As I sit here in my office during what I hope is the last blizzard of the winter, my mind goes ahead to the 13th day of May, when this paper will be read. By then I hope and expect the weather will be warm and balmy, an ideal evening for many things, but certainly not so ideal for sitting inside, so this paper will be short. I shall try to follow the dictates of our original constitution and write a technical paper even though I would much rather write on my bone fishing trip to Cuba, and pass out a few observations on Mr. Castro and his band of "Infant Revolutionarys"

I graduated in 1917 and I hold a Registered Engineers License dated 1920, numbered 207, so you see I am one of the old timers. I started in Contracting in 1922 and have used little technical engineering since that time. One forgets a lot in 40 years. This history is just an excuse, or rather a reason, for not being able to answer certain questions later in this program.

Now for a few observations on Design so this will qualify as a technical paper.

If a body subjected to various forces is in equilibrium, the three basic laws of equilibrium are:

(1) The algebraic sum of all the vertical forces equals zero.

(2) The algebraic sum of all the horizontal forces equals zero.

(3) The algebraic sum of the moments of all the forces about any point equals zero.

A moment may be defined as the tendency of a force to cause rotation about a given point or axis. The maximum tendency of a beam to fail by bending is called the maximum bending moment. The bending moment varies throughout the length of the beam, and the maximum value is used in determining the proper size of beam to use. The maximum bending moment occurs at that section of the beam at which the shear changes from a plus to a minus quantity.

The magnitude of the bending moment at any section of a beam is equal to the algebraic sum of the moments of the forces on either the right or the left of the section. It is convenient to use this statement in the following form: The magnitude of the bending moment at any section of a beam is equal to the moments of the reactions minus the moment of the loads to the left of the section. Shear and bending moment are often confused. Remember that shear is reactions minus loads and that the bending moment is moments of reactions minus moments of loads. As a moment is the result of multiplying a force by a distance, bending moments are generally given in units of foot-pounds or inch-pounds.

Figure 3 shows what happens to a beam when it bends. In determining the unit stresses due to bending it is assumed that a plane cross-section before bending remains a plane after bending. This assumption is not always exactly true, but only in a very unusual cases does it lead to significant error. When the assumption is made, two parallel plane cross-sections AB and CD of an unbent beam will be planes after the beam is bent, but will no longer be parallel. If a third plane, C'D' parallel to AB is passed through the intersection of CD and the neutral axiz (the place where the length does not change), the distance between AB and C'D' will be the original length of all the fibers of the beam between AB and CD in the unbent beam. It will be seen that the change of length of any fiber is proportionate to the distance from the neutral axis. Note that the top fibers have been shortened and are in compression, while the bottom fibers have lengthened and are in tension.

The neutral axis of any cross-section passes through the centroid of the cross-section. If a plane figure has an axis of symetry, the centroid will lie on that axis. On certain figures, such as rectangles, circles, etc, the centroid will lie on that axis. On certain figures, such irregular shapes, the neutral axis may be calculated in various ways, however calculus is the usual method of computing irregular shapes.

Let us now look at the composition of the resisting moment. In figure 3, we saw that the top fibers of a loaded beam are in compression and the lower fibers are in tension. Figure 4(a) represents a rectangular cross section of a beam; b is the breadth and d is the depth. Since the neutral axis passes through the centroid of the section, it is midway between the upper and lower surfaces of the beam.

For the present, let us consider the compressive stresses indicated by the hatched area. This area is b x d/2. The fibers in compression are not stressed equally, and their magnitudes are directly proportional to their distances from the neutral axis. The stress distribution is shown graphically in figure 4(b). Let f = the unit stress on the extreme fiber. Since the stress on the fibers at the neutral axis is zero, the average unit stress is f/2. Then, since the area under compression is b x d/2, the total compressive stress is (b x d/2) x f/2. We know that the centroid of of a triangle lies at a point 1/3 of the distance between the base and the apex. Then the resultant of all the compressive stresses passes through a point 2/3 x d/2 or d/3 distance above the neutral axis. The resultant of a number of forces is a single force having the same effect as combined forces acting simultaneously. As the resultant of all the compressive stresses is $b \times \frac{d}{2} \times \frac{f}{2}$ and its moment arm about the neutral axis is d/3, the sum of the moments of all the compressive stresses about the neutral axis is (b x d/2 x f/2) x d/3. The quanity is the moment of the compressive stresses only, and if we multiply it by two (to include the moments of all the tensile stresses below the neutral axis), we have an expression representing the sum of the moments of all the stresses in the cross section with respect to the neutral axis. This quanity is known as the Resisting Moment, and it is equal in magnitude to the bending moment.

