

Discussion.

Mr. Mansergh. Mr. JAMES MANSERGH, Vice-President, was sure the members would agree that a vote of thanks be presented to the Author for his useful and practical Paper. Any engineer was to be commended, especially a young engineer, who gave to his fellows the benefit of such observations as the Author had made. The Paper dealt merely with subsidence due to coal-workings; but the members were all aware that subsidence took place in many other workings, especially in the district where brine was pumped. The discussion would therefore be open on the subject of subsidence not only from coal-workings but from brine-pumping, and any other operations of that nature.

Mr. Saner. Mr. J. A. SANER exhibited upon the screen a series of photographs illustrating the effects of subsidence due to brine pumping in the district of Northwich. The question of subsidence, as brought forward by the Author, was very interesting; and although, fortunately, he was not frequently called upon to design permanent works over such places as the photographs had illustrated, it was instructive to learn what was done in the coal districts and in other districts where such subsidences took place. A rule was laid down by the Author for finding the area of subsidence caused by working the coal; but he was afraid that in Cheshire, in the Northwich district, such rules would be entirely useless. There, instead of having the coal seams 4 feet to 6 feet in thickness, there were two superimposed beds of rock-salt 84 feet and 82 feet in thickness, and a layer of marl about 30 feet thick between them. The effects that had been seen on the screen were caused by the fact that the salt was obtained in two ways. In one case the rock-salt was mined as in an ordinary mine, the workable portion being about 20 feet thick in each bed, so that the mines when left were about 20 feet high. The remainder of the salt-bearing strata was worked by pumping water which was converted into brine, either natural springs—although he was afraid they had now been eclipsed by the artificial springs—or water which had been allowed to run down into the mines, thus the pillars which supported the roof were eaten away, and the subsidence took place. He thought that in some places the ground had subsided to the extent of 60 feet or 70 feet, and

he knew of much deeper holes in special cases. It was not known whether the subsidence had stopped, neither could the exact area or the exact extent of the possible damage be ascertained. Further, although plans of the old mines were kept to a certain extent, the water had done away with very much larger areas of the salt than were mined. It was impossible to predict where the subsidence would take place next. The terrible looking holes which had been shown on the screen occurred chiefly on the edge, somewhat beyond the edge, of what was known to be the extent of the rock-salt; and he thought in that case it bore out the Author's statement, that the greatest effects of the subsidence were not exactly over the rock or over the coal, but some distance outside the edge of the working. The subsidences in Castle Northwich and Leftwich were about 300 yards south of the rock as at present known; and it appeared as if the draw of the subsidence assumed an angle approximately equal to the angle of repose of the overlying strata, and that those holes might be caused by the overlying marls (because all the rock-salt lay in the Keuper marls) cracking, and the surface-water drawing down the sand and glacial drift into the caverns beneath, forming as it were an hour glass. He thought the cone-shaped cavity which was formed was merely filling a similar cavity below, and that the earth that fell from the cone was deposited in a heap in the cavern below. These conical cavities were sometimes as much as 120 feet in diameter at the surface. That appeared a feasible theory of the extraordinary subsidences which took place, not only in Castle Northwich and Leftwich, but also, as it were, in a ring round the known area of the rock salt. As to the buildings suitable for such places, he would prefer there were none at all; for his experience had shown that however solid masonry might be made, or whatever the work was on the top, it was more or less damaged by such subsidences. One of the bridges over the river Dane, a tributary of the Weaver, for instance, had masonry piers that were exceedingly solid so far as could be ascertained. They had been built for some years, but they were cracked down the centre in halves, not through the joints of the masonry, but straight down the middle. That bridge had, from ascertained figures, subsided to the extent of 7 feet since 1882, so that it could not be wondered that the masonry of the abutments was somewhat cracked. It appeared, so far as ordinary buildings were concerned, that the form of structure which seemed to be a survival of the fittest in Northwich was either wooden or iron framework filled

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Mr. Saner. with stucco or brickwork. The house which had been shown on the screen on its beam end was built in that form, and it seemed very little damaged by being turned over through an angle of nearly 45° . If there had been a foundation upon which to rest hydraulic jacks, that house would never have been pulled to pieces as it had to be. In the subsidence which took place on the 15th November last, a house of similar construction moved bodily over into the street; the lower sills moved about 1 foot, and the upper sills overhung 4 feet. But within 48 hours the owner of the house had borrowed hydraulic jacks and had raised it into a horizontal position again. The Weaver Works, of which he had charge, with the exception of the town bridge at Northwich, which he was now engaged in removing, and replacing with a swing bridge of a special construction he hoped at some future date to explain to the Institution, had been entirely removed from the subsiding district, but up to 1859 the effect on the locks and the weirs was of a disastrous nature. He believed that either two or three locks had to be rebuilt within very short periods close to the town of Northwich. He had, however, raised one part of the towing path 12 feet in less than 10 years.

Mr. Wright. Mr. TYLDEN WRIGHT remarked that the damages caused by salt subsidences were very great, but he was afraid they were beyond all rules, and would not be met by any mathematical formula. The matter was so serious with regard to the coal measures, that he was surprised the subject had not earlier been brought before the Institution. Last year more than 200,000,000 tons of coal were raised, and that represented almost 50,000 acres of coal of a thickness of 3 feet. According to the Author, with whose results he thoroughly agreed, the subsidence over that 50,000 acres would be no less than 2 feet. When that took place in a district permeated with canals and railways, it was a most serious matter for the proprietors of those railways and canals, for the engineers who advised them, and he might also add for the engineers who advised the owners of private mansions as to the effect of that subsidence. He agreed, in general, with the Author; and allowed that the depression would take place in the lines that the Author represented, that if the seams were horizontal, the line of fracture would be vertical; if it was inclined, most mining engineers would allow that it would be half-way between the angle of the seam at the surface and the surface itself. But he did not agree that the wave of subsidence followed the excavation of the coal. He had found from most careful experiments extending over 7 years, month by month, that the subsidence

began considerably in advance of the working of the coal. An instance he might refer to was Newstead Abbey in Nottinghamshire, one of the finest historical mansions in the country. It was his lot to advise the owner whether the pillar of coal that had been planned to protect it should be left, or whether the whole of the coal should be swept out by long-wall work. He found that the pillar required to protect it would be at least 40 acres in extent, and about £4,000 in value; and even if the pillar were left, then the lakes which were close to the Abbey would be thrown out of level, and a great deal of trouble would be caused. He therefore recommended that the pillar be entirely swept out by long-wall work. The workings were 560 yards from the surface, and the seam of coal was 3 feet thick, but the material removed was 3 feet 8 inches in thickness. Observations had been kept by Mr. Bagnold Smith, the managing director of the Newstead Colliery Company for 7 years. Fortunately they began before the coal was worked, and it was found that 9 months before the coal was excavated under any portion of the Abbey, it began to move and to fall at one end at the rate of $\frac{1}{8}$ inch per month. The face of the work was then 90 yards distant from the Abbey. As the work advanced the wave of depression increased from $\frac{1}{8}$ inch a month until it ultimately reached $1\frac{1}{4}$ inch per month, or a total depression of 15 inches in the year. At one time, a year or two ago, one end of the Abbey was 10 inches lower than the other. But to show how smoothly and steadily the fall took place, he might mention that in the west window of Newstead Abbey, which was one of the finest architectural possessions of the country, with the loose tracery of the window, which was there 800 years ago, not a single stone had dropped out, and it was all just as it was, although it had subsided no less than 23 inches. He cited that instance as, in his opinion, confirming the modern view, that the best plan to deal with such questions, where there was a deep seam and the strata were moderately favourable, was to sweep the whole seam out by long-wall work as rapidly as possible. There was no question that if the pillar had been left grinding would have been going on for years, the level of the lakes would have been disturbed, and it would be impossible to surmise the fate of the Abbey. The working face was now 500 yards past the Abbey, and although there was still movement of $\frac{1}{8}$ inch per month, practically it had come to a state of rest again. But matters had not always turned out in that way. He could name another house in the immediate neighbourhood—the house of a

