Induced draft fans are needed with waste heat recovery systems. Their construction resembles power boiler practice except that dual drive for them is seldom installed. These fans are usually selected for 600 degrees F. maximum temperature, with non-overloading characteristic and an effective means of varying the capacity over a much wider range of conditions than in power boiler practice. Control devices in the fan construction are superseding variable speed drive and are more important here than in the forced draft fans. The fans must be capable of handling dusty gasses and must be accessible for inspections, cleaning, and renewal of the rotor.

Waste Heat Recovery

Waste heat recovery is essential in garbage or mixed refuse incineration. The common arrangement includes preheaters for heating the air for combustion from heat in the products of combustion. This equipment is usually based on power plant practice modified to suit the more severe exposure and wide range of conditions. The present tendency is to use easily cleanable plate type preheaters with special attention to renewal of elements and cleaning. Older designs of plate and tube type have required modification to lighter weight temperature-resistant alloys usually of welded construction. Various patented arrangements using refractory brick shapes have been found successful but require study in building arrangement because of the space occupied, and weights to be supported. Study this equipment for ease of cleaning. The metal plate and the tube types can be fitted with soot blowers if steam is available.

A method of preheating air by withdrawing hot products of combustion from the furnace and mixing them with the air to the grates has been successfully introduced and gives promise of further development. It is practicable because the products of combustion usually include excess air of the order of 150 per cent or 200 per cent and only a 15 or 20 per cent mixture is required to give the desired preheat, so that the mixture will readily support combustion.

In the form already developed, the gas mixture is handled by a forced draft fan with induced draft fan construction and characteristics that enable it to pull against negative pressure in the combustion chamber. The principal advantage is in less building space, less equipment, and less maintenance cost being required.

Steam Production

When a use for the steam justifies the cost, further heat recovery is accomplished by waste-heat boilers. This is the most significant recent development in municipal incinerators in the northern section of the United States.

Recent practice has been to install water-tube boilers between the combustion chamber and air preheaters. More than one pound of steam per pound of rubbish has been developed in plants that have been in operation several years. Two pounds of steam per pound of rubbish or more is expected of modern plants and the practice will probably develop to a point where three pounds of steam per pound of rubbish is obtained.

This development is at present limited to localities where the material incinerated is rubbish only or a mixture of higher heat value than the usual mixture of garbage and rubbish as developed in the modern city. However, waste-heat recovery is being developed in variety of combinations with sewage sludge incineration depending on the status of the refuse and sewage disposal in the cities where new installations are being made.

The boiler arrangement must provide for cleaning for which soot blowers of the power plant type are used. The arrangement of tubes should provide as much vertical tube surface as possible to avoid accumulation of dust on the tubes. The gas flow should have as few turns as possible. Otherwise, the construction resembles power boilers.

Recent plants have avoided the large spaces necessary for bypass ducts direct to the stack by installing provisions for wasting the steam when the normal incineration develops more steam than the load requires. This is probably only a passing phase or transition period and future plants will probably be developed along the lines of more complete control of the flow of the gases from the furnace to the waste-heat boiler so that the two processes can operate with less inter-dependence.

The whole process of steam generation brings a factor into the operation of the incinerator opposed to the sanitary considerations that should be paramount in municipal incineration. The wasting of the steam to the atmosphere leads to boiler trouble and control difficulties. Interconnection of the steam generated with other steam generation or of the electric power generated from the steam with other sources of electric power may provide an avenue for this development which does not exist at present, except in scattered instances.

The air preheater problem is simpler where waste-heat boilers are installed. The preheater comes to resemble the conventional power plant air preheater being usually installed between the boiler and the stack.

Waste-heat boilers usually must have auxiliary fuel equipment to provide for generating steam when the incinerator is not in operation or when the heat content of the fuel is low. At present, this requirement is met by installing oil burners with the waste-heat boilers.

These oil burners with their accessories and all the boiler accessories follow power plant practice so closely that inclusion of a discussion of them in this article is not justified. Minimum requirements include boiler-feed pumps and control, feed-water treatment, draft control, storage of an ample supply of boiler-feed water, steam piping, and control valves, steam-wasting provisions, and boiler blow-off systems.

The waste-heat recovery at Providence has been developed to the extent of complete electric power generation for supplying the needs of the plant and the sewage treatment plant which is nearby. While considering this plant, it is well to notice the ash disposal system. The open bottoms of the ash hoppers are sealed by submersion in a trough containing water. At the bottom of the trough is a conveyor which carries the ashes as they collect in it to the end of the battery where they are carried up a slope, which enables them to drain, and discharges them to a cross conveyor. This in turn deposits the ashes in a truck outside the building. This system saves the head room required by the usual ash tunnel, avoids many ash tunnel problems. Its behavior up to date has been successful to the point of being miraculous. It is indicative of the care which designers familiar with incinerator operations, will take to overcome ash-handling difficulties.

The lighting, heating, and plumbing of an incinerator building should involve selection of equipment to resist exposure to dust, vapor, and mechanical injury, either by location or design. Every care should be taken to make the building and every item of equipment sanitary and easy to clean. Dust tight and vapor-proof electric fixtures are desirable in certain parts of the plant.

Complete toilet and wash room facilities and a clean place for lockers and lunch room should be provided for the workmen in order that high standards of cleanliness may be encouraged in the operating staff and enforced throughout the process.

In the selection of all equipment, some attention must be given to noise. Refuse is produced where people live and work. To save the costs of hauling the refuse, the incinerators are logically located near where people live and work.

The success of modern plants, in odorless and smokeless operation, has made practical the operation of incinerators in congested neighborhoods.

Incinerators must not be objectionably noisy especially if operated at night.

The crane is inherently noisy but the noises from it do not carry far, and are not usually objectionable outside the building. Air compressor noises carry considerable distances, in fact, many fire whistles are now compressed-air-operated. These noises are readily silenced and good practice requires the silencing of the compressed air at the compressor intake, and at all points of discharge.

The wasting of steam to the atmosphere which is inherent in some waste-heat recovery plants, may be a nuisance. Since it can be silenced, at small first cost and at no operating cost, silencing equipment should be installed on normal steam-wasting outlets. Safety valves should not be silenced since some dependence on the alarm feature of safety valve discharge is desirable.

The instrument equipment for incinerators usually is limited to draft gages for ash pit and furnace pressure and temperature recorders or indicators for the combustion chamber.

The draft gages are of conventional types, ruggedness, simplicity, and a convenient location are the principal requirements.

Temperature instruments, as installed prior to 1930 seldom remained in operation longer than a year. With more attention to the selection, location, and protection of the thermocouples and the general improvement in the instruments themselves in ruggedness, dust-tightness, these instruments are practicable for continuous operation. The records are of great value in operation of the plant.

It is generally conceded that if the gases from the furnace are passed through a zone where they reach a temperature of 1200 degrees F. or hotter, they will be odorless and with proper air supply will be smokeless. Temperature recorders give a permanent record of the maintenance of this condition and are a great protection to the operators and to the community.

If the temperature exceeds 2000 degrees F., the brick work of the incinerator suffers injury. This is partly due to the severe slagging and compounds formed by the ash at the higher temperatures, partly due to the greater expansion stresses, the lowered strength of the brick, and severity of sudden temperature changes. The temperature records are valuable in controlling this hazard.

The boiler instruments are of the conventional type, required by law or good practice. Flow meters give cost data as to steam generated and wasted and are valuable if the cost records are of value.

The temperature recording and indicating instruments have been successfully equipped to operate dampers for controlling the fire automatically by admitting excess-air over the fire and reducing temperatures. These devices remain in operation and fulfill the purposes for which they are installed. However, it has not been practicable to make them of such capacity as to be fully effective regardless of firing methods. With excessive forcing of a furnace and highly combustible material they only tend to relieve the situation and give a warning which careless or uninstructed operators can disregard.

Summarizing the trends in recent years, the type of plant with weighing, enclosed dumping, storage-bin and crane, charging by a mechanism under control of the stokers, ash quenching and direct discharge of ashes to trucks which haul the ashes to the dump, all seem to be firmly established in the field where economy of operation and twenty-four hour operation of the plants are required. The tendency is to install mechanical equipment more completely throughout the plant but to make each device simpler, more rugged, less automatic.

Effective provision for more complete heat recovery and conversion of this heat into a valuable by-product rather than an auxiliary to the process itself, is well established but capable of considerable development in the immediate future.

RECENT DEVELOPMENTS IN TRADE WASTE TREATMENT METHODS

By Edward W. Moore*

(Presented at a meeting of the Sanitary Section of the Boston Society of Civil Engineers, held on May 3, 1939)

Disposal of the water-carried wastes derived from industrial processes may properly be described as one of the most pressing problems confronting the sanitary engineer. Some idea of the magnitude of the problem may be gained from the message submitted to Congress by the President on February 16, 1939, relating to Federal regulation of stream pollution. In this report, the capital cost of the necessary works to treat industrial wastes, "in those instances where practicable processes are known", was estimated at $900,000,000 with an additional $142,000,000 for the treatment of mining and oil-field wastes. The fixed and operating charges on these works were estimated to be $225,000,000 annually. The President also stated that "In some instances it would be cheaper to move the industrial plants than to install the necessary treatment". States that have attempted programs for the abatement of stream pollution have already been apprised of this fact by the serious objections raised by industrialists. It may be safely predicted that the magnitude of the problem will be increased rather than diminished in the future, because of the present-day tendency of industry to diffuse away from large cities located near the seaboard or other substantial bodies of water.

It is generally recognized that the best method of disposing of industrial wastes, wherever possible, is to treat them in conjunction with domestic sewage. There are, however, many instances where, because of the lack of sewage treatment facilities, or because the waste is highly toxic or excessive in quantity relative to the domestic sewage, separate treatment of the waste is necessary. It is the purpose of this paper to review briefly some of the recently developed methods for the separate treatment of industrial wastes. The paper will be further limited in its scope to those industries which might conceivably be encountered in New England.

