small car which was hauled by cable up the trestle incline to the high platform, from which it was shovelled into the forms. Much of the lining required back as well as front forms, and the space behind the back forms was filled with rock or wood. This back-form and back-filling work was slow and expensive, especially where there were only a few inches between the back forms and the rock. The concreting has been well done, but the work is behind time, owing largely to conditions which the sub-contractors could not control.

The tunnel has been finished 11 months ahead of the contract time, and for a substantial sum less than the price bid. There have been no strikes, or interruptions of the work. The management has had the necessary money and authority, and has been given a free hand, both by the railway company and the contractors, and has had the loyal support and valued assistance of the men.

The railway company did the necessary engineering work. Messrs. F. F. Busteed, H. G. Barber, and W. A. James, were successively in charge, Mr. J. G. Sullivan being chief engineer.

PILE-DRIVING AND THE SUPPORTING POWER OF PILES.*

By Henry Adams, M.Inst.C.E.

TWENTY-FIVE years ago the writer read a paper before the Society of Architects upon "Timber Piling in Foundations and Other Works." The notes then collected and since added to relate chiefly to timber piles, with which the writer has had considerable experience, and upon which much scattered information has already been published; but all driven piles, whatever the material, must behave more or less according to the same laws, and the knowledge gained concerning ordinary timber piles will be likely to enable us to discover the laws and regulate the practice of driving and using piles of other material, including reinforced concrete.

Driving Piles.—Ordinary piles are driven by what is called a "pile engine." It is virtually a large hammer, the weight being arranged to fall freely and strike a succession of blows upon the head of the pile. It consists of a tall framework, with vertical guides on the face to keep the hammer or ram in a direct line with the head of the pile. The base of the pile engine is placed just above the finished level of the pile head, so that in driving long piles a high framework is required. It is, however, sometimes impossible to get the framework high enough for this, and it is then set 6 ft. or 8 ft. above the finished level, and a punch, dolly, or follower, of hard wood, hooped at both ends, is used on the head of the pile when it gets as low as the base of the frame, but the blow is not so effective and the method should be avoided when possible; it is said to reduce the effect of the blow one-third, more or less, according to the rigidity of the material. The length of a pile is generally determined by the local conditions of site and soil, the sectional area chiefly upon the load it has to sustain, usually the ratio—

$$\frac{L}{A} = \frac{1}{4} \text{ to } \frac{1}{8}$$

but no general rule can be laid down, as it depends to some extent upon the unsupported length above ground.

*From a paper read at a meeting of the Concrete Institute held December 21st, 1916.

Pitching and Driving.—In pitching a pile care must be taken that it is started in the right place, as it cannot be shifted, but if the point is not truly in line with the axis of the pile, or gets pushed to one side by meeting an obstruction before it has entered very far, the lower end of the pile will be drawn over to the side to which the point leans. In spite of the greatest care they will sometimes be found slightly out of position, and they have then to be drawn back into place by chains, twisted like a surgeon's tourniquet, while being bolted to the other timbers. If it be necessary for them to be scarfed, the upper portion can be adjusted by cutting the scarf a little out of line to suit. All piles are not required to be vertical; in building jetties the outside row of piles is often doubled, the outer pile being a raking one, at 15 to 30 deg. from the vertical, for increasing the stability, acting like a buttress. At the corners of jetties the outer piles are usually raking both ways, say, about 15 deg. from the vertical. When necessity arises piles may be drawn from the bed of a tidal river by lashing empty barges to them and letting them lift by the tide. Against a river wall, or round the foundations of a bridge, piles should be sawn off by a diver as low as he can get at them in preference to drawing them, to avoid any risk of scour and undermining of the foundations taking place. On land a pile may be drawn by lashing a short piece to the top and then prising it up by another baulk used as a lever, or by a pair of powerful jacks.

Weight of Ram.—One of the most interesting questions in connection with pile-driving is the proportion between the weight of ram and the fall to produce a given result. The ram usually weighs from 5 cwt. to 30 cwt., and is allowed to fall, say, from 6 ft. to 20 ft. Upon a superficial consideration it would seem that a ram of 5 cwt. falling 20 ft. would produce the same result as a ram of 20 cwt. falling 5 ft., as they would both have 5 ft.-tons energy, but the proportion of the total energy ($W h$) which is usefully expended in sinking the pile depends *inter alia* upon the ratio of the weight of ram to the weight of the pile. Some of the total energy is always wasted.

A light ram with a long fall will not have the same effect as a heavy ram with a short fall. In practice it is found that with too great a fall the effect of the blow is to bruise and "broom" the head of the pile, or to shiver the timber instead of to force it downwards. A heavy ram, producing the same effect in distance driven as a light one with greater fall does less injury to the pile. Dobson says: "In working with a fall from 12 ft. to 20 ft. it is common for every tenth pile to be more or less shaken." Of course, he meant to say "one pile in ten." It is as if the top of the pile were driven down while the bottom remained stationary, owing to the inertia of the mass of the pile.

For the first few blows the pile goes down a considerable distance, which gradually becomes less at each blow until the resistance is so great that it will not go any further, or, as it is technically called, "refuses." Were the material of the pile perfectly rigid and inelastic, the impact, however slight, would produce an infinite pressure, but the material is very elastic, and so the fibres of the pile are compressed without the point going any further, and the amount of this compression and the elasticity are strikingly shown in the rebound of the ram when the pile refuses.

The Supporting Power of Piles.—The sustaining power of a pile depends chiefly upon three circumstances: (1) The resistance at the point or shoe to further penetration; (2) the friction of the earth on the sides of the