Mr. Wright. noble Duke in Nottinghamshire—where, instead of depression taking place—the strata tilted up. One night, about 3 years ago, when the family were at dinner, the floor rose suddenly. The Duke's chair was raised 4 inches above the rest at the table and a good deal of alarm was felt; but, no other serious damage had been caused to that house, and he thought £100 would probably pay the whole extent of it. The coal had been swept out from the same depth and to the same thickness as in the case of Newstead Abbey. After that explanation he thought the Author would agree that the best course was, instead of leaving a pillar of 68 yards radius, amounting to about 3 acres of coal, as shown on the diagram, to have swept the coal out and taken the risks in the same way as he had in the case of Newstead Abbey. But all cases of colliery working were not of that nature. He had had many cases in his experience where, instead of the surface subsiding regularly, there had been apparently no sign of subsidence on the surface. He knew workings in the South of England where large areas had been swept out under a city without the slightest perceptible subsidence having taken place. The same thing had also occurred in Derbyshire. He attributed that to the fact that the strata immediately above the coal were much stronger than the strata below, and that when the weight was taken off the coal and the coal was excavated, the "floor," as it was called, being of a soft nature, rose and filled the excavation, or the goaf, and the rock above remained as it was, but the excavation was filled from the floor. That was clearly proved by having to "dint," as it was called, or take up, a portion of the floor to keep headway in the gate roads for the horses. It was further proved, because in driving roads through the old goaf years after it had been made, it was found that the floor of the seam, instead of being in the floor, where it would be expected, was really up where the roof should be. He agreed that general rules for the subject could not be laid down, but that only a certain angle of repose, or angle of rest, could be assumed, which the Author took at values which worked out very satisfactorily and safely. He considered the best method of dealing with ordinary cases of subsidence at considerable depths was to sweep out the whole of the coal as quickly as possible, at the rate of about $2\frac{1}{2}$ yards per week, and pack the waste closely; then very little damage would result.

Mr. Mac-Donald. Mr. J. A. MACDONALD took a great interest in the subject of the Paper, as he was responsible for many important structures on

the surface in coal-mining districts. At the beginning of the Paper, the Author had alluded to the coal-fields in the West of England and Wales, and it was an interesting fact that in a city in the West of England the coal had been worked for a century and a half, and he believed probably longer, under parts of the city, without causing the slightest injury to any of the buildings. But he thought that was not altogether due to the band of rock that was left above the lower coal, but was quite as much, if not more, due to the fact that the coal was pitched up at a very high angle, the full dip being, he believed, 16 inches to 1 yard, and the sandstone rock, which was 40 yards or 50 yards thick, acted as a girder, and there was practically no settlement. He did not agree with the Author's view that structures of the arch form should be avoided if mining operations were proceeding beneath. Arched bridges of moderate spans behaved extremely well while coal-workings were passing underneath, assuming that the coal was of moderate thickness and at a reasonable depth, say 100 yards. He had had an instance within the last few years of an arched bridge carrying the main line of railway over a road. A face of coal-working was approaching the railway, the seam being about 7 feet 6 inches thick, and at a depth of only 72 yards. It was thought by the local engineer in charge of that part of the line that the bridge would probably be destroyed, and it was decided to take down the arch and erect an iron superstructure. The girders were delivered at the site, and the workings proceeded, but the arch showed no cracks. The workings came under the bridge and passed it, and the bridge still showed no signs of distress. The arch was still in a thoroughly good condition, and carried the main line of the railway, and the girders had been used elsewhere for another purpose. The span of the arch was about 20 feet. His remarks would not apply to large spans of 50 feet or 60 feet. The bridge was as good now for practical purposes as it ever was. Another case of a similar kind had occurred not very long ago; a bridge had been constructed in a district where there was coal-mining underneath, with a girder top and headways of 18 feet or 19 feet. The bridge began to settle, the abutments were cracking and moving together a little, and he decided to put in an arch. That bridge was now in a very satisfactory condition, the workings having passed under it. Nor did he agree that in all cases coal should be bought under tunnels; he thought that each case should be considered independently on its own merits. If the coal was swept out steadily, fairly, and regularly, tunnels

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Mr. Mac-Donald. in certain conditions would take practically no harm ; but if, as in the case the Author mentioned with regard to the strike, the workings were suddenly stopped and commenced again, more harm resulted. With regard to tunnels, an instance had occurred in his own experience of a 5-foot seam of coal which had been worked from underneath a tunnel for which he was responsible, at a depth of between 200 yards and 300 yards from the surface. That tunnel hardly had a crack in it and the traffic through it had never been delayed for a single moment. With regard to the question of buying ribs of coal for the protection of structures instead of solid pillars, he had no experience of that arrangement, but he had purchased coal for the support of viaducts by laying it out, on the plan of a chess-board, and buying all the black squares. That had been done a little while ago, and it had answered well, and the viaduct was now in a very satisfactory condition. The pillars should be of a fair size ; in the case he had mentioned, he believed they were about 50 yards by 24 yards.

Mr. Inglis. Mr. J. C. INGLIS observed that the effect of working coal below a structure like a railway viaduct was sufficiently obvious to show that the chances were that serious damage would result. The first impression he had formed of the Paper was that the Author was somewhat bold to at once plunge into mathematics as to the area required to provide a support for the superincumbent structure. He had taken the trouble to test the Author's formula by one or two cases he had had to deal with lately, and, rather against his pre-supposed idea, the result came out fairly correct. At any rate, he thought he might take it, as one of the speakers had said, that the formula represented a practice which was fairly general on the part of mining engineers. There was only one point which occurred to him, and it was one involved in an important case he had under consideration at the present time, viz., dealing with subsidence on coal measures having a somewhat high angle. Taking *Fig. 4* as an example, in the case he was thinking of, a tunnel, he should not have quite gone to the length shown in the *Fig.* ; he should have been inclined to take the coal which was to be purchased further down the slope towards the point *F'*, because he had a lively terror of the effects of "pull." The allowance of support suggested by the Author on the low side of the coal measure would hardly be enough, in the case of a high angle. The formula proposed was merely an expression of practice generally followed, but he would not purchase a piece of coal so much on the high side of the

