opening once be formed, the scour was such that the embankment speedily melted away.

The principal rivers crossed by the railway in the Nerbudda Valley from Bhere to Bagra, a distance of 100 miles, were the Towah, Gungal, Matchock, Karlee Matchock, and the Suktha or Chota Towah, besides the Sconce Jamnee, Hurda, and other nullahs. The greatest flood known for ten or fourteen years, or according to native report for thirty years, occurred in 1864, when, on the 15th of August, the river Towah rose 47 feet in a few hours; and it was estimated that the velocity at the surface was 16.58 feet per second, the fall 4.25 feet per mile, and the discharge 976,629 cubic feet per minute. It had been asserted that the flood of 1864 was an unusual one, but that of 1865 was of a similar character; while the flood of 1866 exceeded its predecessors, both in force and magnitude. The next important river the Gungal, the highest known flood in which took place on the 22nd of July, 1864, when with a fall of 3 feet per mile, the mean velocity from calculation being 166.14 inches per second, the discharge amounted to 732,123 cubic feet per minute. Two subsequent floods occurred in this river on the 8th and the 29th of August, 1866, and then, the fall being as before 3 feet per mile, the mean velocities were found to be from observation 153.68 and 110.22 inches per second respectively, the relative discharges being 477,820 and 109,494 cubic feet per second. Some idea of the force of the current in Indian rivers on such occasions might be gathered from the fact, that in a comparatively small river, 30 feet plate-girders had been carried 7 miles down stream; while, in 1866, masses of masonry weighing 1600 tons and 1000 tons had been washed away from two of the piers of the Towah Viaduct, without a single stone being recovered.

In conclusion, the author expressed the opinion that, in bridging rivers of the description referred to, in the first place, wide spans were indispensable; for the current was so swift, and the rise of water so rapid, after a heavy fall of rain, that any contraction of the waterway caused a dangerous scour and backing up. Secondly, he thought that the next in importance to having as few piers as possible, was the necessity of giving them the greatest strength, by building them of solid block in course, set in cement. Thirdly, that the face of the cut-waters of piers should always be tool-dressed to reduce the friction, the "bush" frequently left on forming an obstruction. And, fourthly, that when rubble backing was used, care should be taken in suspending work, to finish off below high-water level with a bed of solid block in course, as otherwise the water would penetrate the work, and speedily blow up the pier.

February, 1868.—The Paper read was "*On the Supporting Power of Piles; on the Pneumatic Process for Driving Iron Columns, as practised in America*," by Mr. W. J. McAlpine, M. Inst. C.E. (of New York.)

The first part of this communication related principally to the experience gained in driving six thousand five hundred and thirty-nine piles, an average depth of 32 feet, for the foundation of the Government Graving Dock at Brooklyn, N.Y., when the support was mainly derived from the adhesion of the material into which the piles were driven, and slightly from their sectional area. The piles were in rows 2½ feet apart, and at transverse distances of 3 feet, all from centre to centre; intermediate piles of tough second growth oak being frequently employed. The main piles were chiefly round spruce spars, very straight, from 25 feet to 45 feet long, and not less than 7 inches in diameter at the smaller end, and on an average 14 inches in diameter at the larger end. From a record kept during the progress of the work, it was ascertained that it took two and one-third blows to drive each foot of pile, and that the distance moved uniformly diminished from the first to the last blow, ranging from 8 inches at the beginning to no movement at the end, the average distance moved by the last five blows being 1 inch. A considerable number of the piles were driven by a Nasmyth steam piling machine, with a ram of 3 tons, and a stroke, or fall, of 3 feet, and making from sixty to eighty strokes per minute. The other machines were generally operated by steam power, giving an average of a blow per minute; but occasionally the hammers were hoisted by manual and horse power. The rams in the latter machines were of cast-iron, swelled out at the bottom to concentrate the weight at that point, and weighed about 2200 lbs. each, though some were used of 1500 lbs.; the fall being 30 feet. It was observed that the heaviest ram, when striking blows of the same effect as lighter ones, did the least injury either to the head of the pile or to the protecting iron ring, and this injury was still less with the Nasmyth hammer. It was also found that no advantage was gained by the fall of the ram being more than 40 feet, as the friction on the ways then prevented any increased velocity to the ram when falling from a greater height. With the Nasmyth hammer, piles were driven 35 feet in seven minutes, while with the other machines similar piles required one hour or more, to drive them the same distance.