Thus:

$$2 \times (b \times d/2 \times f/2 \times d/3) = RM = BM$$

$$f \times \frac{bd^2}{6} = BM$$

$$\frac{BM}{f} = \frac{bd^2}{6}$$

The portion of the equation $(\frac{bd^2}{6})$ is called the section modulus. By dividing the bending moment by the allowable stress, we find the required section modulus. We may then pick from tables various size beams which have the required section modulus.

The first step in designing a beam is to investigate the external forces and stresses on the beam in question. We must first determine the reactions of the beam, and then the shear and bending moment. The reactions of a beam are the upward supporting forces that hold in equilibrium the downward forces or loads. Figure 1 represents a structural member in equilibrium. Equilibrium, in this sense, is a condition in which forces acting simultaneously produce no motion, a state of rest.

Let us now investigate the beam in figure (1(a)).

Since this beam is symetrically loaded and the downward force is 2400 pounds, it is obvious that each reaction is equal to half the load, or 1200 pounds. R_1 and R_2 each equals 1200 pounds. We can prove this by employing the third law of equilibrium as previously stated. Let us take a point at R_2, the right reaction, as the center of moments. The force R_1 tends to produce a clockwise rotation about this point, and its moment is R_1 x 20. The downward force tends to cause a counterclockwise rotation about the same point, and its moment is 2400 x 10. As the sum of the moments tending to cause clockwise rotation equals the sum of the moments tending to cause counterclockwise rotation, We may write,

$$R_1 \times 20 = 2400 \times 10$$

$$20\ R_1 = 24,000$$

$$R_1 = 1200\#$$

In a similar manner, we can show that R_2 = 1200 pounds.

The maximum bending moment of our original problem is 12,000 foot pounds or 144,000 inch pounds. Dividing this by the maximum allowable stress for timber 1200 psi, we have a section modulus of 120 in^3. From tables we see that any of several beams will be adequate. Let us assume, however, that we desire to use a 12 inch beam (actual size is 11-1/2 inches).

Then

$$\frac{BM}{f} = \frac{bd^2}{6}$$

$$\frac{144,000}{1200} = \frac{b \times 11.5 \times 11.5}{6}$$

$$120 = \frac{132.25\ b}{6}$$

$$b = \frac{120 \times 6}{132.25} = 5.44 \text{ in.}$$

A nominal 6 inch x 12 inch beam has an actual size of 5-1/2 x 11-1/2. Therefore, the 6x 12 is adequate. There are times when either the depth or width are controlled by other factors, but by assuming one, the other can be determined.

Now let us determine the shearing stress in our beam. A beam is considered to be made up of an infinite number of parallel planes (figure 2), normal, or perpendicular to, the length of the beam. Shearing stress acts along the plane, and resits the tendency of one plane to slide relative to an adjacent plane. The magnitude of the vertical shear at any section of the beam is the algebraic sum of the vertical forces on either the right or the left of the section. A convenient form of this statement is: The vertical shear of any section of a beam is equal to the reactions minus the loads to the left of the section. This gives a unit of pounds.

Any other structural problem breaks down to a simple beam or combination of beams. A floor, take a piece 1' wide and design a beam, (a roof) the same thing. A cantilever beam is simply 1/2 of a simple beam.

Concrete Beams

When concrete is used as the material for a beam, it will have good strength properties in compression and very poor strength properties in tension. For this reason, reinforcing steel is used to supplement and reinforce the concrete in tension.

Since the coefficient of expansion of steel and concrete are practically the same, the two construction materials are ideally suited to be used together.