structure to be supported where the angle of the coal measures Mr. Inglis. was high. A slight idea of the general effects which coal-mining had on railways could be obtained from the fact that in one district the Great Western Railway had annually to provide and to replace something between 60,000 yards and 70,000 yards of filling to make good the subsidence which took place from coal-mining. Cases had been known—he thought one was mentioned in another part of the country—of a canal having been raised. There was a canal in South Staffordshire which had been raised 20 feet. In the same district his company had several goods yards which had been raised quite that height, and many other extraordinary lifts, including bridges. The evidence, as far as bridges were concerned, was that the honours were equally divided between arches, as to their good behaviour and their bad. The Great Western Railway had arches which had behaved nobly under very distressing circumstances, and they had others which, so to speak, had thrown up the sponge on the first indication of distress. It was very difficult to predicate much upon the subject in a general way. He had also had experience in another exceptional case, namely in the West of England, where the railway company owned the minerals below their property, and within the last 9 months a considerable area of those had been sold to be worked out; but the coal in that area was overlaid by very thick strata of sound hard rock. It was not anticipated that no settlement would take place; but when there was a large area of solid rock over a coal seam the settlement could be foretold exactly, and it would be uniform within the large limits. It depended upon the amount of packing and the pillars left; but one point was becoming apparent, that, while pillars were of advantage for a time, there was a slow process of disintegration, which occurred year after year, after it was thought the whole settlement had been remedied. He could point to a case involving a large sum of money, where a company, thinking to avoid the large expenditure of buying the whole of the coal, compromised the matter by providing for what was believed to be a safe area of support by pillars. The consequence had been that the maintenance works had been completed apparently after the first settlement took place; but a slow settlement occurred and was found to be much more troublesome to deal with than the first. With regard to the process of gradual subsidence of the ground due to working under the Merthyr tunnel, of which he knew less than Mr. Lloyd,

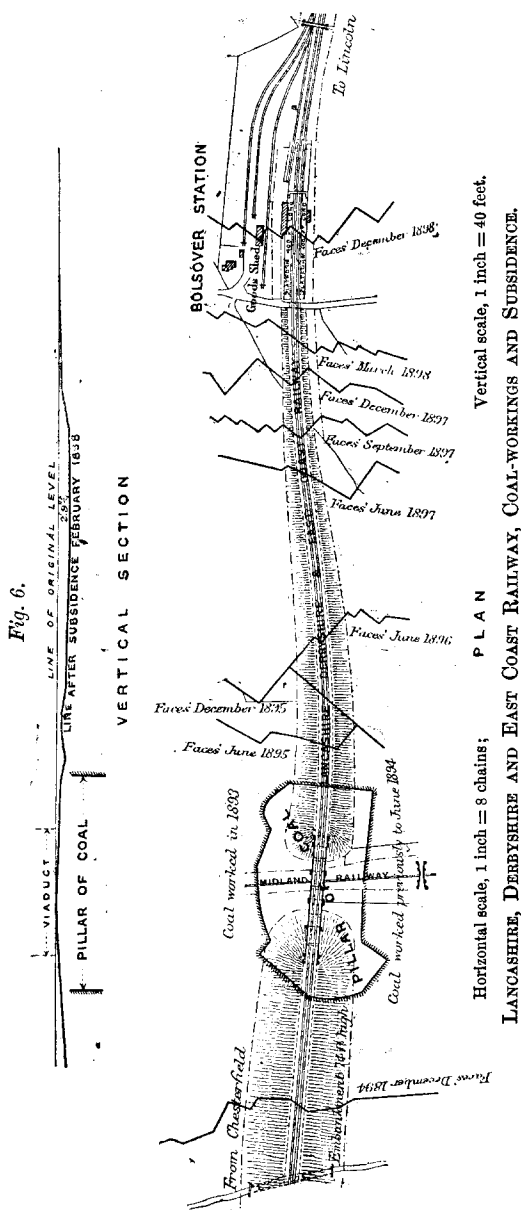
Mr. Inglis, one of the divisional engineers, it was a tunnel about $1\frac{1}{2}$ mile in length, and as the workings progressed the settlement in the tunnel took place. He could not now tell the relative position of the workings and the settlement, but at any rate it took place in waves and progressed from one end of the tunnel to the other, except at points where wide faults occurred. The greatest difficulty arose from the fact that while the rest of the tunnel settled—the total settlement had been about 10 feet—the portion over the faults did not settle and had to be cut down and lowered so as to make it join with the lower portion which was due to the settlement arising from the working of the coal. He should have liked to have seen the data, as an Appendix to the Paper, on which the Author's formula was built. It might have the effect of stimulating other members to add to it. The only value the proposed formula had was the practical area it covered in the way of examples which were found to be more or less efficient, coupled with the circumstances of each case. The sums involved were so large that it was to railway companies' and canal companies' interests to watch each case and deal with it on its merits. He did not know whether it was asking too much of the Author, but the formula was stated to be founded on certain definite cases, and it would be worthy of the volumes of the Institution if those cases were given.

Mr. Cooper. Mr. R. ELLIOTT COOPER remarked that his own experience of the effects of subsidence caused by coal workings had now extended continuously over about 6 years. In 1892 a main line of railway with a number of branches had been commenced through a district that had not been worked except in a slight degree. This was a coalfield about 150 square miles in extent, a large part of which was now being worked, and the effect of the subsidence could be seen, he might almost say, from day to day. When the railway was first laid out, the Chairman of the Company, who was himself a large colliery owner and an eminent engineer and a member of the Institution, expressed his opinion that it was a mistake to buy any coal at all; and that view entirely agreed with Mr. Wright's opinion, who had given that very good advice. With the exception of a single case the opinion of the Chairman was followed; and although several out of fifty or sixty bridges on the railway which would be undermined, only in one or two cases had there been slight signs of damage caused by the subsidence, and practically speaking no injury whatever had resulted; whereas if any attempt had been made to buy the coal and so protect the works, the amount of money that would have been so expended would have

greatly exceeded what it would have cost to even rebuild some of the bridges. The amount that was being asked in the Derbyshire district for each of the several seams of coal for the purpose of pillars was so great that it became a matter of serious consideration as to what extent, even in the one case where a pillar was bought, it should be done. That single case was a viaduct 80 feet high from the foundations to the rail level, and if he had known then as much as he did now, if he had been able to foresee how very little damage the subsidence created, he would certainly have recommended that even in that particular instance the coal should not have been bought. There was a point that perhaps was not sufficiently considered even apart from the question of the safety of the structures. Supposing, for instance, a number of detached pillars of coal were bought, in a district like that he had mentioned—where no coal had been worked and where in years to come the whole of the surface subsided to an entirely new level varying between 1 foot and 3 feet 6 inches—if detached pillars of coal were left, or a number of fixed points were created, which might be very inconvenient. For instance, if there was a viaduct or tunnel immediately adjoining a station, and the level of those two points was fixed, and the coal was not bought under the station, a gradient of considerable steepness would be formed between the two points. The station could not be raised, unless it was pulled down and the sidings ballasted up, and the result would be a very awkward position, which might have been altogether avoided. He had taken great interest in watching the effect of the subsidences, and he had found that any little damage that was done was almost invariably caused by the “pull” rather than by the subsidence itself. He had observed in one case that whereas a parapet of a bridge had slightly opened, caused by the pull, when the bridge had become undermined completely the cracks had been entirely closed, because the surface had returned to its level instead of being, as it were, on a curve. That had occurred not only in the case of one of his bridges, but in the offices of the colliery company itself, where a crack appeared from top to bottom; but now that the whole of the coal had been cleared away from under the building there was not a crack to be seen. Another point that had to be considered in all questions of subsidence was the strata that overlay the coal. In the particular line that he referred to for about 12 miles the strata immediately below the surface, for a great depth was a strong blue bind, but in another district on the same railway there was about 50 feet or 60 feet of solid limestone. The difference between the effect of the