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Milk Plant Waste

Milk processing plants may be divided into three general classifications, namely, receiving stations, pasteurizing and bottling plants, and manufacturing dairies. At a receiving station, the milk is dumped from the farmer's containers, and is weighed, cooled, and reshipped in tank cars and trucks. The wastes consist mainly of drippings and washings from cans and equipment, and will contain 0.35 to 0.7 per cent of the milk intake. Pasteurizing and bottling plants prepare and package the milk for domestic consumption. The wastes are principally washings and drainage from the apparatus, and contain roughly the same percentage of the milk intake as the wastes from receiving stations. Manufacturing dairies may perform a variety of operations, including cream separation, manufacture of butter, cheese, condensed, evaporated or dried milk, and ice cream, and recovery of by-products such as lactose and casein, and chicken feed.[1*] The quantity and concentration of the wastes from manufacturing dairies will depend on the operations involved and the extent to which by-product recovery is practised.

For the most part, the wastes from all types of plants are similar in character, and differ only in quantity and concentration. They are essentially dilute solutions of milk solids. Their distinguishing characteristics are high concentrations of milk sugar (lactose) and easily decomposable protein materials. They are susceptible to rapid fermentation, with the production of high acidities (lactic acid) and foul odors (fatty acids and nitrogeneous decomposition products). The volume and composition of wastes from plants of various types is given in Table 1.

Table 1—Volume and Composition of Milk, Wastes
(Eldridge—Michigan Eng. Expt. Sta. Bull. 82, p. 29.)

Type of Plant	Volume per 1000 lbs. milk Gallons	Total milk solids p.p.m.	5-day B.O.D. p.p.m.
*Condensery	150	1200	800
**Creamery	100	1500	1000
Receiving station	160	700	600
Dry milk plant	150	1200	800
Bottling plant	225	600	500
Cheese factory	170	—	—

*Exclusive of vacuum pan water.
**Including butter washings, but not buttermilk.

*Numbers refer to Bibliography at end of paper.

Installation of drip-savers and pre-rinsing facilities will materially decrease the concentration of milk solids in the wastes. The milk thus recovered should not be used for human consumption. The whey from cheese plants must be separated from the rest of the waste, as it is strong enough (B.O.D. 32,000 p.p.m.) to render subsequent treatment difficult. It may be disposed of by drying, by recovery of lactose or lactic acid, by feeding to hogs and cattle or by dumping on farm land.

Milk waste treatment has been under investigation for a number of years, and several reasonably satisfactory methods of handling the waste have been evolved. Recent work has been confined principally to the investigation of high-rate trickling filters and the Guggenheim activated-chemical precipitation process. The use of the high-rate filter for milk waste treatment has been studied by Halvorson,[2] Eldridge,[3] and Trebler, Ernsberger and Roland.[4] The plant designed by Halvorson for a creamery at Lakeville, Minn., treats about 10,000 gallons per day of strong waste (B.O.D. 2000-8000 p.p.m.), reducing the B.O.D. to 200 p.p.m. or less, so that the effluent may be passed to the city sewer. The plant includes a souring tank with 4-day storage, a resettling tank with 2-hour detention period, and a high-rate tile filter 10 feet in diameter and 10 feet deep. Recirculation is effected by pumping filter-effluent to the resettling tank, the recirculated effluent amounting to 23 gallons per minute. The resettling tank also receives 7 gallons per minute of effluent from the souring tank. The gross filtration rate is thus about 25 m.g.a.d., the net rate 5.8 m.g.a.d. After a preliminary breaking-in period the plant reduced the B.O.D. of the waste from 2500 p.p.m. to from 62 to 132 p.p.m. (95 to 97% reduction).

In the experimental high rate filter plant designed by Eldridge, the waste enters a holding or equalizing tank, and passes to a sump in which it is mixed with settled filter effluent for recirculation. The mixture passes to a gravel filter and thence to a settling tank with one hour detention period. Settled effluent is wasted at a rate equal to the rate at which the raw waste is fed, the remainder being returned for recirculation. Eldridge recommends a gross rate of 20 m.g.a.d., and a net rate of 2.0-2.5 m.g.a.d. (recirculation 8 to 10 times). Under these conditions, with an average B.O.D. of 714 p.p.m. for the raw waste, B.O.D. reduction is 83.5% (Average of effluent B.O.D., 118 p.p.m.). For small milk plants (less than 3000 gallons of waste per day) Eldridge recommends a recirculating filter operated on a fill and draw basis.

Experiments using tin cans as a filter medium have been performed by Trebler, Ernsberger and Roland. The cans have proved to be a satisfactory and economical filter medium under the reducing conditions prevailing in milk waste. A commercial installation consisting of a Halvorson tile filter followed by a tin can filter has been operated at Wellington, Ohio. The tile filter is 8 feet in diameter by 8 feet deep, and the can filter 4 feet deep, with a top area of 300 square feet. At a rate of 4.1 m.g.a.d. on the can filter, the average overall B.O.D. reduction is 92.3 per cent for an average influent B.O.D. of 688 p.p.m. The influent to the tile filter contains an unspecified proportion of recirculated effluent from the can filter.

The Guggenheim bio-chemical process has been found satisfactory for the treatment of milk wastes by Eldridge and by Trebler and coworkers. Eldridge recommends about 100 p.p.m. lime (pH 7.4-7.8), 30 p.p.m. of ferric chloride, and 2 to 3 cubic feet of air per gallon of waste treated (3 hour aeration period). The suspended solids in the aeration tank should be held at 2000-3000 p.p.m. with a sludge index of 50-70. The influent waste should be fresh. Under these conditions a B.O.D. reduction of 89.3 per cent is secured when the average B.O.D. of the raw waste is 564 p.p.m. Two bio-chemical plants are in operation, at Glen Karn, O., and Marshall, Ind. The former occasionally receives considerable quantities of whey, which produces some operating difficulties, but otherwise gives final B.O.D. values below 50 p.p.m., from an influent having B.O.D.'s of 600-2000 p.p.m. The chemical costs at the two plants are $1.00 and $1.60 per day respectively, for flows of the order of 10,000-15,000 gal. per day. Excess sludge is disposed of without difficulty by lagooning.

An English treatment process described by Davis[5] subjects milk waste to a controlled aerated fermentation process. This is followed by separation of the precipitated fat and casein, and treatment of the effluent on a trickling filter. The B.O.D. of the waste is over 100 p.p.m. and that of the final effluent less than 1 p.p.m. The production of artificial silk and wool fibres made from casein may exert a considerable effect on the development of milk waste treatment by increasing the value of by-product casein.

Packing and Slaughter Houses

The basic operations carried on in slaughter houses are the slaughtering of the animal, the preparation of the various portions of the carcass (packing), and the extraction of fats (rendering). Many subsidiary processes are also involved. The quantity of waste produced in the course of the operations will range from 1000 to 1500 gallons per animal killed for a small slaughter house, and from 500-800 gallons per animal killed for a large packing plant. The waste is high in organic matter, particularly in fats and proteins, and may contain blood, hair, and large amounts of salt. The range of B.O.D. values most commonly encountered is 500 to 1000 p.p.m., but much higher values may occur. In a large packing plant a high proportion of the inedible material is recovered in the form of tankage. The wastes from a large packing plant are, for this reason, generally less concentrated than those from a small slaughter house.

Opinion has been divided as to the merits of the activated sludge process for the treatment of packing house wastes, and indeed, many difficulties have been encountered in its application. The work of Milling and Poole[6] at Muncie, Ind., shows that this process, properly applied, produces a high degree of treatment at relatively low cost. The plant installed for the Kuhner Packing Company of that city is provided with a preaeration tank with a detention period of 30 to 60 minutes, which receives both the raw waste and the excess activated sludge. This tank is followed by a primary clarifier providing 2.5 hours detention. The aeration units are designed for an aeration period of 17 to 22 hours and the final clarifier for about 2 hours' sedimentation. Facilities for digesting the waste sludge are contemplated. In the first six months of operation the plant has used 4.25 cu. ft. of air per gallon of waste treated (780 cu. ft. per lb. of B.O.D. removed). For two 24-hour sampling periods, the influent B.O.D.'s were 980 and 353 p.p.m. and the effluent B.O.D.'s 17 and 5.5 p.p.m. respectively. The cost of treatment has been $0.055 per hog unit, or $21.93 per day (215,000 gallons of waste per day), apportioned as follows: labor $7.00, power $4.95, interest, depreciation and maintenance $9.98.

Modern chemical precipitation of packing house waste is exemplified by the plant of the Tovrea Packing Company[7] at Phoenix, Arizona, which also receives molasses and soap manufacturing wastes, distillery slop, and domestic sewage. The plant consists of a screen and grit chamber, mixing and flocculating tanks, a sedimentation tank equipped for grease skimming, two-stage sludge digestion, and sand beds for sludge drying. The effluent passes to an irrigation field. The plant makes its own ferric chloride from chlorine and waste baling wire. Lime and sulfuric acid are also used occasionally. The quantity of waste treated is 250,000 gallons per day, with suspended solids ranging from 1500 to 5700 p.p.m. and B.O.D. from 750 to 2000 p.p.m. The effluent has averaged 167 p.p.m. of suspended solids, and 198 p.p.m. of B.O.D., with extreme values of 442 and 300 p.p.m. respectively. The chlorine consumption has been 230 lbs. per day. The grease recovered is 100 to 200 lbs. per day, and the gas production 18,000 cubic feet per day, which is utilized at the plants contributing the waste. The operating cost has been $18.00 per day, excluding fixed charges and depreciation. The values recovered in grease, digested sludge, gas, and effluent for irrigation are expected to offset this cost.

