Discussion.

The PRESIDENT moved a vote of thanks to the Authors for their Paper. The President.

Mr. MATTHEWS exhibited several lantern-slides of the works described in the Paper. Mr. Matthews.

Mr. R. ELLIOTT-COOPER, Vice-President, wished to call attention to one or two points of the Paper, because he thought a great deal was now being said and done in connection with reinforced concrete which the circumstances did not justify. The object of reinforcing concrete was to obtain increased strength by an entirely different process from the ordinary use of steel. In such work as was described in the Paper, which to his mind would be more correctly described as reinforcing the steelwork rather than reinforcing the concrete, he did not quite see the advantages of the process. Before referring to the structures described, he would like to say a few words upon the subject of why such high results, which appeared to be out of all proportion to the materials used, were obtained with reinforced concrete. He believed that if ordinary concrete without reinforcement were made with the same extreme care in methods and in the choice of materials as was used in the case of reinforced concrete, much higher results would be secured than were obtained at present. People were apt to compare a material, and a form of putting that material together, with what they were accustomed to in ordinary concrete foundations and concrete piers, and that really did not give the concrete in its ordinary state a fair test. Lately he had seen several very large reinforced-concrete works in course of construction, and the extreme care that had been taken was quite remarkable. That was necessary when it was remembered that many of the bars forming the reinforcement came within 2 inches of the surface, and the great care that had to be adopted both in putting the material together and in selecting the material itself could be quite understood. But he thought that reinforcement was used in many cases in which there was no practical advantage in it. The object of reinforcing concrete was presumably to obtain a structure that was cheaper than one in which a larger mass was used to obtain the same strength. If, in order to obtain a certain strength, a form of construction was adopted which cost a considerably larger sum of money than would otherwise be necessary, then, from a practical and commercial point of view, he did not see that the great advantages claimed were obtained. He admitted that Mr. Elliott-Cooper.

Mr. Elliott-Cooper. in many of the cases he had seen, where space had been of great importance, the results obtained could not have been improved upon by the use of other materials, so far as he was able to judge. Taking the illustrations in the Paper, Fig. 2, Plate 5, showed an arched bridge of a span, from centre to centre, of 100 feet, although the clear span really was about 85 feet, the angle of skew being 45°. There was nothing very remarkable about that. The thickness of the arch at the centre was given as 3 feet 9 inches. If the same bridge were built of brickwork the dimensions referred to would be just about what would be adopted. Rather curiously, he had been called in to advise upon a bridge abroad, where they had built the arch slightly less than 3 feet thick at the centre for a bridge of very nearly the same span as the one illustrated, and he recommended that as they were going to build six other bridges of the same kind, they should increase the thickness of the arch at the centre to 3 feet 9 inches. He also mentioned in his report that according to the ordinary English practice it would be 3 feet 6 inches, but that, as the bridge was in a foreign country, and he did not know the degree of reliability of the workmanship, he had given a small margin. It therefore appeared that a similar bridge to that shown by the Authors, constructed of stone without any reinforcement, would be amply strong with the same dimensions, and accordingly he could not see the use of putting in a series of bars at the top and bottom of the arch to make it stronger. As illustrating that point, the other day he was looking at a building in which there was a floor, with a slightly groined roof, of 40 feet span in one direction and 32 feet span in the other, and the thickness of the floor, which was calculated to take 500 lbs. per square foot, was 8 inches. He thought that was somewhat thin, but if it would stand, it was a great achievement for reinforced concrete. Where a structure was of the full thickness, however, and could be built of ordinary materials, he could not see the advantage of reinforcing it. The box abutment specially referred to in the Paper was the ordinary form English engineers were accustomed to, but instead of a flat slab—which he noticed was 3 feet thick for a span of 13 feet—an ordinary arch would have been put in. He did not believe there was very much saving in the actual quantity of material, and, if so, there could be no possible advantage in reinforcing that thickness of concrete with steel bars. Coming to what he considered the most curious of the designs shown, the ordinary single-line bridges, they appeared to him to be ordinary steel structures encased in concrete, and he could not think that the mere encasing of the rolled joists or built-up girders in concrete would add materially to the strength. It might add stiffness, but he did not think it could add to the permanent and actual strength. In one of the cases where a special form of structure was employed (Fig. 5, Plate 5) it was stated that that form was adopted for the purpose of getting a very small space between the rail-level and the underside of the girder. The depth was given as 2 feet 6 inches. He had built a bridge over the Midland Railway where he was limited very much in depth, and he managed to get across with 1 foot 3 inches. Therefore he could not quite see where the advantages of reinforced concrete of the kind shown in the Paper came in, or why, if headway was a special feature, it could not be managed with less depth than 2 feet 6 inches. It was stated in the Paper that in cases where it was very important that the structure should be watertight a particular blending of material had been used, but it seemed to him that, if the reinforcement principle was used at all, it was a question not whether water was coming down on to the heads of people below, but whether water was penetrating into the material; because if it did penetrate the steel bars would corrode sooner or later, and if the bars corroded and continued to corrode, the structure, so far as its strength depended on the reinforcement, would fail. He considered that all reinforced concrete ought to be perfectly watertight if the material of which it was made was to be permanent. With regard to the culverts, he had taken out the cost of culverts of the ordinary circular form and found they came out almost exactly the same; so that even in that case he was sorry to say he could not quite see where the economy of reinforced concrete of that description occurred. Mr. Elliott-Cooper.