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subsidence on those two portions of the line was very remarkable. Where the blue bind existed there was invariably a considerable "pull," the effect was quite noticeable. Where the limestone was found there was no effect whatever of the "pull." There it simply went as if the surface were a piece of india-rubber. At one place he had in his mind where there was a long piece of level line perfectly straight, it could be seen year after year how a slight curve was formed, but without the slightest injury to any single structure. As the subsidence proceeded, the level piece of line would eventually take its original form, but it would be about 18 inches lower. The mines in

both cases were between 400 yards and 600 yards deep. Where the

limestone came to the surface, and, as he had said, was about 60 feet thick, the subsidence at the most that he had been able to find was only between 1 foot and 18 inches. At the adjoining colliery, and with the same depth to the coal, but where the blue bind was the overlying strata, it had amounted to between 2 feet 6 inches and 3 feet 6 inches. The effect of subsidence amounted to practically nothing, but the "pull" undoubtedly had a slight effect. One seam was 5 feet thick and the other 5 feet 6 inches thick. Several speakers had referred to the probability that even where a supporting pillar of coal had been left slight subsidences will follow when the coal round the pillar had been taken out, and he could corroborate this fact from instances within his own knowledge. He had a station where the coal was being worked along the line of the railway, the face being at right angles. When the workings reached a point about 60 yards from the end of the platform there was not the least subsidence but a distinct "pull," and the gas-pipe running under the coping of the platform broke. At the present time there were three or four small cracks of about $\frac{1}{2}$ inch; but now that the workings were under the station apparently the "pull" had entirely ceased, and the platform was gradually settling to its final level. All the experiences that he had had, and they entirely agreed with what Mr. MacDonald and Mr. Wright had said, pointed to the fact that engineers need not be very much afraid of building structures and allowing the coal to be worked out underneath, at any rate if the depth was anything like 400 yards. As to the question of the relative advantages of arches and girders, he did not think there was much difference. He was not speaking of large arches, but small bridges, such as occupation bridges under deep embankments, where it would be foolish to carry up abutments to carry the railway by a steel superstructure merely to avoid running the risk of any possible damage to a small bridge. On the railway under his charge he had a great many small-arch bridges, and in no single case had the least damage occurred.

Mr. H. S. CHILDE desired to suggest that there was an element which the Author had probably not considered in laying out the size of a pillar, namely the nature of the coal that was to give the support. Some of the coals—he referred to Yorkshire and North Derbyshire—were hard, and the pillar to be left would not be so large as the pillar of some of the softer coals, and it might be that the Author's rule would not apply in that case. With regard to *Fig. 1*, there was another cause of damage sometimes to buildings on the surface when the coal was worked from the

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Mr. Childe.

Mr. Child. inner angle of the fault. There were cases where to support a building coal must be left under the fault to the extent of about 220 yards from the foot of the fault. The lie of that fault was probably an average Yorkshire one, about $2\frac{3}{4}$ to 1, or an angle from the vertical of 20° . With regard to the other cases the Author had brought forward in the *Figs.*, he thought that, generally, the members would agree with the Author, excepting that probably he had not considered the question of the line of subsidence going into the solid. His line of subsidence went goaf-ward only, but there were cases when it went into the solid to the extent of 12° to 17° from the vertical, and that required a great deal of watching. If the formula was meant to apply where the whole of the coal was to be left, the question arose when the owner, who was leaving coal, was to be compensated, whether he should not also be paid for consequential damage or extra cost of working. It might be that it would be more economical and better to go further and buy the whole pillar. The attrition and decrepitation set up in some seams in those pillars were in progress from month to month, and it would be better to buy a solid pillar than buy in what was sometimes called gridiron fashion. Then the structure that was to be supported had to be taken into account. It might be that there were only some light buildings, but if there was almost a village, the question of a pillar or no pillar would have to be considered very carefully, and if a pillar, it would have to be a very large one. The other question that had to be considered very often was where water had to be supported. In supporting railways or buildings there was no fear of damage to the mine. The surface might or might not be damaged. But if it was a reservoir bank or a canal, it sometimes had to be considered whether, although the working of the coal might not do very much damage to the canal, it might not cause fissures in addition to subsidence, and there might be a claim in respect of damage by the water flowing into the mine.

Mr. Ross. Mr. A. Ross observed that in devising a new railway scheme over an undeveloped field of coal or a field that had probably not been proved, engineers had not very much guide, and it should be recollected that a good number of the railways in England were so constructed. But if an engineer had knowledge that he was on a coal-field, and had probably the mining engineer's report, it was only due to the work that he should take certain precautions. Whether he should avoid tunnels and viaducts was another matter. The physical conditions of the coal-fields of England did not admit of avoiding them altogether, but certain

precautions ought to be taken. No doubt the tunnels, for instance, Mr. Ross. ought to have inverts, and the foundations ought to be perhaps better than usual. As for the viaducts, he did not suppose arches could be dispensed with. He was not so afraid of arches as had been anticipated; but there was no doubt that in single bridges a metallic superstructure had great advantages. It had been his practice for many years to divide those superstructures so that each line of rails was self-contained. The great advantage of that was that when subsidence had taken place and the railway had to be lifted, one line could be lifted at a time, and the other could remain in use. With regard to arches, in many cases of his own he had to pull down an arch, especially an arch over a railway. If there was only limited headway to start with, and there was subsidence at all, and the line was kept up, the arch came within the gauge and the rolling-stock would come into contact with it. Generally for that reason alone overlying arches had to be pulled down when there was serious subsidence. But, after all, it was largely a matter of degree. The case that the Author had referred to, was that of a subsidence caused by one seam only, but in most of the coal-fields—and in some more than others—settlements had scarcely taken place from the subsidence caused by one seam, when other seams were taken out, so that the subsidence due to coal working might extend not only over 5 years, but even over 20 years; and he had known in his own experience many cases of that kind in which the extent of subsidence had been very great. In the case of buildings, the precautions necessary and obvious were to provide framed buildings at the stations, when the lifting would be much easier, and the damage would be much less. As was well known, an existing railway company, before the working commenced, received due notice of the intended coal-getting under the Clauses Act, 1845, and they had 30 days to consider what was the best course. The mining engineer usually made his report to the engineer responsible for the safety of the works, and he decided whether to recommend purchase or not. He was not much in favour of purchasing unless he was actually compelled to do so. There were cases where, for the safety of the line, it was obvious that coal purchases must be made, and in the case of several seams of coal lying underneath tunnels and viaducts, sooner or later purchase would become necessary. He had found, from many years' experience, that the mining engineers' reports told with very great accuracy what was going to occur; but with coal-mining, although not quite so much perhaps as with other

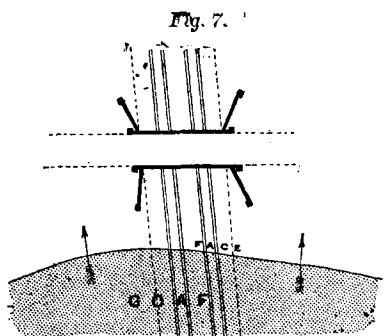
Mr. Ross. mining, the unexpected did happen. There was the pull and the draw, and in many cases the pumps working in a wet mine drew quicksand for long distances, and the effects were felt at such long distances that it was even doubtful which mine was causing it. Therefore he thought it was obvious that a definite procedure could not be stated that would help in deciding, under all circumstances, when not to purchase the coal. The whole disturbance has to be carefully watched and dealt with according to the effects.