Distillery Waste

The troublesome portion of the waste from a distilling plant is the spent liquid from the still known variously as "slop" or "spent mash". A small part of this material is returned to the process ("slopping back"), and the remainder is either discharged or treated to recover stock feeds. This waste amounts to 45-55 gallons per bushel of grain ground, and contains 5 to 6 per cent of total solids or 2 to 4 per cent of suspended solids. It has a B.O.D. of 15,000 to 20,000 p.p.m. The waste is starchy, and therefore ferments rapidly.

For large distilleries, which predominate in present day practice, the accepted method of treatment has been the complete evaporation of the slop, and recovery of the solids as stock feed. In the older process, the slop was screened to remove coarse solids, and the screened liquid evaporated to a heavy syrup in multiple effect evaporators. The syrup and coarse solids were then dried together in rotary steam driers. Difficulty was experienced in the evaporation, which could be carried only to 15 to 17 per cent solids because of the formation of gels at this concentration. Two new processes have been developed to overcome this difficulty.

The Hiram Walker process[8] interposes a basket-type centrifuge between the screen and the multiple effect evaporator. The removal of solids thus accomplished permits concentration of the syrup in the evaporator to 45 or 50 per cent solids. This effects considerable savings in the drying operation, in which screenings, centrifuge solids (80 per cent moisture) and syrup are dried together to a 10 per cent moisture content. The feed thus produced sells for $17 to $30 per ton. The production is 16.5 lbs. of feed per bushel of grain.

The Bassett process[9] accomplishes the same result without any preliminary screening, by heating the slop to 35°C for a short period with live steam. This process coagulates the solids, which are then removed by filtration in a filter press or rotary filter. The liquid is evaporated to 60 per cent solids, and the syrup and filtered solids dried as usual. The press-cake contains 55 per cent moisture, as against 80 per cent in the screenings from the older process. The overall recovery is 21.5 lbs. of stock feed out of a possible 22.5 lbs. Rye slop requires more heating than slop from the manufacture of Bourbon whiskey.

Both processes require large capital investment, ($750,000 to $1,000,000 for a 20,000 bushel per day distillery) and are therefore not suited to the small distillery. No attention seems to have been given in recent literature to the disposal of distillery waste on a small scale.

"Pickling" Wastes

"Pickling" wastes result from the use of acids to clean metal surfaces prior to such operations as galvanizing, tinning, electroplating, and wire drawing. The most common type of pickling waste is that derived from the treatment of iron with sulfuric acid (10 to 20 per cent). It is essentially an acid solution of iron in the ferrous state, containing as much as 70,000 p.p.m. iron and 5000 or more p.p.m. of unspent acid. Hydrochloric acid is occasionally used in place of sulfuric.

One of the best-known methods of handling this waste consists of crystallizing out a part of the iron as ferrous sulphate ($Fe\,SO_4 . 7\,H_2O$), and re-using the mother liquor after making up to strength with acid. Several new variants of this process have been developed in Germany, including continuous cooling and crystallization cycles, and the use of partially dehydrated ferrous sulphate ($Fe\,SO_4.H_2O$ as a promoter of crystallization. Another process uses very dilute hot acid (0.1 per cent) for pickling. At this low acid concentration, the iron may be oxidized and removed as hydrated ferric oxide, and the liquor returned for use, after replacement of the acid consumed.

Because of the hygroscopic nature of iron chlorides, hydrochloric acid pickling liquors cannot be treated by these methods, but must be neutralized and the iron removed as hydrated oxide.

If concentrated pickling liquors are neutralized with limestone or dolomite, a sludge composed of ferrous hydroxide and calcium and magnesium sulfates is produced.[10] This sludge may be dewatered and molded to any desired shape. The material then dries and oxidizes to a hard tan-colored, porous mass. This substance has been given the name Ferron. It is claimed to be fire-proof, water-proof and capable of being sawn, cut, or machined. Its heat insulating properties are equal to those of 85 per cent magnesia, and it can withstand temperatures up to 900° Fahrenheit. In addition to its possibilities as a building material, it may be used for removing hydrogen sulfide from gases and liquids, as a filter material, and as a soil conditioner. The Sharon Steel Company of Sharon, Pennsylvania, has under construction a plant for the manufacture of 25 tons per day of this material. The process is patented.

Tannery Waste

The operations involved in the tanning of leather are too numerous to permit even the briefest of descriptions, but they may be classified into two groups, namely, those concerned with the preparation of the skin, such as soaking, liming, unhairing, and fleshing, and those concerned with the tanning and finishing of the skin.[11] The composite waste averages 6 to 7 gallons per lb of hide treated, and contains grease, particles of flesh, hair, lime, salt, and spent tanning materials. In the vegetable tanning process the B.O.D. of the composite waste will range from 500 to 2000 p.p.m. (2 to 3 lbs. per hide) and the alkalinity from 1000 to 3000 p.p.m. The spent tan liquors, comprising only 6 per cent of the total volume, contain nearly 50 per cent of the B.O.D. In the chrome tanning process, this waste is absent, and the B.O.D. of the composite waste is correspondingly lower. Toxic chromium salts may be present in chrome tanning waste.

Tannery waste has received little attention in recent literature, possibly on account of the poor economic condition of the industry. The problem of securing a high degree of treatment of the waste at a cost that can be borne by the tanner remains substantially unsolved. Present practise is confined largely to screening and sedimentation of the mixed wastes together with such expedients as that of holding the spent tan liquors for periods of high stream flow. Chemical precipitation and treatment on trickling filters following sedimentation has been used in some cases. Many elaborate schemes have been proposed, such as two-stage biological filtration, and combinations of biological filtration with chemical precipitation, but in most instances the costs have proved too high. Much can be accomplished by separate discharge of the weaker portions of the waste, and by mixing the remaining strong wastes in such a way as to induce maximum flocculation.

The sewage disposal plant at Rockford, Michigan,[12] treats a sewage containing 90 per cent tannery waste, and having a pH of 9.0 and a B.O.D. of 600 p.p.m. The sewage is given a 2-hour sedimentation, and the sludge is dewatered on a vacuum filter, using lime (6.4% of the dry solids) as a conditioning agent. The sludge is dumped on farm land. No further treatment is given to the effluent. Sludge filtration costs, including power, labor, and chemicals, amount to 0.28 cents per lb. of dry solids, or $6.35 per day.

TEXTILE WASTES.

Recent work on textile wastes has been concerned mostly with their treatment in conjunction with domestic sewage. Developments in this field up to 1936 are covered in the report issued by the Textile Foundation,[13] which is too extensive to be reviewed here.

Rayon boil-off waste is the liquor which remains after boiling knit rayon goods in a solution of soap and soda ash prior to dyeing. The waste contains sodium carbonate, soap, and emulsified oil. According to Snell,[14] this waste can be treated by adding calcium chloride and filtering through cotton cloth, or by filtering through a bed of ashes. The latter method is preferred because of its simplicity and low cost. It reduces the pH of the waste from 10.6 to 7.0 and the oxygen consumed value from 3760 to 660 p.p.m. The bed of ashes is 3 ft. deep, and is divided into three sections, the oldest section being replaced each week. The entire bed contains 1440 cu. ft. (30 tons) or ashes and will treat one m.g. of waste. The ashes are subsequently used in building secondary roads. This process would bear investigation as an inexpensive method of partial treatment for other types of industrial waste.

A dyehouse in Mohnton, Pa.,[15] successfully treats its waste by coagulation with 10-12 lbs. of lime and 2-3 lbs. of copper as per 1000 gallons, followed by sedimentation for three hours. After passage through sand beds, the effluent is colorless. The sludge is dried on coke beds.

Laundry Wastes.

The wastes from laundries consist of the various waters used for washing, rinsing and starching the clothes. They contain grease and dirt extracted from the clothes, soap, soda ash or caustic soda, blueing, and hypochlorite bleach. The volume of the waste waters is of the order of 1500 gallons per 100 lbs. of dirty clothes. The average B.O.D. of the composite waste is 400 p.p.m., but it may run as high as 1000 p.p.m.

Experiments performed at the Texas Engineering Experiment Station[16] have shown that laundry wastes may be treated on a standard trickling filter at a rate of 1 m.g.a.d. Without final sedimentation a B.O.D. reduction of 70 to 75 per cent was obtained on a waste having an average B.O.D. of 450 p.p.m. Instances have been recorded, however, where the high alkalinity of laundry wastes containing caustic soda have interfered with trickling filter operation. Laboratory scale experiments on chemical precipitation were also performed, using sulfuric acid in conjunction with the coagulants, in order to reduce the pH of the waste to 6.4-6.6. Chemical dosages were of the order of 1-2 lbs. of coagulant ($FeCl_3$ $Al_2(SO_4)_3$, or $Fe_2(SO_4)_3$), and 2 lbs. of sulfuric acid per 1000 gallons. B.O.D. reductions of 85 to 90 per cent were obtained. The Lawrence Experiment station has treated laundry wastes on a larger scale by coagulation with ferric sulfate. The coagulated and settled effluent was clear and had a B.O.D. of 52 p.p.m., corresponding to reduction of 87 per cent. The sludge was dried on sand beds.

Conclusions.

While important advances have been made in the past two or three years in the treatment of industrial wastes, many problems remain to be solved. The principal objective for the future should be the reduction of treatment costs to levels at which they can readily be met by industry. Table 2 contains some cost figures derived from data given by the authors of the papers cited in this discussion. These figures should be regarded merely as rough approximations since costs are greatly affected by local conditions. Since most of the treat-

TABLE 2—ESTIMATED COSTS OF TREATMENT OF TRADE WASTES

Waste	Treatment Process	Cost in Cents per 1000 gallons	Source of Figures*	Remarks
Milk Plant	Bio-chemical Process	10	(4)	Chemicals only.
Packinghouse	Activated Sludge	10	(6)	Total, including fixed charges and depreciation.
Packinghouse	Chemical Precipitation	7.2	(7)	Includes other wastes. Omits fixed charges and depreciation. No credit for recovery of valuable materials.
Tannery	Sedimentation Vacuum Filtration of Sludge	2.8	(12)	Estimating interest plus depreciation at 8% yearly.
Laundry	Chemical Precipitation	4 to 5	(16)	Chemicals only.

