heading of this section, and of unsymmetrical form; as well as to that arch whose pressures and form are similar on both sides of the crown, as described in Section II.

It is also evident, that the above method will apply to any irregular form of arch, and that the principles and method described in Section III. might also be applied.

The paper is illustrated by a series of large diagrams, from which the Plates 27 to 37 are engraved.

Mr. STEWART thought he had, in practice, seen arches fail, at points not shown in the diagrams, and it must be evident, that an opening. such as was shown in the case alluded to, could only occur after a portion of the stone had been split off.

Mr. SNELL explained, that the diagram to which Mr. Stewart alluded, represented the failure of an arch, under the theoretical condition of the materials being infinitely strong, to resist compression; in that case, the arch would fail, by one of the voussoirs turning on its extreme edge, upon that of the adjacent voussoir.

This would take place, only when the line of resistance, that is, the position of the resultant of the pressures, passed without the intrados, or the extrados of the arch; so that such an arch would be stable, so long as no pressures, to which it would be subjected, would cause the line of resistance to fall without the extrados, or the intrados. This, however, was not the case, even with the strongest materials as yet known, and therefore an arch would fail, when the line of resistance fell within the section; but less than a certain distance from the intrados or the extrados; which distance would be dependent upon the ratio of the amount of the resultant pressure, to the amount of pressure, per square inch, the material would be capable of sustaining. Thus at this point of the discussion, it became a question of strength of materials, which could not be solved by theory; but the practical judgment of the engineer must guide him, or actual experiments must be resorted to; theory would tell him the direct position, and amount of the resultant pressures; it was for him to decide, either by direct experiment on the material, or by a comparison of the case with the results of former experiments, whether a block of the material, such as one of the voussoirs, would sustain such a pressure, applied at such a position and in such a direction:—this question being decided, the strength of the arch was determined.

Mr. R. STEPHENSON regretted the necessity for reading the paper in abstract,* as its merits were not rendered sufficiently prominent, and it could scarcely be well understood until it was printed, so as to be read by members at their leisure. Indeed he should avoid making any lengthened observations until he had perused it carefully. He thought, however, it might be said of this, as of Mr. Barlow's paper, that it was not so practically useful as it might have been, had it treated of the stability, instead of the instability, of certain arches. The problems given, hardly met the wants of the engineer. It appeared, that examples of arches nearly in a state of equilibrium were selected, instead of investigating the more abstruse question, of an arch unequally balanced. The old theories all viewed the arch in the same manner, and had for object, to establish when the acting force had not a tendency to move. These old theories and formulæ were looked upon by Mr. Stephenson with great respect, and acting upon them, he had been generally successful. The investigations of Professor Moseley, Mr. W. H. Barlow, and Mr. Snell, were most important, but Mr. Stephenson must own, that he had studied attentively the elegant and scientific investigations of the former of these gentlemen, without clearly understanding their practical application.

Mr. Snell explained, that if it was determined under what conditions of strength of material, an arch, or any other structure, would fail, under the pressure to which it would be subjected, and the strength of the material was also known, either by direct experiment, or by the results of former experiments, on the same material, the engineer would, he conceived, have sufficient information on the subject, and the methods described in the paper, would enable him to arrive at this knowledge: however, he thought it would be well to attach to the paper an Appendix, in which those methods should be applied to the discussion of some practical case, and this he would do for any example that should be given to him.

Major-General Pasley had paid much attention to the subject nine years since, and had, at that time, been impressed with the inapplicability of Hutton's theory, to many forms and conditions of arches. He did not agree in considering the arch-stones as perfectly smooth bodies, except in a purely theoretical view; in practice, the angle of slipping, the adhesive property of the various cements, or mortar, when quite dry, the horizontal joints of the piers, and the various forms of the arches resting upon them, required also to be considered. Some arches of the forms condemned by Hutton's

* The paper is printed in full.

theory, had stood for centuries, without exhibiting any symptoms of failing.

Mr. Scott Russell had always found a difficulty in applying, practically, Professor Moseley's theory, and he did not see clearly, from the diagrams before him, what determined the relative proportions of the distance of the line of resistance, from the intrados and from the extrados, in any given case. It must be evident, that if the stones were incompressible and of infinite strength, then the distance would not exist: in fact, the masses would turn upon each other at their edges, or points of contact: but in practice, and taking into consideration the strength of materials, it was of importance to ascertain the point to which the line of resistance could approach towards the intrados, in order to know how much of the intrados would split off, on the opening of the joint at the extrados. He thought these points could only be ascertained by careful experiments, on a large scale, to which also might be applied the formulæ given by Mr. Snell, in order to test their accuracy.

Mr. Snell observed, that the published results of experiments, already made on various building materials, would, he supposed, suffice for the determination of most questions, with as much accuracy as was required by the engineer, who would of course be careful not to consider the material to be of too great strength; but would make sure that it was twice, or three times, as strong as was shown by theory to be requisite.

Appendix I.

Art. 1. On the determination of the centres of gravity of surfaces, required in the application of the problems, in the preceding articles.

This subject is treated in a simple elementary manner in Professor Moseley's 'Illustrations of Mechanics,' Articles 140 and following, and is fully discussed in his 'Mechanical Principles of Engineering and Architecture,' Articles 20 and following, and formulæ for calculating the centres of gravity of different figures, are given in the latter and other works.

The author of this paper used a very simple apparatus, by the aid of which, the centre of gravity of any shaped surface, representing the section of a material of uniform specific gravity, may be found with great accuracy. The principle upon which the method is founded, is treated of in 'Moseley's Illustrations of Mechanics,' Art. 141, and this is merely a more accurate method of applying that principle, than any there proposed.

The apparatus consists of an upright rod, with a centre line drawn down it; this rod is fixed to a stand, on three screw legs, so that the centre line can be adjusted to a vertical position, as indicated by a plummet; a few holes are drilled in this centre line, and a peg, with a needle at its end, is turned to fit these holes. A piece of cardboard must be cut to the shape of the surface, whose centre of