Experiments were made at different times to ascertain the weight which the piles would sustain. For this purpose a long lever of oak timber was employed, with which a number of the foundation and coffer dam piles of nearly the same size, and driven under exactly similar conditions, were withdrawn. It was thus ascertained that a weight of 125 tons was required to move a pile, driven 33 feet into the earth, to the point of ultimate resistance, with a ram weighing 1 ton, and falling 30 feet at the last blow. These trial piles averaged 12 inches in diameter in the middle. From a number of other experiments, it was believed that the extreme supporting power of the pile, due to its frictional surface was 100 tons, or 1 ton per superficial foot of the area of its circumference. From an analysis of the experiments, the following general laws seemed to have prevailed in these cases:—1st. That the effect of lengthening the fall of the ram was to increase the sustaining power of the pile in the ratio of the square root of the fall. 2nd. That by adding to the weight of the ram, the sustaining power of the pile was increased by 0.7 to 0.9 of the amount due to the ratio of the augmented weight of the ram. 3rd. That a pile driven by a ram weighing 1 ton and falling 30 feet, would sustain an extreme weight of 100 tons. The formula based upon these data, as applicable to rams weighing from 1000 lbs. to 3000 lbs., falling from 20 feet to 30 feet, was $X = 80\ (W + 0.228\sqrt{F} - 1)$, in which X was the supporting power of a pile driven by the ram W, falling a distance F; X and W being in tons, and F in feet. The author was of opinion that under the most favourable circumstances, the pile should not be loaded with more than one-third of the result given by this formula; and when there was any danger of a future disturbance of the material around the pile, or when there was any vibration in the structure which might be communicated to the piles, the load imposed should not exceed one-tenth.

The bearing support due to the sectional area of the pile had not been considered in the preceding inquiry; but numerous experinents had been made, which gave results of from 5 tons to 10 tons per square foot.

The island occupied by the city of New York was separated from the mainland by a navigable tidal estuary, called the Harlem River, and this was spanned by several bridges. In reconstructing the bridge forming the continuation of the Third Avenue, it was decided to make a pivot draw in the centre; and, with a view of creating the least possible obstruction to the current, the draw pier was composed of one central and ten circumscribing iron columns, each 6 feet in diameter and 50 feet in height, the water in the middle of the river being 20 feet deep. Careful experiments upon the supporting power derived from the frictional surface of these columns, when sunk from 20 feet to 30 feet in moderately fine material, had led the author to adopt a co-efficient of half a ton per superficial foot of the exterior surface. These piles were sunk by the pneumatic process (both plenum and vacuum), and the method of sinking them was next described in minute detail, as well as the apparatus and means taken to ascertain their sustaining power. Although the lateral support, as determined by the experiments, in addition to that which would be derived from a base of 6 feet in diameter, showed that it would be ample for that place; yet, in view of subsequent operations, the importance of devising a method of increasing even the large base due to the size of the column offered advantages too great to be neglected, and various methods of accomplishing this result were proposed. The one adopted was as follows: It had already been decided to fill the columns with concrete, and it was naturally suggested to extend this masonry below the bottom as deep as men could work in the water, and also to undermine the adjacent earth, as far as practicable, and to extend the concrete into the space. This was done in sections of about 2 feet in width, and when the ring had been completed, it was found that the column was virtually extended, and that the water would readily sink under pressure to a level with the bottom of the concrete, so that the sand within it was easily removed, and the space filled with concrete to a depth generally of 4 feet, or more. Contrary to statements occasionally made, it was found that the cement set with far greater rapidity under pneumatic pressure than in the ordinary atmosphere.

The experience gained, and the reflections resulting from the operations at the Harlem Bridge proved, among other things, the rapidity, facility, and economy of driving iron columns of large size, under favourable circumstances. The extracts from the author's journal showed, that the last columns were driven from 16 feet to 20 feet in from three to six days, in sand and porous material, free from obstructions. The economy of this work was indicated by the small force employed at Harlem, which was twelve men, all told, including the engine drivers, stevedores, and foreman. Their aggregate wages, and the expense of fuel, did not exceed £6 per day. The cost of the plant was under £1500. The metal in the column, is but 1¼ inch thick, which was quite sufficient, would have been in New York £13 per lineal foot of the column. It was remarked that at Harlem the officers and workmen experienced neither temporary nor permanent ill-effects from a pressure of two-and-a-half atmospheres. It was believed that cylinder piles might be driven to great depths, through extraordinary obstacles, such as rocks, logs, and sunken vessels, without serious loss of time, or at much cost; and that they would penetrate quicksand, which was so troublesome by all other methods, with unusual facility. Again the columns might be regulated in their descent, and be suddenly arrested at any precise point, at the will of the director, by means of a pneumatic reservoir. Thus, the descent was commenced at first slowly, the velocity gradually increasing until the movement became dangerous, when it was instantly stopped. In some cases the piles could be