*Numbers refer to bibliography.

ment processes involved are similar to those utilized in the treatment of domestic sewage, it would appear that the sanitary engineer is best fitted to accomplish this reduction in cost. It is necessary, however, that he possess an adequate background of practical chemistry, and a degree of familiarity with industrial operations, since he must work in close cooperation with plant chemists and technologists. In the hands of such men must rest the abatement of industrial pollution of waterways envisioned in the President's report.

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OF GENERAL INTEREST

JOINT EXCURSION TO 18-MILE METROPOLITAN PRESSURE AQUEDUCT AND PLANT FOR MANUFACTURE OF LOCK JOINT CONCRETE PIPE — BOSTON SOCIETY OF CIVIL ENGINEERS, NORTHEASTERN SECTION, AMERICAN SOCIETY OF CIVIL ENGINEERS AND SANITARY SECTION, B.S.C.E.

An excursion by members of the Boston Society of Civil Engineers, Northeastern Section, American Society of Civil Engineers and of the Sanitary Section, B. S. C. E. was made on Saturday, June 10, 1939, to the work of the new Metropolitan Pressure Aqueduct and the manufacturing plant for the making of lock joint concrete pipe in Natick. About two hundred members and guests made the trip, in private automobiles.

Prior to the inspection trip about one hundred persons had luncheon at the Howard Johnson Grill, on the Worcester Turnpike in Framingham.

Immediately following the luncheon the party went to the manufacturing plant of the Lock Joint Pipe Co., on Speen Street, Natick, where the members were divided into groups under the direction of numerous guides who described the process of manufacture and conducted the groups through all parts of the plant.

A visit was made to Shaft 2 of the Southborough Tunnel, including the shops and tunnel excavating equipment. Also the trip included the Southborough plant of the Lock Joint Pipe Company, Section 1 of the pressure aqueduct and the excavating equipment at Shaft 1 of the Southborough Tunnel. At this plant 150 in. pipe was being cured in the yard. The excavating equipment for deep rock and earth cut and the laying equipment for the 150 in. pipe was in operation for the benefit of the excursion members.

The excursion party disbursed about 4:45 P. M.

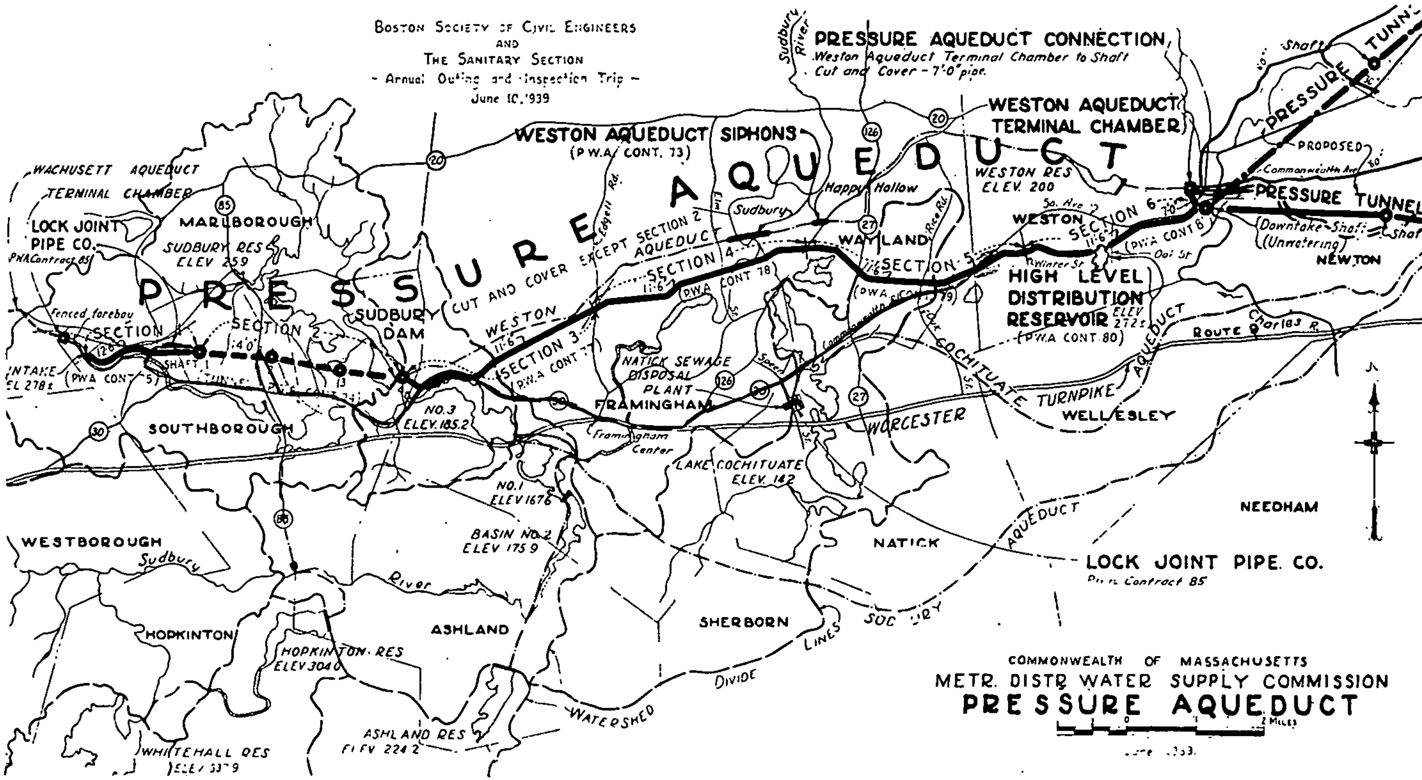
The inspection trip was arranged through the courtesy of the Metropolitan District Water Supply Commission, Karl R. Kennison, Chief Engineer, the Lock Joint Pipe Co., W. R. Rand, Branch Manager; the American Concrete and Steel Pipe Co., H. R. Bolton, General Superintendent; the West Construction Company, H. E. Carlton, General Manager; and B. A. Gardetto, Inc., Julius Abrams, General Superintendent.

Detail arrangements for the excursion were directed by George W. Coffin, Assistant Engineer, Metropolitan District Water Supply Commission assisted by a number of the other engineers of that staff.

About fifteen members of the Sanitary Section spent a part of the time inspecting the new Natick Sewage Disposal Plant, located on Speen Street just opposite the lock joint concrete pipe plant. The details of this inspection were arranged through the courtesy of Mr. B. C. Sargent, Superintendent of the Natick Public Works Department.

New Pressure Aqueduct

During the past twelve years the Metropolitan District Water Supply Commission has been engaged in the construction of works for an additional



BOSTON SOCIETY OF CIVIL ENGINEERS
AND
THE SANITARY SECTION
– Annual Outing and Inspection Trip –
June 10, 1939
PRESSURE AQUEDUCT CONNECTION
Weston Aqueduct Terminal Chamber to Shaft
Cut and Cover – 7'-0" pipe
WESTON AQUEDUCT TERMINAL CHAMBER
WESTON AQUEDUCT SIPHONS
(P.W.A. CONT. 73)
PRESSURE AQUEDUCT
WACHUSETT AQUEDUCT TERMINAL CHAMBER
LOCK JOINT PIPE CO.
PWA Contract 85
MARLBOROUGH
SUDBURY RES ELEV 259
CUT AND COVER EXCEPT SECTION 2
WESTON AQUEDUCT
WESTON RES ELEV. 200
PRESSURE TUNNEL
PROPOSED
Commonwealth Ave
Downtake Shaft (Unwatering)
Shaft
NEWTON
WESTON
WAYLAND
Sudbury
Happy Hollow
SECTION 1
SECTION 2
SECTION 3
SECTION 4
SECTION 5
SECTION 6
(PWA CONT 5)
(PWA CONT 77)
(PWA CONT 78)
(PWA CONT 79)
(PWA CONT 81)
Fenced forebay
INTAKE EL 278±
SHAFT 1
SUDBURY DAM
HIGH LEVEL DISTRIBUTION RESERVOIR
ELEV 272±
(PWA CONT 80)
ROUTE 9
Charles R.
NATICK SEWAGE DISPOSAL PLANT
FRAMINGHAM
Framingham Center
SOUTHBOROUGH
NO. 3 ELEV. 185.2
NO. 1 ELEV 167.6
BASIN NO. 2 ELEV 175.9
LAKE COCHITUATE ELEV. 142
WORCESTER TURNPIKE
COCHITUATE AQUEDUCT
WELLESLEY
NEEDHAM
NATICK
WESTBOROUGH
Sudbury River
HOPKINTON
HOPKINTON RES ELEV 304.0
ASHLAND
SHERBORN
ASHLAND RES ELEV 224.2
WHITEHALL RES ELEV 337.9
SUDBURY WATERSHED DIVIDE LINES
SUDBURY AQUEDUCT
LOCK JOINT PIPE CO.
PWA Contract 85
COMMONWEALTH OF MASSACHUSETTS
METR. DISTR. WATER SUPPLY COMMISSION
PRESSURE AQUEDUCT
0 1 2 MILES

water supply for the Boston Metropolitan District from the Ware and Swift rivers.* Water from these new sources will be of excellent quality and in order to deliver this water as well as that from Wachusett Reservoir, which is also of excellent quality, to the water consumers in the District, without its being contaminated with water from the older, and now seriously polluted Sudbury and Cochituate supplies, an 18-mile pressure aqueduct is being constructed from the terminal chamber at the easterly end of Wachusett Aqueduct to a point near the terminal chamber of the Weston Aqueduct, where connections will be made with the present distribution system of the District. Although this aqueduct will by-pass Sudbury Reservoir an emergency connection will be provided from this reservoir. Ultimately this pressure aqueduct will form the main delivery line to a rock tunnel pressure aqueduct which will loop around the cities and towns of the Metropolitan District and from which water will be delivered to the existing mains.