Mr. Worth- Mr. W. B. WORTHINGTON desired to add a few remarks as to the ington. relative qualities of the arch and the girder bridge. He did not go quite so far as Mr. MacDonald, but inclined towards the view expressed by the Author. He had never had to take down a girder bridge from this cause, yet he had had to take down several arches, owing to their failing through coal subsidence. With regard to the point named by Mr. Ross, namely, the superiority of the girder bridge to the arched bridge over a railway, if 5 feet of coal was worked underneath a girder bridge, and it subsided 3 feet 4 inches or so, the girders could be lifted easily without interfering with the traffic on the railway, but if the bridge over the railway was a stone or brick arch, unless it was abnormally high to start with, it was necessary either to let the railway stay at the level to which it had subsided or pull the arch down. That was a very important point with lines which were so crowded with traffic as the railways which passed through coal districts. With regard to the pillar to be left for the support of structures, he had had an opportunity of observing the effect of leaving pillars; and he thought there was no doubt that greater damage was caused to the structure on the surface from leaving a pillar which was too small than from the entire taking out of the coal. If the pillar was too small the pull at the structure on the surface from all sides was such that it was very seriously damaged. With regard to the gridiron pillars it happened that within the last few months he had met with a case which threw a little light upon that subject. In a railway which was made 48 years ago the line was made above a bed of coal which had been worked on the pillar-and-stall system, rather more than half the coal having been got, and the spaces were partly filled in with rubbish. The seam was near the surface—in fact, running out of the surface at one point and gradually getting deeper and deeper. At a point where it was about 5 yards deep a subsidence had occurred within the last few months, the top crowning in. That appeared to show that the pillars and roof had decrepitated

during the 48 years. They had carried the weight up to the end of 48 years. Mr. Worth-
ington.

Mr. W. WALTER ROWLEY exhibited upon the screen four photographs illustrating the effect of subsidence of about 4 feet upon the banks of a canal, under which two seams of coal amounting to 7 feet 6 inches in thickness had been extracted, at a depth of about 200 yards. When he had first, many years ago, to consider and apply experience previously gained in mining operations to the working of minerals under, and the support of, railways, canals, reservoirs and other engineering works, he thought the task would be easy if the rules governing the size of a pillar to support a building could be reduced to a formula. But the longer his experience the more he was impressed with the difficulty of arriving at such a satisfactory issue. He found in practice the laws of theory could be used only to a certain extent in framing a general rule, which had to be modified according to the circumstances and surroundings of each case. According to a rule sometimes recognised, the pillars should extend on all sides to a distance equal to one-tenth of the depth of the seam plus 20 yards. Such a case as that given by the Author, namely, 400 yards deep, would give a fringe of 60 yards. This rule is applicable, as an approximate basis, to horizontal mines in which the thickness of the seam did not exceed 6 feet. In theory the circular pillar was correct, but in practice it was not found so desirable; often a square, rectangular, or still more irregular shape, had to be adopted in order to meet the special necessities of the case. One of the first points to be considered was the amount of subsidence that could be expected, because if that was small, the question of support might possibly be dispensed with. Such a question was affected by packing and other considerations. In considering the extent of support, the compensation to be paid to the mine-owner was often considered a very serious item to deal with, but he had sometimes found it difficult when advising that no pillar be purchased, to justify throwing on the engineering department such a grave responsibility as rested with them in maintaining the permanent way. From his record of over six hundred cases he had dealt with he found that less than 10 per cent. had had pillars purchased for their support. Protection for the railway by a pillar was never sought for unless the gravest sense of economy, safety and convenience, rendered it necessary. In working coal under bridges the method to be employed had to be taken very carefully into consideration. The advantage of the face of coal workings approaching a bridge broadside was shown in *Fig. 7*. If coal could be worked rapidly in this Mr. Rowley.

Mr. Rowley. manner the minimum amount of damage would take place; but if the bridge was approached end-ways, the girders were found to



LONG-WALL FACE APPROACHING A BRIDGE
BROADSIDE.

yield and the buttresses gave way; and if there was any stoppage in the operations of the mine, the effect upon the bridge was far more serious.

In *Fig. 8* was illustrated the first principle of support, namely, as far as possible to utilize the existing workings of a mine when worked on the pillar-and-stall system, so as to provide, with little interference to the mine—

which meant the minimum of cost to the railway—an adequate support. An adaptation of the existing blocks or pillars of coal was also illustrated in *Fig. 9*, dispensing to a great extent

with the important question of severance by simply recognizing the existing pieces of coal, and ordering them to be left in such

a position as would best serve and protect the property. It had been mentioned by Mr.

Elliot Cooper that in a line in which he was concerned no pillar had been purchased for the protection of the works, except in one case. That line

ran from west to east, beginning at Chesterfield and extending to Lincoln. A few miles distant from Chesterfield it left the

exposed coal measures, which had an eastwardly dip under the Permian rocks and New Red Sandstone, and gradually

assumed a great depth, rendering the difficulties of subsidence comparatively slight. The coal-field was not yet opened up

under the greater portion of the line, and in the only case where

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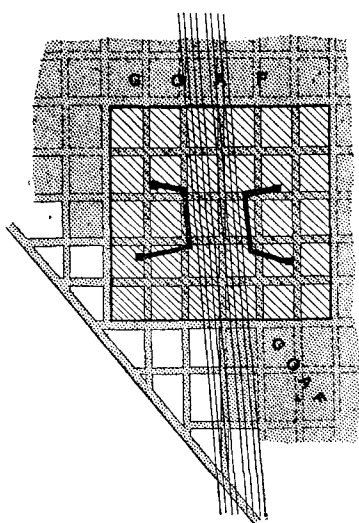
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Fig. 8.



SUPPORT FOR A BRIDGE IN PILLAR
AND STALL.

