Mr. CUDWORTH said, he had but little to add to the Paper, in which, although condensed as much as possible, it did not occur to him that anything material had been omitted. He was glad to have had the opportunity of bringing under the notice of the Institution, a viaduct in which economy of materials had been much studied, and in which this appeared to him to have been carried almost as far as was consistent with due regard to safety. He had brought into comparison with this viaduct one constructed of iron; and as both structures were designed by the same Engineer, it might be inferred that similar ideas, as to economy of materials and of fitness, prevailed in both cases.

Mr. G. P. BIDDER, Past-President, said, every Engineer must be guided in the selection of the particular material, or mode of construction, by the locality, the facility of obtaining different materials, and the purposes which the work was intended to serve. No doubt viaducts, like all other works, were now constructed at less cost than was the case in the early days of railways, when the stereotyped price of a viaduct was 6*s.* 8*d.* per cubic yard. It appeared from the Paper, that the Hownes Gill Viaduct had cost 5*s.* 1*d.* per cubic yard. This was a reduction of nearly 20 per cent.; but he did not think that was more than had been effected upon other works, as the result of better appliances, and the application of larger capital. The admirable spirit in which this Paper was written was highly commendable; and if it had been prepared by Mr. Bouch himself, the comparison between the different works could not have been more fairly stated. This evinced such a desire to elicit real truth, that the Author was deserving of great praise. With regard to the use of either iron, or wood, or brick for structures of this description, the decision must entirely rest upon the judgment of the Engineer. There were circumstances in which timber structures were obliged to be erected, as ancillary to other designs. In Norway, viaducts of 90 feet and 100 feet in height had been constructed of that material, in the readiest manner, and with great economy, where they were afterwards to be replaced by embankments. It would appear from the statement of the Author, that under the particular conditions with which Mr. Bouch had to deal, iron was the most suitable material for those works, which were simple, substantial, and free from undue motion; and looking at the cost, it showed that economy of material had been carefully considered. The Paper brought out facts of great practical value, and gave data for the construction of extensive viaducts. This information could not fail to be useful to Engineers, when they were called upon to design works of this description.

Mr. BOUCH said, the subject had been dealt with in so fair and comprehensive a manner, as to leave but little room for remark.

With regard to the comparison which had been made between the Hownes Gill viaduct and the iron structure, he thought that there were no points of analogy between the two works. He quite agreed that the brick structure described in the Paper was a proper one in that particular situation; but in the other case the circumstances were so changed, that neither brick nor stone could have been used. The Hownes Gill viaduct was designed for a railway which had already been many years in operation. There were thus facilities for the conveyance of the materials, which were procured in the district, on the most favourable terms, as the viaduct was to be built for the owners of the railway. Therefore, if he had again to design that bridge, he should adhere to the plan that had been adopted. But in the case of the two iron viaducts on the South Durham and Lancashire line, the circumstances were entirely different. At Deepdale, there was a cutting of 200,000 cubic yards, which could not be commenced till the viaduct was completed, as the whole of the material had to be carried across the valley, to form an embankment on the other side; while at Beelah, there was a cutting containing 50,000 cubic yards of rock, which also had to be taken across the bridge, and could not on that account be commenced until the viaduct was built. Those were circumstances which weighed with him, in estimating time as money, and as railways must be treated as commercial enterprises, the delay of a few years in their construction might be sufficient to condemn an undertaking. It was therefore necessary, without reference to cost, to adopt some form of structure which should enable the line to be completed within a reasonable time. Although in the immediate vicinity of both works there was a vast quantity of stone, yet it was only on one side of the Gills, for on the other side, especially at Beelah, he scarcely knew any district in which stone was so scarce. In point of fact, looking at the quantity of stone required for the foundations of the Beelah viaduct, it cost nearly as much as the whole of the ironwork. On the South Durham line, there were a great number of viaducts, many upwards of 100 feet in height, which were built of rubble, after the plan first adopted by Mr. Hawkshaw. Those were the cheapest on the line, and he had built two viaducts upon that plan in Scotland, 80 feet in height, at a cost of £20 per lineal yard for a single line. In all cases he had used stone, where time allowed him to do so, and the material was at hand. In other cases, he had adopted stone piers, with trussed iron girders; but then the iron was merely used to save time, bearing out the remark, that in works of this description no fixed rule could be laid down. He might mention that the sixteen openings of the Beelah bridge were completed in four months, or at the rate of one span per week, including the erection of the piers. In

some instances the difficulties with regard to the foundations were the greatest he had ever encountered. The Westmoreland Gills, as they were termed, were nothing more than great cracks in the mountains. There might be rock at the sides of the Gill, giving the appearance of great solidity; but as soon as it was disturbed, it was found to be only débris from the sides, easily set in motion, and with considerable tendency to slip. In fact, there was one large slip close to the viaduct, which carried away a cottage and a smithy, and for a time placed the viaduct in jeopardy. As an instance of the difficulties of the foundations, he stated that, after the railway had been for some months in operation, it was found that one of the columns of the piers, instead of resting upon the masonry foundation to which it was bolted, had the masonry hanging to it. Although express and heavy mineral trains had been running over the line perhaps for months before this condition was discovered, still the work had withstood this test. It was speedily remedied, and he had no fear that it would occur again. It was but fair to the contractors to add, both as regarded the Hownes Gill viaduct, and the Deepdale and the Beelah iron viaducts, that as examples of good workmanship he believed they could not be surpassed.