The ductility of steel is much greater than concrete, which permits only partial use of the steel strength. However, by using prestressed steel in concrete beams, it increases the efficiency of the reinforcing steel used.

Figures 5, 6 and 7 represents typical reinforced concrete cross sections. Figure 5 is the simple reinforced beam used when subjected to positive bending only. Figure 6 is a tee beam which takes advantage of a large compressive area, thus utilizing the compressive strength of concrete and is suited to the floor construction of buildings.

Figure 7 is a reinforced concrete beam that is used where it is subjected to both positive and negative bending moment.

In design of a reinforced beam, the cross-section of one material is converted into a cross-sectional area at equal strength of the other material, and the design is made using the equivalent cross-section.

These foregoing procedures of design can be used for any type of materials, or any combination, and form the basic design for beams for all types of structures.

Unlike Doctors, Engineers cannot bury their mistakes, so again unlike doctors they can and do lean backward so there are few. They just figure the beam as they should, add 100% for safety on their own assumption, 100% for the contractors sloppyness, and the public who never knows the difference, simple pay the bill.

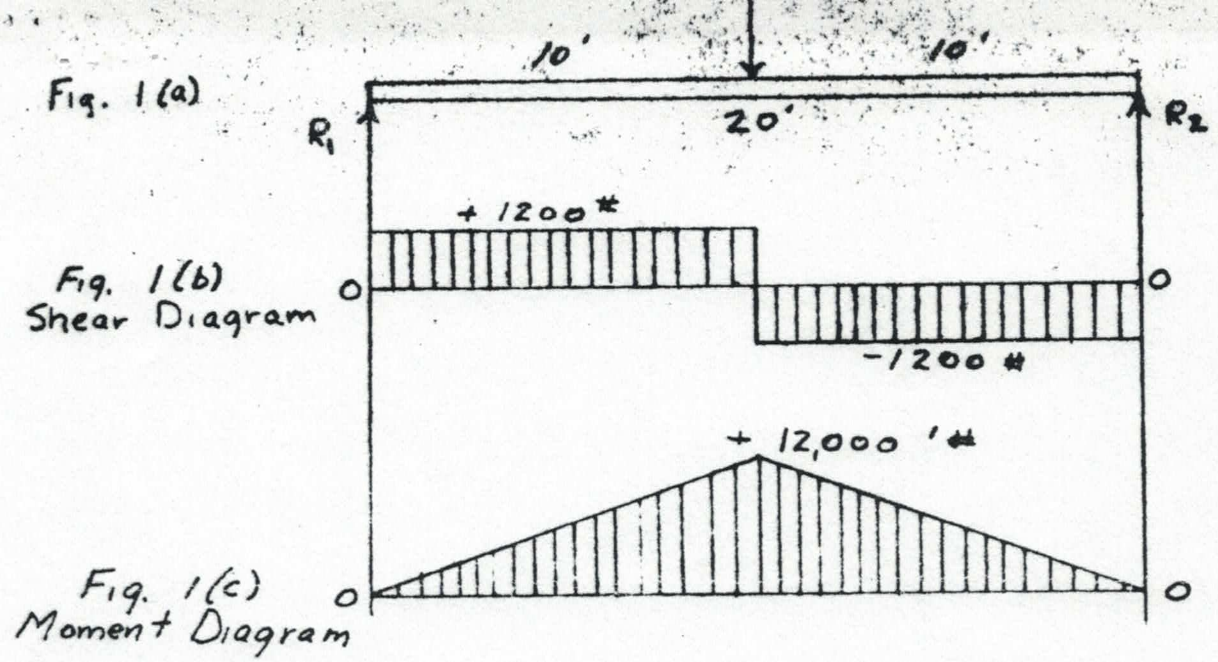

FIG. 1

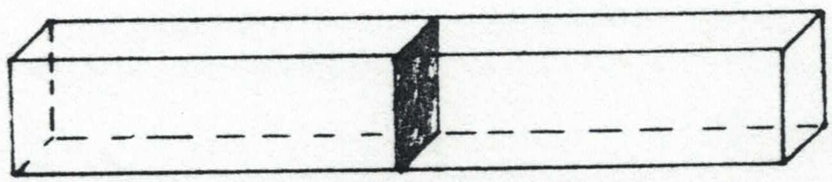

FIG. 2

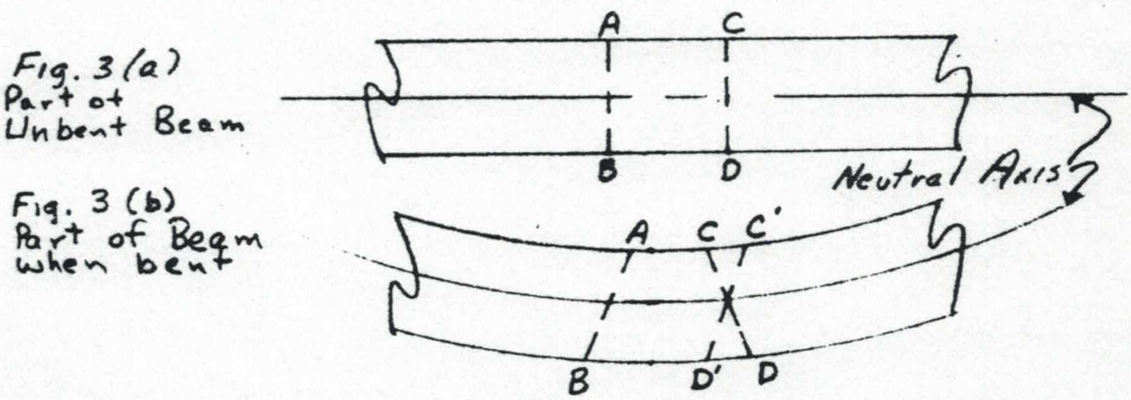

FIG. 3

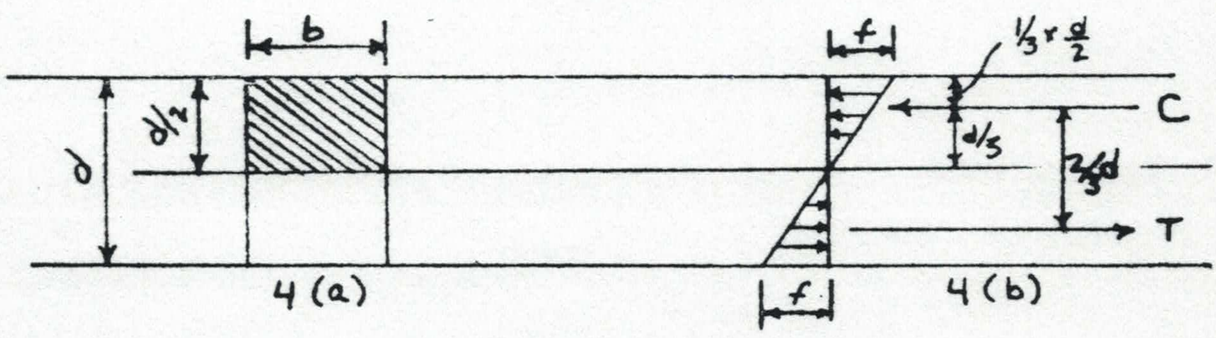

FIG. 4

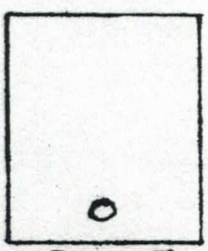

FIG. 5

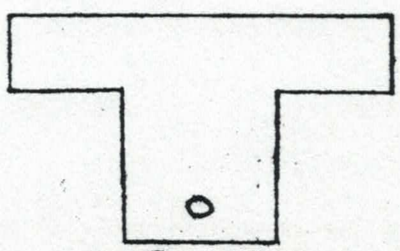

FIG. 6

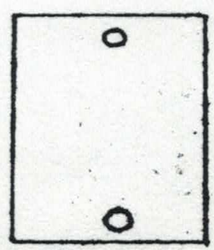

FIG. 7