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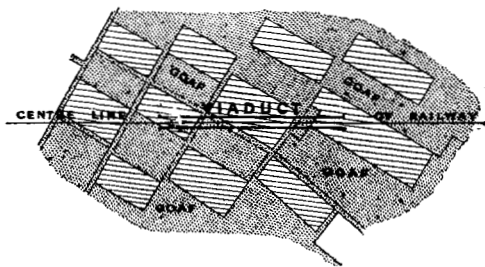
there was any necessity for the serious consideration of the effects of subsidence, namely, an important viaduct, support was purchased. The case of this railway was very different to the old mineral lines which had a very great mileage in the heart of the exposed coal-fields, with minerals varying between 2 feet and 30 feet in thickness, being worked at all depths. Modern railways had the advantage of experience, obtained at great cost by the older systems with regard to the difficulties of subsidence, and in some cases circumstances might enable them to so construct the works as to allow of a moderate subsidence. In his experience of the older lines which were made before the extending character of the coal-fields was properly understood, there had been such a limited margin in the height of some bridges that the rails had

had to be lowered—a process which could only be carried on to a very limited extent, and in the end sometimes requiring the bridge to be rebuilt. He would only add that in judging of such an important matter it was desirable not to base conclusions on excep-

tional cases, for proper study of such a subject could only be carefully undertaken from the consideration of many cases distributed over a wide area of observation.

Mr. R. J. GIFFORD READ remarked that the subject of the Paper had come under his notice in the case of bridges he had been concerned with in South Wales. A short time ago he had been employed by the Council of the Rhondda Valley to design the steel-work of some bridges that they were reconstructing over the River Rhondda. He had laid on the table two photographs of the old stone-arch bridges, which had been taken down. One of those bridges was a single-arch and the other a double-arch bridge—the arches being built of brickwork and the outsides faced with stone. Rhondda Valley was well known for its coal-workings, and the bridges were in the very middle of the district where the coal strike had occurred a short time ago. The bridges had been built 30 or 40 years, but settlements were first noticed about 8 or 9 years ago, and then they

Fig. 9.



PILLARS LEFT FOR VIADUCT IN ORDINARY COURSE OF WORKING.

Mr. Read. seemed to stop and nothing further was thought of it until about 2 years ago, when the bridges commenced settling again. In the one-arch bridge the crown seemed to rise and the haunch on one side sank, and cracks appeared at various places; the arch stones in many cases appeared to be suffering such compression that they were splintered and cracked. In the two-arch bridge there seemed to be a tendency of the arches to slide one way on the abutment, pulling the arches over the centre pier, which then cracked. The cracks were not shown well on the photographs, as the latter were not intended to illustrate the Paper, but were simply taken with a view of preserving a memento of the old bridges. The bridges continued to move so much that the Council determined to take them down, and they had been taken down and the new bridges erected on stone abutments with steel girders. The bridges were only just finished. The cause of the settlement of the bridges apparently was the working of the upper seams of coal in or near them. Those seams were about 3 feet 6 inches thick and about 60 yards below the surface. The first settlement was probably occasioned by these workings, and then the bridges remained stationary for some years until the lower workings came into operation at a much greater depth, about 200 or 300 yards. It was supposed that the latter settlements were caused by the lower workings, combined with the effects of the upper workings. A little further down the valley from where the bridges were situated, he was informed that the Council, 7 years or 8 years ago, had built a new stone-arch bridge over the same river, which had remained there for 4 years or 5 years, and then suddenly had given way; so that they had to take the arch down and build the abutments higher and throw girders across; and those abutments had remained without any apparent settlement or trouble until the present time. That was an example of the effects of coal subsidence in that particular part of the country, where the coal was worked to an enormous extent in all directions. The strata above the coal was mostly rock, with seams of shale and fire-clay, and the bridges were founded on the rock. While on the subject of settlements he might perhaps be allowed to call attention to settlements in another direction entirely. On the last occasion the members were shown the effect of subsidences in the salt district of Cheshire. He had noticed during the past 2 years, and especially during the last autumn, the enormous effect produced by

the subsidence or contraction of the London clay, due to the dry summer. He believed that hundreds of houses had settled in various directions and had been cracked in many ways, in the district in which he lived, in the west of London. He did not understand the action of that subsidence, but it seemed that clay, owing to the dryness, contracted in a regular way, forming large masses of a crystalline form, such as was seen in the pillars at the Giant's Causeway, and the cracks went sufficiently deep to affect the foundations of houses, which were generally built 18 inches to 2 feet 6 inches below the surface. But recently the builders were sinking them 5 and 6 feet deep on purpose, as they said, to be out of the influence of the drought.

Sir BENJAMIN BAKER, K.C.M.G., Past-President, had noticed that several speakers had touched upon the advantage of pushing on as rapidly as possible with work of an undermining character, which must necessarily be more or less of a trial to surrounding land and buildings. Speaking after an experience of the construction of from 20 miles to 30 miles of tunnelling of various kinds, he fully endorsed that opinion. He had been struck with the practical application of the principle many years ago in Chicago when carrying out the Lake tunnels. It was well known that the soil in Chicago was for about 200 feet to 300 feet deep little but mud. The American contractors were driving the tunnels, about 8 feet or 9 feet in diameter, lined with brick, straight ahead, under buildings, through that bad ground, and they had no hydraulic shields and no iron-lined tunnels in those days. But the vigour with which the work was being carried on was astounding. The men worked so hard that they could only keep at it for 10 minutes at a time, and then they stood aside, utterly exhausted, stripped to the waist and dripping with sweat, and gave up their picks and shovels to other men, who attacked the face as if they were charging a battery of Maxim guns. Working through that soft clay there was no attempt at timbering in the English sense of the word, but the brickwork was rushed in as fast as the mud was got out. Owing to no time being given for the soft clay to flow, the work was carried through the bad ground with practically very little settlement. Engineers who were accustomed to drive tunnels knew, of course, that some of the greatest damage arose from carrying timbered headings the whole length of the tunnel and leaving them standing a long time, because that gave the ground time for the slow flow, which took place in almost every kind of

Mr. Read.

Sir Benjamin
Baker.

Sir Benjamin
Baker.

soil that constituted the crust of the earth. An illustration of that slow flow was found in asphalt. If a piece of asphalt was cast in a mould, such as was used for Portland-cement test-pieces, and was broken in the same way that a specimen of Portland cement was broken, a sharp fracture would be obtained practically without elongation and with a tensile strength of 300 lbs. or 400 lbs. per square inch. But if a weight of 5 lbs. or 10 lbs. were put on that test-piece of asphalt and left, it would be found that in the course of a certain number of days it would break all the same; that a slow steady drag on the asphalt would effect a rupture with the mere infinitesimal fraction of the weight which would be necessary if the fracture were conducted quickly. He thought most engineers would agree with him that there was very much the same experience in tunnelling. If the work was pushed ahead as fast as possible and the ground was not given time to settle, there would be considerable self-contained arch and girder strength in the soil and nothing like the settlement which would be obtained were the work proceeded with very slowly and deliberately, although, on the basis of a false theory, it might appear to be a more secure and elaborate way of doing the work. It had been mentioned more than once during the discussion that the settlement of the ground surface did not nearly correspond with the amount of solid excavated underneath. It was also known in practical experience that ground which had been once disturbed, or buildings which had been once cracked, yielded much more readily than they did if they were intact, when mining operations were being carried on near them. The reason that the ground did not settle to the full extent of the excavations taken out was the fact, no doubt, that the virgin undisturbed soil was occupying the smallest bulk it possibly could, and that any disturbance of that ground would make it occupy a larger bulk, owing to the increased size of the interstices. That was seen in walking along the sea-shore, near the edge of the water, when the sand was just slightly glistening with moisture. In walking along and treading on the sand it would be noticed that the sand dried all round the foot. Instead of water squeezing out it disappeared like a flash, and the sand was dry all round the foot. The reason of that was that when pressed by the foot, the sand, which previously was in the smallest bulk it could occupy, was disturbed and made to occupy a larger bulk, and therefore the interstices formed, which constituted more or less of a vacuum, sucked up the water at once. In attacking virgin soil, gravel, sand, or anything of that sort, a little

