pile; and (3) the strength, as a column, of the pile above the ground or above the firm subsoil.

Although it would seem that these are simply elements, each of which could be fairly estimated, the complexity of the case is shown by the numerous formulæ which give results ranging up to about 450 per cent.

In Newman's "Earthwork Slips and Subsidences" the frictional resistance of timber piles is stated to be less through wet soils than dry, in the following proportions:

In sandy gravel, 5 to 10 per cent. less.
In sand, about 12 per cent. less.
In sandy clay or gravelly clay, about 40 per cent. less.

Experiments with cast-iron piles by McAlpine gave about ½ ton per square foot of surface as the supporting power from friction when sunk 20 ft. to 30 ft. in rocky gravel. He considers it would amount to 3 tons per square foot in fine earth, but this seems to be an extravagant assumption. In experiments made previous to the sinking of concrete piles for the works of the Vienna-Danube Sand Dredging Company in 1909 it was found that the frictional resistance was about 14.19 lbs. per square inch of surface = 2,054.36 lbs. per square foot, or just over 18 cwt.

G. B. Bidder was of opinion that "in clay or wet soils it was not advisable to trust a greater weight than 12 tons upon each pile, but in gravel there was scarcely any limit to their vertical bearing strength."

French engineers (*vide* Berg's "Safe Building") allow a pile to carry 50,000 lbs., provided it does not sink perceptibly under a ram falling 4 ft. and weighing 1,350 lbs., or does not sink ½ in. under thirty blows.

A common rule for safe dead load on each pile is 5 tons per square foot of cross-section in soft ground, or 1 ton per inch side of square piles in firm ground.

The New York Building Regulations permit a load of 20 tons per pile, but the size is not specified.

The writer believes they use Wellington's formula for safe load.

Haswell (Minutes of "Proceedings" of the Institution of Civil Engineers, cxv., p. 318) says: "In deciding upon a factor of safety in a formula for pile-driving, the following elements must be considered: The friction of the machine; the resistance of the atmosphere to the fall of the ram and the cushioning on the head of the pile, however square it may be dressed off; the want of verticality both in the fall of the ram and in the plane of the pile, and the consequent lateral vibration; the inertia; the vibration and condition of the soil. Were all the conditions known definitely and allowed for, a factor of safety of 2 would be ample, but as the formulæ do not take account of all the conditions a larger margin is necessary. In some ascertained supporting powers recorded by Trautwine they were found to be from 2.3 to 3.7 times greater than given by the formulæ.

There seems to be no general rule as to the factor of safety it is desirable to adopt; the practice appears to vary from 2 to 10, the former being suitable for dead loads and the latter for live or vibrating loads. Intermediate factors would be produced with varying proportions between the dead and live loads. Obviously, unless the ultimate resistance given by the formula is reliable, the resulting factor is unknown.

In Dobson's "Foundations and Concrete Works" (Weale's Series) we are told that "of the comparative effect of impact and pressure in driving piles we as yet know nothing, and the question is so complicated, from the great number of points that have to be taken into consideration in reducing the results of experiment into a definite form from which some rule for our guidance might be obtained, that we can only lay down in general terms the following empirical rule that in ordinary cases if a pile will safely resist an impact of 1 ton, it will bear without yielding a pressure of 1½ tons," and he gives $W v$ = impact, therefore safe load = $1.5\ W v$.

Dobson is, however, wrong in his theory; he assumes that the force of a blow is measured simply by the product of the weight into the velocity, and this assumption leads him to conclude that a 1-ton ram with a fall of 16 ft. will have the same effect on the head of a pile as a 2-ton ram falling 4 ft., while the former takes double the expenditure of power to raise it. In other words, he says $f = m v$, instead of $f t = m v$, which is the well-known formula where f = force, t = time, m = mass = $\frac{w}{g}$ v = velocity —that is, a force f, acting for time t, will move a mass m, with a velocity v—but action and reaction are equal in magnitude but opposite in direction; therefore, a mass m moving with a velocity v, and expending its energy in time t, will produce a mean pressure—

$$f = \frac{m v}{t}.$$

Weight = product of mass into force of gravity, or $W = m g$, therefore

$$m = \frac{W}{g}, \text{ or } f = \frac{W v}{g t}, \text{ instead of } f = W v$$

as Dobson puts it. The same error is made by Molesworth, and a table of results is given assuming that the force of the blow varies as the square root of the fall instead of directly as the fall. The product $m v$ gives the momentum in its original sense. It is also known as quantity of motion, but it cannot be compared with force or pressure unless time be taken into account.

A worked example will perhaps make this clear—

Let W = 0.25 tons, h = 20 ft., S = set at head of pile = ¾ in., then

$$v = \sqrt{(2 g h)} = 35.7 \text{ ft. per second,}$$

but v varies from 35.7 to 0 while passing through the ¾ in., therefore mean $v = \frac{35.7}{2} = 17.85$ ft. per second, and ¾ in. = 1/16 ft.; therefore time occupied in passing through ¾ in. = 1/(17.85 × 16) = 1/285 of a second. Then by formula—

$$f = W v / g t = (0.25 \times 35.7/32 \quad 1/285) = 79.5 \text{ tons}$$

but if the exact fraction be taken it will give 80 tons mean pressure. By formula—

$$W v^2 / 2 g = W h = 0.25 \times 20 = 5 \text{ ft.-tons,}$$

or a mean pressure of $\frac{5}{1/16}$ = 80 tons, as before.

It will be observed that S is taken as the set of the head of the pile, and attention must be directed to one very important point. The distance the head of the pile moves after being struck is the criterion of the resulting force in pounds, but only part of this force is returnable as supporting power; some of it is expended in compressing the pile, and any formula that does not take account of the compression of the pile as well as the penetration of the point can only be approximately true. The resistance at the head of the pile begins at zero and terminates at such a pressure that the total movement multiplied by the average pressure equals the foot-pounds energy of the blow.

The test of a pile at Royal Victoria Dock, London, is recorded in "Engineering," December 29, 1899, p. 826, as follows:—