The completion of the pressure aqueduct now under construction will eliminate the danger of external pollution of the water between Wachusett Reservoir and Chestnut Hill and Spot Pond Distribution Reservoirs; and the completion of the loop aqueduct and a by-pass at Spot Pond (this by-pass to be constructed as a part of the present program) will eliminate local sources of pollution at Chestnut Hill and Spot Pond. The distribution hazard of broken supply mains and about 95 per cent of the pumping now required within the district will also be eliminated upon completion of the loop aqueduct.

The new aqueduct will have a present capacity of about 200 million gallons daily, ultimately 300, and will deliver water to the present high-service distribution system in downtown Boston under a pressure of 100 pounds per square inch.

*For previous articles dealing with the Ware-Swift Development and the Metropolitan Water Supply—see Bibliography in the Journal of the B. S. C. E. Vol. XXV—July, 1938, pp. 390-393.

The aqueduct is being constructed by the Commission with part of the unexpended balance (about $15,000,000) of funds originally made available for the Ware and Swift development and with a Federal grant amounting to about 45 per cent of the total cost. The Federal authorities in making this grant required that the work be completed by July 1, 1940.

The total construction cost of the Pressure Aqueduct, including the Weston High Level Distribution Reservoir and other appurtenant structures, has been estimated at $10,700,000. Seven contracts totaling $9,995,000 have been already awarded and construction is now well advanced.

Location of Aqueduct

The aqueduct begins in Marlborough at the terminal chamber of the Wachusett Aqueduct and passes through Southborough, Framingham and Wayland, and ends at the Weston Aqueduct Terminal Chamber in Weston just west of Norumbega Park on the Charles River. It has a total length including the forebay and a high level distribution reservoir in Weston of about 18 1-3 miles.

Description of Aqueduct

The aqueduct and principal structures consist of:

(1) An open forebay and low diversion dam to divert the water from the existing grade line Wachusett Aqueduct into the pipe aqueduct, this forebay being formed from the upper end of the open channel section of the Wachusett Aqueduct.

(2) 1.8 miles of 12′ 6″ precast reinforced concrete pipe cut-and-cover, grade-line aqueduct, to a downtake shaft in Southborough.

(3) 3.0 miles of rock tunnel under Southborough and the Sudbury Reservoir to an uptake shaft just below Sudbury Dam.

(4) 10.8 miles of 11′ 6″ precast reinforced concrete pipe, cut-and-cover pressure aqueduct, to a high level distribution reservoir in Weston.

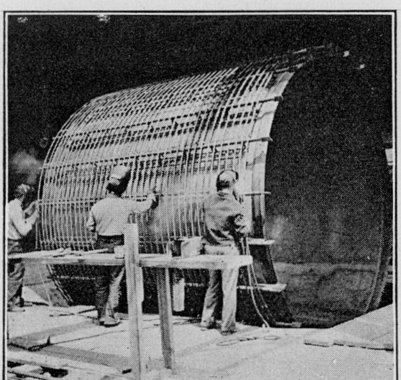
(5) A 140 million gallon high level distribution reservoir at about elevation* 272 feet (72 feet higher than the existing Weston equalizing reservoir).

(6) 2.0 miles of 11′ 6″ precast reinforced concrete pipe, cut-and-cover pressure aqueduct, to a plugged end at Riverside on the Charles River at which point a connection will be made to the proposed rock tunnel to Chestnut Hill. Construction of this tunnel has been authorized but funds for its construction will not be available until December 1941.

(7) 0.5 miles of 7′ 0″ precast reinforced concrete pipe, cut-an-cover pressure aqueduct, to the existing Weston Aqueduct Terminal Chamber. A "Y" branch will be installed in this line so that water can be delivered directly to the 60″ main to Spot Pond Reservoir.

Pipe Manufacturing Plant

The precast concrete pipe is being manufactured in Natick and Southborough by the Lock Joint Pipe Company of Ampere, New Jersey. The pipe is made with an all-welded steel circular core outside of which are wound spirally two cages of round reinforcing steel, one circular and the other elliptical. Spacers hold the cages from the cylinders during winding and the cages are then spot welded firmly in place. Joint rings are welded to both ends of the cylinder to form the bell and spigot ends of the pipe. After these rings have been welded to the cylinder, the cylinder is hydrostatically tested for strength and water tightness at pressures varying according to the thickness of the plate from 50 to about 120 pounds per square inch, these pressures being sufficient to stress the plate to 23,000 pounds per square inch. The concrete shell of the pipe is poured in the yard beneath a gantry serving 72 form units. Electric vibrators are hung on the outside of the steel forms in which the concrete is poured in order to insure a concrete of maximum density. The forms are removed after twenty-four hours and a canvas jacket placed over the pipe and the pipe cured for three days with steam at a temperature of about 120° F. The pipe is then stored in the yard and kept wet with hose or sprinklers for twelve more days, after which it is ready for delivery to the laying contractors. The pipe is delivered to the laying contractors by 50 ton Diesel powered low bed semitrailers. These trailers are equipped with 26 pneumatic tired wheels, including the ten wheels on the motor unit. Access roads are being constructed by the laying contractors on the aqueduct right-of-way, for storing the pipe until it is ready to be laid in the trench.



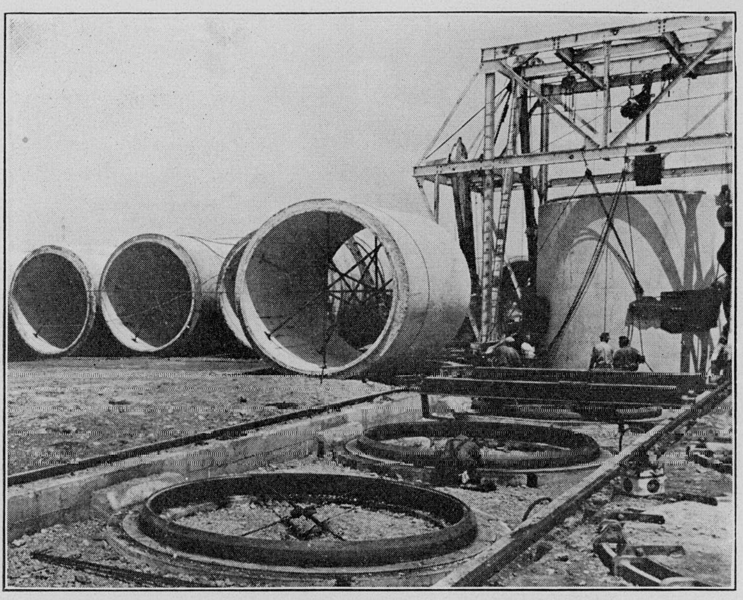
Welding Cages to Steel Cylinder. Lock Joint Pipe Co., Manufacturer. (Photo Donald Coe)

Both the 12′ 6″ and the 11′ 6″ pipes weigh about 45 tons to the length. The 7′ pipe which is manufactured in 12 foot lengths weighs about 17 tons per length.

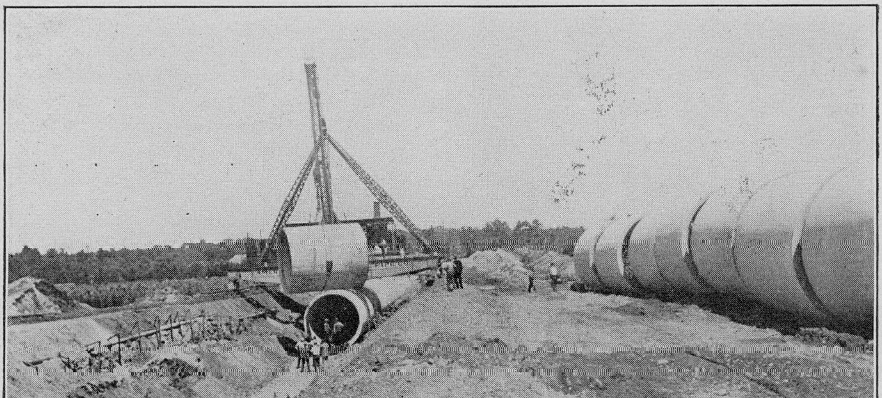
Pipe Laying

The first pipe, of 11½ feet diameter, was laid on May 24 on Section 5 by the American Concrete and Steel Pipe Company of Los Angeles. About 750 feet of this pipe, which is manufactured in 16 foot lengths has been laid to date. This pipe is being laid with a 50 ton steam operated gantry crane brought from California where it was used on a

*Boston City Base, 5.76 ft. below mean sea level.



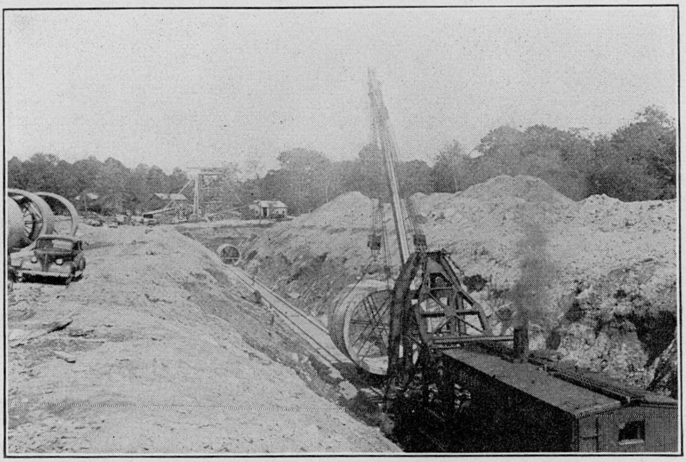
BASE RINGS FOR POURING FORMS, AND GANTRY FOR TURNING 138″ PIPE.
LOCK JOINT PIPE CO., MANUFACTURER.