Mr. SHEILDS thought the comparison between the cost of a brick viaduct and of an iron one was hardly fairly put. In his opinion, in almost all cases, except under extraordinary circumstances, an iron viaduct of the dimensions referred to, could be erected more economically than one of masonry. He did not mean to say that either in durability, or in solidity, an iron viaduct was superior to one of masonry, provided the foundations were good; as a more rigid structure could be formed of masonry than of iron girders, which always involved a greater amount of deflection and vibration, and probably therefore of comparative instability; but for various commercial and practical considerations, he thought iron was generally superior to masonry for this class of structures. For instance, in the comparison made by the Author, the brick structure in question was estimated to cost £20,681, whereas it was calculated that an iron one could be erected in a similar situation for £16,249, or with a saving of one-fifth. Moreover, in considering the prices on which these estimates were founded, it must be noticed that the bricks were obtained on favourable terms, both as regarded first cost and delivery, whilst the ironwork was taken at £22 10*s.* per ton, which, in the present day, was certainly a high rate. Under these circumstances, he believed the saving in first cost by the use of iron would be considerably more than had been stated. The fact that large quantities of bridge ironwork were sent to India, Spain, Russia, and the most distant parts of the world, even where masonry work was cheap,

was an argument in favour of the superior advantages of iron structures for large bridges, as it was reasonable to suppose that cost was an important element in these cases.

Mr. BIDDER could not allow the observation to pass unnoticed, that the large extent to which ironwork was sent to India and other places was a proof of its superiority to masonry. That was a mistake; and indeed it might just as well be said, that iron girders were used in the Charing Cross Bridge, because they were cheaper than brickwork, whereas it was well known that that plan of construction was adopted, in order to avoid increasing the height of the railway. Ironwork was sent to India, not on account of its economy over brickwork, but to serve a particular object—in other words, to keep down the level of the railway over the rivers where brickwork could not be applied without raising the railway to an undue height.

Mr. SHEILDS said he had referred to cases in his own practice, where the cost was calculated, and where iron was selected solely for the purposes of economy. There was more scope for economically designing a large viaduct in iron than in masonry; as the spans could be made much wider in the former material. Of course the greater the openings, the fewer would be the piers, and vice versâ; and when the piers were of great height, it was important to diminish their number by enlarging the spans; which could be done more easily and cheaply with iron girders than with arches of masonry. Keeping this in view, it would be seen, that when the cost of a pier, and the weight of ironwork for girders of various-sized openings, were known beforehand, it would be easy, by a trial and error process, to arrive at a minimum of cost for the piers and girders together forming the whole bridge, and he repeated that his own experience had proved to him that ironwork, except under peculiar circumstances, could be erected at a cheaper cost than masonry, in a viaduct such as that referred to in the Paper.

Professor POLE said, that having sent out large quantities of material for Indian railways, he could state that one great reason for the large use of iron upon works of construction in that country, was the saving of time. On the greater part of the East Indian line, for example, brickwork was the natural material of the country; both bricks and labour were very cheap, and the work could be well executed by the native workmen at a cost much lower than in Europe. But there was found to be a limit to the quantity of bricks which could be made in a given time, and as the nature of the country required bridges and flood-works of enormous extent, it soon became evident that if all these were to be constructed of brickwork, the completion of the line must be delayed to an almost indefinite period. For this reason, it was the interest of the com-

pany to send out large quantities of ironwork, at an expense much greater than need have been incurred, if the normal material of the country could have been used.

Mr. W. H. BARLOW concurred in the remark, that no rule could be laid down, as to the material of which viaducts should be constructed. He was at present constructing a line of railway upon which there were several viaducts of considerable extent; and in all ordinary cases he had found simple rubble to be the cheapest and the best. But for skew bridges, and under some other circumstances, iron could be used with advantage. He did not think that, at present, either iron or stone could be said to be the cheaper material for viaducts; the choice must be governed by the locality.

Mr. JOHN FOWLER, V.P., said, it was difficult usefully to compare ironwork with masonry, unless all the circumstances were stated in great detail. He had seen the Hownes Gill viaduct, and could pronounce it to be a most substantial work. The dimensions were of the ordinary kind, the material was good, and the foundations were carried down according to the nature of the ground. There was, however, one peculiarity upon which further information was desirable; that was the remarkable spread of the piers, by means of the buttresses. This was carried to a greater extent than he had ever known in a viaduct of similar dimensions. The piers had been extended, laterally, to nearly three times their length at the springing of the arches. He should be glad to know whether the object was to give greater base to the foundations (which he presumed must be the case), and for architectural effect, or whether it had been done with reference to the vertical stability of the piers, which he could scarcely think necessary. The buttresses were certainly not, primâ facie, a necessity for the stability of the work, or for its appearance, and they must have involved considerable additional expense. As to recesses, or openings, in piers, the question, whether desirable or otherwise, must always depend upon the nature and value of the materials used.

Mr. J. SCOTT RUSSELL said, in the bridge aqueduct of Roquefavour,[1] on the line of the canal of Marseilles, there was the peculiarity of the buttresses spreading very much at right angles to the centre line; but the piers were perfectly parallel and vertical on their inner faces. In the Hownes Gill viaduct there was an increase in the dimensions both ways, which required to be accounted for.

Mr. BOUCH remarked, that the lateral spread of the piers was to secure a greater area for the foundations. As the piers were only 12 feet in length at the springing of the arches, and the height of

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 190.

the loftiest ranged from 110 feet to 114 feet, he thought buttresses were necessary to give steadiness to the structure. As a proof that this view was agreed in by other Engineers, it was only necessary to refer to the fact, that inverts had been added to the original design, in order to give a larger base.

Mr. CUDWORTH said, with regard to the remark, that the comparison between the two constructions was not a fair one, he had furnished data from which every one might form their own conclusions, and thus be enabled to judge how far he had been justified in the observations he had made.