settlement might be caused all round the timbering in driving a tunnel, but the sand readjusted itself and occupied a larger bulk, and therefore the surface did not settle so much as might have been calculated. It might be said that such disturbed and open sand would not carry weight, but it would. A long time ago he had made experiments on that point by taking a long vertical column of sand in a square box, about 20 feet high and 2 feet square. He filled the box lightly with sand, loaded it with 20 tons to the square foot, which was carried without the slightest settlement. Then he hammered away at the load on top to imitate the vibration of a girder carrying a railway train, and no settlement whatever resulted. The sand with open interstices carried 20 tons to the square foot perfectly. He did not put on more; not because the sand would not carry it, but because there was no necessity for his doing so. Then he removed the load and gave the box three taps with a hand-hammer, and the surface sank 2 feet, showing that the sand was in the open and disturbed condition it might be in when driving a heading or tunnel, and yet it was perfectly competent to carry 20 tons to the square foot. That was the reason why in tunnelling through virgin ground and near to buildings which had not been previously cracked, as much damage was not done as where the ground had been already disturbed, or where the buildings had been cracked. In the latter case soil was being dealt with which would not afford any more interstices to compensate for abstraction of solids, and, in the other, soil was being dealt with that had been deposited by water into the smallest bulk that it would occupy and could afford interstices. In cases of settlement, as in many other cases, he thought models might be used by engineers more than they had been as a means of investigation. It was known what invaluable experiences had been gained from models of ships; that if a model of a ship was pulled along a canal with a velocity proportionate to the size of the model, then not only was the resistance obtained, but the actual forms of the waves which were originated by that body were of the same character as they would be in a full-sized ship. It was known also that if a model of a tidal estuary was made, and the water was allowed artificially to flow up and down—say a model the size of a large table—sandbanks would be produced such as Nature had produced herself in the estuary. Similarly in the case of settlements from tunnelling operations. A number of years ago, before the Blackwall Tunnel was thought of, he had to consider, for the Metropolitan Board of Works, the question of

Sir Benjamin Baker. the construction of a Thames tunnel, and in considering the form of shield which was to be used, he made use of a model. The model constituted, in effect, a square box with a glass side, the glass side representing as a picture the soil and the shield in the same way as a longitudinal section of a drawing would. The soil he made of alternating layers of dry peas and hemp seed, so as to get horizontal strata of ground, and then he drove the shield from one end to see exactly what flow of ground took place, as indicated by the altered positions of the coloured layers of seed. On the glass side of the box a picture was presented of which it was possible to take a photograph. Subsequently, some 8 years or 10 years afterwards, he found that the same thing was being done in a more perfect way by a French or Belgian engineer in connection with the pressure of earth on retaining walls, and the displacement of earth which occurred when the wall slid slightly forward or tipped over a little way. In that case the investigator used some very mobile sand in coloured layers, and fixed it after movement by pouring in isinglass or something of that nature into the sand, when the latter could be taken out as a solid. These model blocks exhibited every possible movement of a retaining-wall, and could be kept in a museum for reference. He thought, in many cases of settlement, there might really be obtained very useful information by reproducing the conditions on a small scale in a model with a glass side to the box.

Mr. Kay. Mr. S. R. KAY, in reply, said that in the preparation of the Paper he had endeavoured to adhere to general conclusions as far as possible, single instances being misleading. The formulas he had given were, he believed, those which an engineer might safely adopt as a basis in estimating and advising upon the support necessary to be left. No doubt, in the case of deep mines, more damage was to be apprehended from the pull than from the subsidence, but this was only the case in the absence of faults, otherwise the risk would be fairly divided. He considered it difficult to imagine subsidence taking place over solid ground; the sinking described as taking place so far in advance of the working face was due rather to the stretching of the more or less elastic strata consequent on the pull than to actual subsidence. Where deeper mines were being worked below one or more seams worked previously, and in which pillars had been left, the working of the low seam was liable to cause more damage to the surface than when such superior workings did not exist. The risk was accentuated, and both pull and subsidence might be looked for around the edges of the old pillars, and if these had been rather

small in the first place, so much greater the risk. Mr. Read's observations with regard to the two bridges corroborated his statement, the arches acting as might be expected when their equilibrium was destroyed. With deep seams, and in the absence of faults and superior workings, it was possible for the coal to be rapidly worked out without inflicting more damage than might be almost negated after the subsidence wave had passed, when the surface resumed its former contour, and the original conditions were restored. There were, however, certain risks connected with it, the chief one being a stoppage of work from some unforeseen cause, such as a strike or an accident, when the pull would be intensified, and any damage probably rendered permanent. It had been remarked by Mr. Inglis and others that isolated pillars left for support became eventually crushed and broken by the weight of the overlying strata. He had no doubt this was the case in the deeper mines, except with very large pillars. The resistance of coal to a crushing force was comparatively low, and consequently, when the strata finally settled, the coal became crushed in a greater or less degree, according to its strength, and therefore a larger pillar was necessary for a soft coal than for a hard one. The crushing of the pillar, however, did not mean that it then failed in its power to support, as the coal could only be crushed into a space vacant to receive it. Generally the goaf was either packed or fell tight around the pillar, and the coal had no power of spreading under the pressure. Thus, although the coal might be crushed, it still might occupy almost the same space as when solid, and therefore had nearly the same sustaining power, the surface slightly sinking in proportion to the new form the pillar had assumed. With a more open goaf around it, as in the case of a rock roof and hard floor, the crushing of the pillar would cause it to spread rather more, and the surface would subside in a greater ratio than under the former conditions. The movement due to crushing was, however, very slow, and sometimes long delayed, so as to be seldom felt at the surface. He had no experience of damage actually resulting from that cause, although that such sometimes did occur he gathered from the experience of Mr. Inglis and Mr. Worthington. In the case cited by the latter, however, it might be caused by the old goaf caving in, rather than from the pillars decrepitating. In cases where the coal and roof were hard and the floor soft, the pillars were forced down into it by the weight above, and subsidence took place in spite of the pillars. The curious subsidence following the working of the coal under the railway