LAYING 138″ PIPE IN WESTON WITH GANTRY. NOTE PIPE WELL SYSTEM TO KEEP TRENCH DRY. AMERICAN CONCRETE & STEEL PIPE CO., CONTRACTOR.

similar job. The aqueduct through this section goes through an area of high ground water and to keep this water out of the pipe trench, a Moretrench well-point system has been installed along each side of the aqueduct pipe trench.

Section 1, the upper end of the aqueduct, is nearly ready for pipe laying. The pipe on this section is 12′ 6″ in diameter and is made in 12 foot lengths. It will be laid by a 50 ton locomotive crane operated on standard-gage railroad track laid in the pipe trench. B. A. Gardetto, Inc., of Boston is the Contractor for this section and also for Section 3.



LOCOMOTIVE CRANE FOR LAYING 150″ PIPE, SECTION 1.
B. A. GARDETTO INC., CONTRACTOR.

On Section 6, the lower end of the aqueduct, the Contractor, M. F. Gaddis, Inc., of Boston, plans to lay the pipe using two 60 ton Diesel powered tractor mounted cranes.

Joints are of the self-centering type and are sealed with cold-calked fibre-filled lead gaskets. After the pipe is set in place in the trench, concrete is poured around and under the lower part of the pipe to form a firm foundation. Concrete anchorages are attached to the pipe in wet ground.

Weston High Level Distribution Reservoir

This reservoir located near the easterly end of the pressure aqueduct will serve primarily to equalize the flow in the aqueduct. It will have a capacity of about 140 million gallons, an area of about 50 acres, and a maximum depth of about 20 feet. It will be formed by means of earth dikes with rolled soil cores and concrete cut off walls.

Southborough Tunnel

The Southborough tunnel, of 14′ 0″ circular section, is being constructed from four 14-ft. diameter vertical shafts ranging in depth from 155 to 235 feet. The shafts were excavated by means of derrick and bucket hoists. The shafts have all been sunk to tunnel grade and head frames and cages are being installed. Tunnel driving is already under way and as soon as the cages have been installed mechanical mucking machines and electric locomotives will be used in the tunnel. The tunnel as well as the shafts will be concrete lined. Alongside of the uptake shaft, (Shaft 4) at Sudbury Dam, there will be a steel inter-lined unwatering shaft, at the bottom of which will be installed a 22 million gal-

138″ Reinforced Concrete Pipe Aqueduct in Weston Ready for Back Fill.
American Concrete & Steel Pipe Co., Contractor.

Southborough Tunnel. Head Frame and Spoil Pile at Shaft 2.
Stiff-leg Derrick used to Excavate Shaft.
West Construction Co., Contractor

lons per day (15,300 gallons per minute) pump for unwatering the tunnel. This pump will be driven by a 900 horsepower electric motor.

Real Estate

For the construction of the tunnel, a permanent casement has been taken underground and a 50 foot temporary easement has been taken on the surface. At each shaft site about ten acres have been taken in fee for disposal of spoil and for construction purposes. For the construction of the cut-and-cover aqueduct, a 125 foot strip has been taken in fee. In addition to this taking, a 50 foot temporary easement for construction purposes has also been taken.

Personnel

The Quabbin Reservoir development of the Ware and Swift Rivers was constructed, and the present pressure aqueduct planned, by the late Chief Engineer Frank E. Winsor of the Metropolitan District Water Supply Commission. The work is being carried to completion by his successor, Chief Engineer Karl R. Kennison. Stanley M. Dore is Assistant Chief Engineer and Charles L. Coburn is Principal Designing Engineer. Division Engineer Frederick W. Gow has charge in the field of Sections 1, 2 and 3, and Division Engineer Coleman C. McCully has charge of Sections 4, 5 and 6.

The precast concrete pipe is being made and delivered under the direction of W. R. Brend, Branch Manager of the Lock Joint Pipe Co. P. M. Putnam is Resident Engineer for the Commission at the Lock Joint Pipe Company's plant.

Sections 1 and 3 of the pressure aqueduct are being constructed under the direction of Julius Abrams, General Superintendent for B. A. Gardetto, Inc. D. K. Sampson is Resident Engineer for the Commission on these sections.

Section 2, the Southborough Tunnel, is in charge of H. E. Carleton, General Manager for the West Construction Co. D. S. MacLean is Resident Engineer for the Commission at Shafts 1 and 2, and J. J. Vertic is Resident Engineer for the Commission at Shafts 3 and 4.

Sections 4 and 5 of the pressure aqueduct are in charge of H. R. Bolton, General Superintendent for the American Concrete and Steel Pipe Company. R. W. Moir is Resident Engineer for the Commission on these sections.

Section 6 of the pressure aqueduct is in charge of E. F. McGee, General Superintendent for M. F. Gaddis, Inc. R. F. Fryar is Resident Engineer for the Commission on this section.

The entire project, since its start in 1926, has been under the direction of the Metropolitan District Water Supply Commission, a special construction commission, of which Eugene C. Hultman is the present chairman and Thomas D. Lavelle and Edward J. Kelley are the present associate commissioners.

BOSTON SOCIETY OF CIVIL ENGINEERS SCHOLARSHIP IN MEMORY OF DESMOND FITZGERALD AWARDED TO NORMAN B. CLEVELAND, STUDENT AT NORTHEASTERN UNIVERSITY

Norman B. Cleveland, of Beverly, Mass., a senior student, class of 1939, in Civil Engineering in the School of Engineering, was awarded the Desmond FitzGerald Scholarship of the Boston Society of Civil Engineers, on May 17, 1939. The presentation of the Scholarship of $100 was made by Mr. Frank B. Walker, Vice-President of the Boston Society of Civil Engineers, at a meeting of students held at Jordan Hall.

REPORT ON CONFERENCE OF THE NEW ENGLAND STUDENT CHAPTERS OF A.S.C.E., MAY 12, 1939

The Northeastern University Section of the Boston Society of Civil Engineers sent four delegates, including Professor E. A. Gramstorff, to the second annual Conference of New England Student Chapters of the American Society of Civil Engineers, which was held Friday, May 12, 1939, at the University of New Hampshire, Durham, N. H. Representatives from nine engineering schools in New England composed the group of about eighty at the afternoon session. This session was devoted to the reading of three student papers, two by men from Massachusetts Institute of Technology, and one by a delegate from Worcester Polytechnic Institute.

President Fred Engelhardt of the host University briefly addressed the group. The meeting was under the direction of Mr. Abbott, Chairman of the University of New Hampshire Student Chapter. Dean Case of the Engineering School also spoke a few words. Mr. Abbott called for reports of activity in the various student chapters, and announced that there were at present nine member groups in the Conference. The four charter members are Rhode Island State, Brown, Worcester Polytechnic, and New Hampshire. The five new members are the chapters from Tufts, Harvard, M. I. T., Maine, and Northeastern. The Northeastern Student Chapter was voted admittance as an associate member with full privileges due to its affiliation with the B. S. C. E. rather than the A. S. C. E.

A meeting of the Executive Committee of the Conference was called immediately after the adjournment of the afternoon session, at which the announcement was made by the Chairman, Mr. Marcello, of the future Conferences. Next year the meeting will be held at Worcester Polytechnic Institute, and in 1941 at Northeastern University. Each host chapter was given the privilege of choosing its own Conference date in order to avoid interference with their respective school functions. The Executive Committee voted to assess each member chapter dues in the amount of three dollars per annum. Of this fund, fifteen dollars is to be given as two prizes, ten dollars and five dollars, for the two best student papers presented at the Annual Conference of the Chapters. The remaining twelve dollars is to go toward defraying the cost of each Conference, and any cost over this amount will be met by additional assessment on each participating student chapter.

The Executive Committee, which is composed of two delegates from each student chapter, then elected their officers for the current year, these positions being Chairman and Vice-Chairman. Mr. Van Tuyl of Northeastern and Mr. Nash of Tufts were chosen to fill the respective offices.

The evening session was a meeting of the Northeastern Section of the A. S. C. E. in conjunction with the Conference of New England Student Chapters, and was preceded by a dinner served in the Commons. The guest speaker of the evening was Professor J. K. Finch of Columbia University who spoke on "The Relationship of the Practicing Engineer to Engineering Education." He outlined what has been done and what can be done in the future to give the student of engineering a better bridge between graduation and professional placement.

The Conference as a whole was a great success, both from the point of view of interest and attendance. At the first Conference, held last year at Rhode Island State, there were only eighteen delegates in contrast to the eighty or ninety this year. The Conference is fulfilling its purpose by bringing about closer relationship between the Student Chapters and stimulating interest in our chosen profession through activity in such organizations.

NORMAN B. CLEVELAND, *Chairman.*

NORMAN W. VAN TUYL,
Acting Clerk Northeastern University Section.

IS MEMBERSHIP IN THE B.S.C.E. WORTH WHILE?

Observations of a Member After Twenty Years

By Anonymous

If a young member of the Boston Society of Civil Engineers were asked, "Why did you join the Boston Society of Civil Engineers?" he would probably reply that he wished to advance in his profession.

Twenty years from now, he may ask himself, "Why did I join the Society?" He may think of what he could have done with the total of $200 yearly dues, wondering if he could not have made a better investment.

A newly elected young member may find his answer in some book, but the older member will read the book of his own experience. Joining the Society is a good beginning, but the benefits to be assured require more than the investment of $10 a year.

As a member of more than twenty years standing (and in good standing) I have the opportunity to review the events in the Society's life and to evaluate my experiences therein.

Probably the most important contribution that membership will make toward one's advancement will come from the contacts with those who have already trod the path which lies ahead of the young engineer. Many times have older engineers of prominence helped young members with their first professional papers, shown them the way to straight thinking on difficult problems, or encouraged them by putting them in line for Society office. They were glad to help those who were receptive. YOUNG MEMBER, you too, may receive similar help from your Society contacts.

As time goes on, you will learn, or, perhaps the lesson has been learned already, that much engineering work is not purely technical. A great deal of it involves problems not only of organization in field and office, but also of dealing with owners, officials, and the public. Someone, well qualified to do so, has said, "A good executive is a man who can get people to do things his way and like it." In your professional work you will have to deal with both subordinates and superiors. In all of your contacts with others, you will be helped by your Society contacts. This is particularly true of committee work. One can gain much useful experience from aiding in the work of various committees.

Still another benefit to be gained from active interest in the work of the Society is the development of salesmanship, and its principal ingredient, the power of expression. Throughout life, each will have something to sell: yourself to a prospective employer; your instructions to subordinates; your ideas to superiors, public officials and clients. Society contacts, with their opportunities for explanation and discussion, will have much value in the development of your power of expression.

Fine personalities that inspire, helpful social contacts, opportunities for discussion of problems and practices, information on contemporary progress, reference facilities,—all these are the return on your investment. Like dividend checks, they are no good until you cash them. When you do, however, by giving of yourself, you will no longer doubt the wisdom of your having joined the Boston Society of Civil Engineers.

25TH ANNIVERSARY OF FAY, SPOFFORD & THORNDIKE

In observance of the 25th Anniversary of the formation of the firm on July 1, 1914, the partners and staff of Fay, Spofford & Thorndike, Consulting Engineers, 11 Beacon Street, Boston, held Open House on Friday, June 30, 1939, at the Engineers Club, Boston. This celebration was enjoyed by about 200 engineers and others who have known this organization and members of the staff for many years.

The members of the firm as originally organized consisted of Frederic H. Fay, Charles M. Spofford and Sturgis H. Thorndike. Mr. Thorndike died Feb. 16, 1928.

The present partners are, Frederic H. Fay, Charles M. Spofford, John Ayer, Bion A. Bowman, Carroll A. Farwell, and Ralph W. Horne. The principal Engineers on the Staff are E. B. Myott, H. J. Williams, W. L. Hyland and F. L. Lincoln.

PROCEEDINGS OF THE SOCIETY

MINUTES OF MEETINGS

Boston Society of Civil Engineers

April 21, 1939.—A regular meeting of the Boston Society of Civil Engineers was held this evening at the New Lecture Hall, Harvard University, Cambridge, and was called to order at 7:30 P.M., by the President, Gordon M. Fair. This was a joint meeting with the Northeastern Section, American Society of Civil Engineers, and the Designers Section, Boston Society of Civil Engineers. The meeting was attended by about 700 persons. About 40 members and guests attended the dinner at the Harvard Faculty Club, previous to the meeting.

The President introduced the speaker of the evening, Colonel John P. Hogan, Chief Engineer and Director of Construction, New York World's Fair 1939, who gave a very interesting illustrated talk on "The New York World's Fair 1939." The Fair designed to portray the World of Tomorrow included the Magic Carpet, Spiral Garden, House of Jewels, Tomorrow Town, Rocket Ship; buildings of plate glass, mirrors, stainless steel, shaped like gas burners, radio tubes, airplanes and other things designed by man. Many innovations in the use of materials are of interest to Engineers. Colonel Hogan stated that "This is the first Fair that was ever built by Engineers."

The meeting adjourned at 9:30 P.M.

EVERETT N. HUTCHINS, *Secretary.*

May 17, 1939.—A regular meeting of the Boston Society of Civil Engineers was held this evening at the Engineers Club, and was called to order by Vice-President, Frank B. Walker. Thirty-eight members and guests were present. Thirty-three persons attended the supper.

Vice-President Walker announced the death of the following members:

Howard Perkins, who had been a member since January 25, 1928, and who died August 1, 1938.

Richard J. McNulty, who had been a member since March 5, 1915, and who died March 14, 1939.

Prof. Henry B. Alvord, who had been a member since May 19, 1909, and who died April 20, 1939.

The President also announced the death of Miss Joan M. Ham, who had been office secretary for the Society since August, 1934.

The President called upon Past President, Karl R. Kennison, to outline plans for the excursion to be held June 10, 1939, to the work of the New High Pressure Aqueduct, under construction by the Metropolitan District Water Supply Commission in Natick, and the manufacturing of reinforced concrete lock join pipe to be used on parts of Aqueduct.

Vice-President F. B. Walker reported on the presentation of the Boston Society of Civil Engineers Scholarship, in memory of Desmond FitzGerald, to Norman B. Cleveland, of the Senior class, at a meeting of Students of Northeastern University today at Jordan Hall.

Vice-President Walker introduced the speaker of the evening, Dr. Martin Wagner, Assistant Professor of Regional Planning, Harvard Graduate School, who gave a very interesting talk on "Shelter from Air Raids in Town Planning." The talk was illustrated by lantern slides.

The Society gave the Speaker a rising vote of thanks for his interesting talk.

Adjourned at 8:40 P.M.

EVERETT N. HUTCHINS, *Secretary.*

SANITARY SECTION

MAY 3, 1939.—A regular meeting of the Sanitary Section was held this evening at the new Engineering Building, Northeastern University. Twenty-two persons attended supper at the "Lobster Claw," prior to the meeting, and forty-three persons attended the meeting.

The Chairman, Ralph M. Soule, introduced the speaker, E. W. Moore, Asst. Prof. Department of Sanitary Chemistry, Harvard Graduate School of Engineering. Prof. Moore discussed the recent developments in trade waste treatment and discussed some of the problems encountered, and the equipment and treatment used for the disposal of tannery, textile, laundry, brewery, slaughter house and pickling wastes. At the conclusion of the paper an interesting discussion followed in which about ten members of the Section took part.

The meeting adjourned at 8:45 P.M. at which time the members were conducted through the new chemical, mechanical and hydraulic laboratories of the University, this inspection being arranged through the courtesy of Prof. C. O. Baird.

GEORGE W. COFFIN, *Clerk.*

DESIGNERS' SECTION

APRIL 21, 1939.—The Designers' Section of the Boston Society of Civil Engineers participated in a meeting which was held jointly with the Boston Society of Civil Engineers and the Northeastern Section of the American Society of Civil Engineers this evening. The meeting was held at 7:30 P.M. in the New Lecture Hall of Harvard University.

The speaker was Colonel John P. Hogan, Chief Engineer and Director of Construction of the New York World's Fair. Colonel Hogan gave an illustrated talk entitled, "The New York World's Fair of 1939." He was introduced by Professor Gordon M. Fair, President of the Boston Society of Civil Engineers, who presided.

Approximately 700 members and guests were present.

JOHN B. WILBUR, *Clerk.*

MAY 10, 1939.—The Designers' Section of the Boston Society of Civil Engineers held a regular meeting in the Society rooms this evening, and it was called to order at 6:45 P.M. by the Chairman, Professor J. D. Mitsch. The minutes of the two previous meetings were read by the Clerk and were approved. The Chairman requested that any members who had ideas concerning suitable topics for future meetings, communicate them to him.

The speaker of the evening was Mr. J. R. Nichols whose subject was "The Proposed Boston Building Code." Mr. Nichols discussed the legal aspects confronting the adoption of the Code and the technical aspects of the new Code. The talk was followed by an extended discussion.

Eighteen members were present.

JOHN B. WILBUR, *Clerk.*

HIGHWAY SECTION

APRIL 26, 1939.—A regular meeting of the Highway Section of the Boston Society of Civil Engineers was held in the Society's rooms, 715 Tremont Temple, this evening.

The meeting was called to order by the Chairman, Mr. Arthur E. Harding.

The reading of the minutes of the previous meeting was omitted.

The report of the nominating committee for the office of Clerk, not filled at the annual meeting, was made. Mr. Parker Holbrook of Winchester, Mass., was nominated and elected.

The chairman then introduced the speaker of the evening, Mr. Otis D. Fellows, Chief Engineer, Division of Metropolitan Planning, Commonwealth of Massachusetts, who spoke on the subject "Highways in the Metropolitan District, Their Origin and Evolution."

The speaker was very interesting and by the use of a map pointed out the location of the old Colonial roads and their development into the present day highways with pertinent facts and comparisons, especially as to traffic volumes.

After the speaker completed his talk, there was a brief discussion period.

The speaker was accorded a rising vote of thanks and the meeting adjourned at 8:25 P.M. with an attendance of 25 members and guests.

PARKER HOLBROOK, *Clerk*.

NORTHEASTERN UNIVERSITY SECTION

MARCH 24, 1939.—A meeting of the Northeastern University Section (Day Division) of the Boston Society of Civil Engineers was held today to elect officers for the year 1939-'40.

The minutes of the last meeting were read and accepted.

Nominations were submitted by the Chairman and Executive committee. Several names were added to this list from the floor.

Louis Reiniger, '40, was elected Chairman; John Bean, '40, Clerk; and Gardiner Lewis, '41, as a member of the Executive Committee, all by written ballot.

JOHN H. MANNING, *Acting Clerk*.

MAY 11, 1939.—A meeting of the Northeastern University Section of the B. S. C. E. was held today at the University, preceded by a dinner at the Lobster Claw Restaurant.

The meeting was called to order at seven o'clock by Mr. Cleveland, Chairman of the section. Mr. Van Tuyl was appointed Acting Clerk for the remainder of the year. A nominating committee, composed of Messrs. Smith, Hunt, and Metherall, was appointed to nominate candidates for office for the coming year. A report of the nominating committee is to be made at a special meeting of the Northeastern Section to be held on May 18th, and the election of officers held at that time.

Mr. Cleveland read an announcement concerning a prize award which may be given by the B. S. C. E. to a member of the Northeastern University Section for an original paper prepared and presented during the year at a regular Engineering Conference meeting. The award consists of a book or books of a value not exceeding fifteen dollars suitably inscribed and signed by the President of the Society and the Chairman of the Section. Present Junior Members were urged to avail themselves of this fine offer, and, at the same time, show their interests and capabilities.