Mr. Kay. described by Mr. Cooper, where more pull over and more subsidence were noticed where bind was at the surface than in limestone, might, he thought, be explained by the unconformability of the Permian limestone to the coal measures. That would act like a fault and intercept the effects of pull and vary those of subsidence. The harder limestone, having strong lateral support, would naturally take considerably longer to subside than the coal-measure binds and shales. He regretted he could not follow Mr. MacDonald in preferring even small arch spans to steel superstructures above coal-workings; he preferred the methods adopted by Mr. Ross and Mr. Worthington. The stability of the arch depended entirely upon the rigidity of the abutments, and if either abutment subsided the equilibrium of the arch was destroyed and it became unsafe, and repairs or rebuilding might cause a cheap bridge to be a very costly one in the long run. The same remarks applied to the support of tunnels, even if inverted. He thought, in most cases, it would be less expensive to purchase support than to incur the expense and risk that damage from subsidence occasioned. Tunnel repairs were always costly; the possible repair of the tunnel from end to end might exceed its original cost, and very much exceed the value of the coal required for its support. He gathered that Mr. McDonald favoured working the coal from beneath the short tunnel he mentioned, and if it were the tunnel that his company were now opening out he agreed with him in not electing to purchase support, but not otherwise in the absence of any special facts bearing upon the case. He generally agreed with Mr. Rowley's remarks. No doubt, in cases of deep mines, the purchase of support would be a very large item indeed if it were decided to buy the coal, because large pillars were necessary, but he thought the grid-iron or the draught-board plan of buying pillars was a very good one, although Mr. Childe seemed to think that the former method would be almost as expensive as buying a solid block of coal. He differed from him in that respect, because from his experience the saving effected in allowing say one half the pillar to be worked was considerably greater than the consequential damage from the extra cost of working. It had been said that he was rather bold in deducing a formula for that class of subsidence; but, as far as his experience went he had failed to find a formula for subsidence resulting from coal-mining operations, and in that case it was difficult for an engineer approaching the subject to have any idea of what reasonable amount of support was necessary if he had had no previous experience on the subject. His view with regard to

that formula was to present something which would be a reason- Mr. Kay.
 able guide to an engineer who had not had perhaps much experi-
 ence on the subject ; but, whether he had or had not, it would be
 a means towards forming an opinion as to the quantity of support
 which he should buy. If he decided to do so the formula gave,
 he thought, a fairly correct minimum pillar. In special circum-
 stances it would have to be enlarged, and there were consider-
 ations allied to each separate case which would have to be
 considered individually, and the pillar decided upon accordingly.
 Sir Benjamin Baker's proposal with regard to models was, no
 doubt, an excellent one with regard to homogeneous masses of
 strata, or where the strata were fairly uniform one above the
 other ; but, with regard to deep workings in coal mines, he hardly
 thought that such a method could be adopted. In the first
 place, the strata were of a very varied character, hard and soft
 and medium strata following upon one another without any
 regularity, with sometimes thick rocks and sometimes thick soft
 shales ; and in the second, the strata themselves were so broken
 up by the natural processes that had taken place since they were
 deposited that it was difficult to reproduce the conditions pre-
 vailing in any colliery with regard to the overlying strata.
 Therefore he failed to see how experiments in that direction
 could help much with regard to subsidences following coal-
 workings. The following Table showed the calculation of a few
 cases from the formula he had given :—

TABLE OF MINIMUM RADIUS OF PILLAR (IN YARDS) ACCORDING TO DEPTH OF SEAM AND THICKNESS OF EXCAVATION, CALCULATED FROM THE FOREGOING

FORMULA $\left(r = \frac{\sqrt{3d \times \frac{3}{t}}}{0.8} \right)$

| Depth in Yards. | Thickness of Excavation. | | | | | | | |
|-----------------|--------------------------|---------|---------|---------|---------|---------|---------|---------|
| | 2 Feet. | 3 Feet. | 4 Feet. | 5 Feet. | 6 Feet. | 7 Feet. | 8 Feet. | 9 Feet. |
| 50 | 19.3 | 22.1 | 24.3 | 26.2 | 27.8 | 29.3 | 30.6 | 31.8 |
| 100 | 27.3 | 31.2 | 34.4 | 37.0 | 39.3 | 41.4 | 43.3 | 45.0 |
| 150 | 33.4 | 38.2 | 42.1 | 45.3 | 48.2 | 50.7 | 53.0 | 55.2 |
| 200 | 38.5 | 44.1 | 48.5 | 52.2 | 55.5 | 58.4 | 61.1 | 63.5 |
| 250 | 43.1 | 49.4 | 54.3 | 58.5 | 62.2 | 65.5 | 68.5 | 71.2 |
| 300 | 47.3 | 54.1 | 59.5 | 64.1 | 68.1 | 71.7 | 75.0 | 78.0 |
| 350 | 51.0 | 58.4 | 64.3 | 69.3 | 73.6 | 77.5 | 81.0 | 84.3 |
| 400 | 54.6 | 62.5 | 68.7 | 74.0 | 78.9 | 82.8 | 86.6 | 90.1 |
| 450 | 57.9 | 66.2 | 72.9 | 78.5 | 83.5 | 87.9 | 91.9 | 95.5 |
| 500 | 61.0 | 69.8 | 76.9 | 82.8 | 88.0 | 92.6 | 96.8 | 100.7 |
| 600 | 66.8 | 76.5 | 84.2 | 90.7 | 96.4 | 101.5 | 106.1 | 110.3 |
| 700 | 72.2 | 82.6 | 90.9 | 98.0 | 104.1 | 109.6 | 114.6 | 119.2 |

Mr. Kay. These dimensions, as stated previously, were for pillars under normal conditions, and were intended to be set out in plan, from the exterior points of the structure to be protected. He feared, however, the citing of all cases during his experience, upon which the formula was founded, would not only occupy much space, but would need many illustrations to show in an instructive manner the precise elements of each case. Having regard to the fact that the formula had met with general acceptance, he would suggest it to be taken as embodying all he could show in such an appendix. In conclusion, he considered the question of support to be one requiring all the skill and prudence of the mining engineer to determine, combined with experience in the investigation of the effects of subsidence both in their geological and physical aspects, and in the observance of any accompanying conditions which might tend to mitigate or exaggerate the risk of injury to the surface.

Correspondence.

Mr. Brough. Mr. BENNETT H. BROUGH considered the subject of the Paper one of great importance to mine surveyors, and the results of the long experience there recorded formed a valuable contribution to the solution of a problem that had not received in England the attention it deserved. On the Continent elaborate investigations had been conducted by Callon,¹ Fayol,² Hausse³ and others. In Germany the size of the pillar was determined by the angle at which the bounding planes of the broken mass were carried to the surface. In Westphalia, for example, it was usual with seams dipping at 45° to assume that the angle was 65° to 75°. From a careful study of the subsidence occurring in the Saxon coalfield, a Table⁴ had been constructed showing, for seams dipping at various angles, the direction of the plane of fracture occurring on the breaking of undermined strata, as determined by the angle of fracture, or in other words, the angle made by the plane of fracture with the horizontal plane. This Table was constructed from the general

¹ "Lectures on Mining," translated by W. Galloway and C. Le Neve Foster, vol. ii. London, 1881, p. 304.

² Bulletin de la Société de l'Industrie minière, vol. xiv. p. 818.

³ Jahrbuch für das Berg- und Hüttenwesen im Königreiche Sachsen, 1886, p. iii.

⁴ "Treatise on Mine Surveying," by B. H. Brough. London, 6th edition, 1897, p. 273.