Mr. Cleveland read a notice of the Conference of New England Student Chapters of the A. S. C. E. to be held at the University of New Hampshire, Friday, May 12th, to which the Northeastern University Section of the B. S. C. E. has been invited. This Conference will consist of two sessions, afternoon and evening. It was reported that three members from the Northeastern University Section planned to attend with Professor E. A. Gramstorff. Mr. Van Tuyl was chosen to represent Northeastern's Student Chapter at the Conference.

This concluded the business meeting for the evening. The guest speaker, Mr. J. Stuart Crandall of the Crandall Dry Dock Engineers, was introduced to the members by Mr. Cleveland. Mr. Crandall, whose subject was "Dry Docks," spoke on the construction of the three types of docks used for marine repairs and construction, contributing highlights from his own experience as a designer and consultant in this field of engineering. Many ingenious devices employed in the Americas and in Europe were explained and their relative values considered. The members were privileged to ask questions during the talk, with the result that Mr. Crandall was besieged with queries from an interested audience. Pictures of dry docks under construction and in use all over the world accompanied the talk. Mr. Crandall was given a rising vote of thanks by the thirty men present.

The meeting was adjourned at 9:15.

DONALD W. VAN TUYL, *Acting Clerk.*

MAY 18, 1939.—A special meeting of the Northeastern University Section of the B. S. C. E. was held in the South Building, Northeastern University, today for the purpose of electing officers for the coming year.

The minutes of the meeting held May 11, 1939, were read and approved, followed by a report on the Conference of New England Student Chapters of the A. S. C. E. held at the University of New Hampshire on May 12, 1939. Three members of the Northeastern University Section of the B. S. C. E., accompanied by Professor Gramstorff, attended this meeting which was the Second Annual Conference of the organization.

Following the report of the Nominating Committee, which was read and accepted, the retiring Chairman of the Section, Mr. Cleveland, then asked for any further nominations from the floor for the office of Vice-Chairman. The Nominating Committee proposed Mr. Van Tuyl, and Mr. Miles' name was added. Voting was by written ballot, and Mr. Miles was elected. Two vacancies on the Executive Committee were filled by the election of Mr. Grady and Mr. Bamber, who had been proposed by the Nominating Committee, and the names of Mr. Kelley and Mr. Van Tuyl having been added from the floor of the meeting.

With no further business on hand, the meeting adjourned at 3:10 P.M.

DONALD W. VAN TUYL, *Acting Clerk.*

APPLICATIONS FOR MEMBERSHIP

[July 20, 1939]

THE By-Laws provide that the Board of Government shall consider applications for membership with reference to the eligibility of each candidate for admission and shall determine the proper grade of membership to which he is entitled.

The Board must depend largely upon the members of the Society for the information which will enable it to arrive at a just conclusion. Every member is therefore urged to communicate promptly any facts in relation to the personal character or professional reputation and experience of the candidates which will assist the Board in its consideration. Communications relating to applicants are considered by the Board as strictly confidential.

The fact that applicants give the names of certain members as reference does not necessarily mean that such members endorse the candidate.

The Board of Government will not consider applications until the expiration of fifteen (15) days from the date given.

For Admission

CHARLES N. BUSH, Boston, Mass. (b. January 15, 1910, Dorchester, Mass.). Graduated from Boston Mechanic Arts High School in 1927; entered Wentworth Institute in the fall of the same year, taking a one-year course in Building, followed by a two-year course in Architectural Construction, graduating in the summer of 1930. During 1931 was employed by F. B. Jameson, contractor for the A. & P. chain stores. From 1933 to 1937 was employed as mechanical designer and draftsman for the Reece Folding Machine Co., of Boston. In 1938 worked with R. L. Vaill, contractor and builder in Waterbury, Conn. At present time is employed by Metropolitan District Water Supply Commission as Senior Engineering Aid. Refers to *S. M. Dore, F. W. Brittian, D. O. Fisher, C. J. Ginter, L. Gentleman.*

For Transfer from Grade of Junior

WALTER E. BUTLER, Denison, Texas. (b. November 23, 1911, New Bedford, Mass.). Graduated from Northeastern University with B.S. degree in Civil Engineering, June 1934. From 1930 to January 1933, with City Engineer Office, Newton, Massachusetts, during periods of Co-Operative work while attending Northeastern University. For nine weeks starting June 19, 1934, with Providence, R. I., District U. S. Engineer Office on 1st and 2nd order triangulation in the establishment of fire Control Stations for the Coast Artillery Batteries at Fort Rodman, Mass. From Oct. 4, 1934 to March 22, 1935, in City Engineers Office, New Bedford, Mass., as transitman and chief on various projects sponsored by the city. From March 23, 1935 to April 7, 1936, with Department of Public Works, New Bedford, Mass., as Junior Engineer on various types of Municipal Engineering. From April 8, 1936 to November 12, 1936 with Flood Control Division, Boston Mass., District U. S. Engineer Office, stationed in U. S. Geological Survey Office, Augusta, Maine, in preparation of hydraulic and hydro-electric power data and also in the Maine Public Utilities Commission Office. From November 13, 1936 to Sept 7, 1937 in the Boston Office, U. S. Engineer Office with Design Section, Flood Control Division on material and earthwork design on the proposed Franklin Falls Dam, and on design of North Nashua River Channel improvements, Fitchburg, Mass. From September 8, 1937 to March 31, 1939 with the Memphis (Tenn.) District, U. S. Engineer Office, on layouts, design and detailing of structures for various flood gates. From April 1, 1939 to date with Denison (Tex.) District U. S. Engineer Office, with Design Section on the proposed Denison Dam. Refers to *C. O. Baird, Jr., A. E. Everett, J. W. Greenleaf, Jr., M. R. Stackpole.*

ADDITIONS

Members

ROBERT I, HAYES, 34 Choate Street, Belmont, Mass.

THADDEUS MERRIMAN, 380 Riverside Drive, New York, N. Y.

HAROLD J. NICHOLSON, 43 Monmouth Avenue, West Medford, Mass.

THOMAS HEGGARTY, 42 Minnesota Avenue, Somerville, Mass.

Juniors

LEONARD J. A. FENOCKETTI, 73 Barnes Avenue, East Boston, Mass.

ADAM MARTIN COOK, 440 Summer Street, Lynn, Mass.

Students

JOHN E. BAMBER, 18 Gardner Road, Norwood, Mass.

WILLIAM J. COCORAN, 17 Bentley Street, Brighton, Mass.

WILMOT H. DECKER, 48 Harrison Avenue, Greenwood, Mass.

HARRY L. FREEMAN, 64 Lawrence Avenue, Roxbury, Mass.

JAMES F. HALEY, Pleasant Street, Groton, Mass.

ROBERT D. HENDERSON, Main Street, Sherborn, Mass.

RALPH F. JOHNSON, 4 Vernon Court, Newburyport, Mass.

WALTER B. KELLEY, 88 East Cottage Street, Dorchester, Mass.

ROBERT J. KILEY, 90 Claybourne Street, Dorchester, Mass.

ERNEST B. KETCHEN, 43 Pinkham Road, Medford Hillside, Mass.

PAUL M. LEVENSON, 10 Wardman Road, Roxbury, Mass.

JOHN F. METHERALL, JR., 64 Hobart Street, Wollaston, Mass.

CLYDE C. STONE, 840 N. Montello Street, Brockton, Mass.

CLARENCE E. STONE, 840 N. Montello Street, Brockton, Mass.

DONALD W. VAN TUYL, North Road, Greenport, N. Y.

ROBERT A. WOOLACOTT, 17 Argyle Street, Melrose, Mass.

BOOK REVIEW

"Duodecimal Arithmetic," 1938, by GEORGE S. TERRY. Longmans, Green, New York. 408 pages. Price, $7.50.*

The number 12 plays an important part in our daily life—the year is divided into 12 months, the linear foot is also divided into 12 parts; so too is the dial face on your watch and countless other things. Why don't we count that way?

The past century has brought forth several books, under various titles, relating to the use of 12 as a base for counting instead of our present base—10. These books have passed by as ships in the night, but George S. Terry and his "Duodecimal Arithmetic" makes us sit up and take notice.

In this large volume of 408 pages, decimally, or, 2Xo pages duodecimally, Terry has put the cart before the horse and produced a finished product with little left to be desired. Within its covers the elementary processes of addition, subtraction, multiplication, division and fractions are compared with the decimal system. In addition Terry has included usable tables of conversion, powers, roots, angles, logarithms, functions natural and logarithmic, Digamma and Bessel functions, etc. "Duodecimal Arithmetic" is therefore not a primer, but a handbook ready for use.

Mr. Terry sincerely sets forth the advantages of the duodecimal system over the decimal system. One advantage is that more is known about a number by inspection than can be determined by the same metho don our present decimal system. For example—"Powers of whole numbers are simpler because of the more consistent endings. In the first place, all squares end in either 0, 1, 4, or 9, a considerable help in determining at sight whether or not a number is a perfect square."

The notation is easy to remember, because the digits remain the same as in the decimal system up to and including 9, at which point two characters are added. The first character resembles the Greek letter chi and it is called 'dec'; the other appears as an inverted and reversed 3, called 'el'. These are followed by 10, called 'do' or one dozen. Thus 4 times 4 is not 16 but 14 (one dozen and 4. Large numbers appear s m a l l e r—"expressed duodecimally" 1,000,001 is 402,855.

Mr. Terry claims that our children will have an easier time with fractions in the duodecimal system, for "of the eleven fractions from one half to one twelfth, five can be expressed exactly by a one place duodecimal, two by two place duodecimals,—seven in all. Decimally three can be expressed exactly by one place, one by two places, one by three places,—five in all.

Whether or not counting by dozens ever becomes general, Terry has made a major contribution. The magnitude of his labors and the accuracy of the work is evident. Those who like to play with figures will at least find "Duodecimal Arithmetic" an interesting diversion.

*By R. Newton Mayall, Landscape Architect and Engineer, 115 Newbury Street, Boston, Mass.

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BOSTON SOCIETY OF CIVIL ENGINEERS

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