Mr. F. HUDLESTON noticed that the Authors stated that the structures described were as cheap as ordinary masonry, but, as Mr. Elliott-Cooper had shown, there was not very much difference between their cost and that of brickwork. He had compared the Sangamon River bridge with what he thought would be the modern price of the magnificent Wharncliffe viaduct on the Great Western Railway at Hanwell, built about 70 years ago. The two viaducts were very similar in height, the arches of the English one being about 65 feet in span, while the American viaduct was about 85 feet. Brunel's viaduct was built entirely of stock bricks, and was still a very fine example of an English viaduct; it looked as sound as ever from the outside, except that the westernmost arch seemed to have had a slight settlement at one period: possibly the abutment had yielded a little bit. He made out, from external dimensions, that that viaduct at modern prices, unless the foundations were something extraordinary, would cost about £100 per lineal Mr. Hudleston.

Mr. Hudleston. yard, while the American bridge cost £125—assuming that each abutment was about 100 feet long. Of course, in America prices were higher than in England, but he thought it would be generally admitted that if things were compared properly there was not much to choose between those two viaducts in price per lineal yard. Then with regard to the durability, it was said that reinforced concrete was permanent. No doubt it was extremely lasting, but he did not think anybody would care to say that a reinforced-concrete structure could have the same life as a brick structure such as Brunel's viaduct. There was a great deal to be learnt about reinforced concrete. It was well known that concrete had a tendency, especially when rich, to develop hair cracks, and it might be that something of that sort would happen at some future time in reinforced bridges. For plain arched viaducts he thought nothing was gained by using reinforced concrete instead of ordinary bricks, which it was known were very durable and cost next to nothing for maintenance. Again, the Authors said that, as compared with steel, reinforced concrete was altogether superior, as it required no maintenance. Of course it did not require painting, and probably it had a longer life than steel girders; but after all, the comparative cost of a brick-arch bridge and a steel-girder bridge of the same span showed that the brick arch would come to about £100 or £150 more than the other; the one would be between £400 and £500, and the other between £500 and £600. When considering maintenance, it was necessary to take into consideration the extra interest on the capital. That extra £100 meant £3 or £4 a year, and £3 or £4 a year would go a long way towards a sinking-fund for a steel bridge. Even in brickwork it was necessary to allow something for repointing occasionally. He did not think, therefore, that the comparison, which at first sight seemed a fair one, was quite as reasonable as it ought to be. If a thing had to be built cheaply, then the steel girder certainly held its own; but taking the real cost —the interest on the capital expenditure plus the cost of maintenance —he did not think there was much difference to be found between a reinforced-concrete bridge of ordinary span and a steel one. With regard to the other examples in the Paper, on looking carefully it would be found that the structures consisted of steel girders buried in concrete. That rather gave the case away for reinforced concrete for underbridges and girders. In England the Board of Trade would not allow it to be used, although they might do so in time. It would be seen that on the Wabash Railroad they had not really had the courage of their convictions, all their large bridges being of steel girders buried in concrete. With regard to the floors, he thought they were very ingenious and ought to have a much longer life than the steel floors used in England. Mr. Elliott-Cooper's point about water percolating through was a very good one. It seemed to Mr. Hudleston that if a certain quantity of bituminous substances was mixed with concrete, as apparently had been done here, it must interfere somewhat with the strength of the concrete. A great deal had been written and said about the design of reinforced-concrete work, but he thought engineers were still very much in the dark as to what really ought to be done. There were very few experiments to serve as a guide in forming a theory for calculating the reinforcement. In steel-girder work there was a vast amount of experience with regard to the theory of stresses and so on. A great deal more had to be learnt with regard to reinforced concrete before it could be said definitely that any set of rules could be really applicable to all sets of circumstances. Looking at the figures given by the Authors at the beginning of the Paper, there were one or two things a little inconsistent. The unit stress allowed was fixed by a rule well known in America. On p. 134 it was said that the maximum allowance for steel, including impact, live load, and dead load, was 18,000 lbs. or about 8 tons per square inch. That gave an old limit for ordinary mild steel—about 8 tons where all the load was dead and 4 tons where all the load was live. A little later on the Authors said that a 47-ton high-carbon steel, with a breaking-stress of about 105,000 lbs. per square inch and an elastic limit of 66,000 lbs. per square inch, was used. He did not see the advantage of having such a high-carbon steel, and thought that an ordinary mild steel, such as was used in England for structural purposes, would serve all the Authors' purposes. The 18,000 lbs. was practically the kind of load used in America for mild steel, and he would like to have an explanation as to why the Authors used a high-carbon steel when their stresses were 8 tons for dead load and 4 tons for live load. The limit of 18,000 lbs. mentioned in the Paper corresponded practically with the Board-of-Trade regulation. Taking into consideration the dead load and everything else, in the main girders of an ordinary English railway-bridge it was hardly possible to get much more than 6½ tons, even with 18,000 lbs. as the limit. Mr. Hudleston.

Mr. C. S. Meik considered that the information given in the Paper was hardly sufficient to enable any reasonable criticism to be offered with regard to the various designs that were shown, but on carefully looking through the Paper one or two things had occurred to him much the same as had occurred to Mr. Elliott-Cooper. The question of the arch of the Sangamon bridge was one in particular. Mr. Meik.

Mr. Meik. Reinforcement was quite unnecessary for that bridge if it was made of good concrete, because the arch was amply strong enough. With regard to the Forest Park bridge, No. 11, the floor was shown as being of reinforced concrete 8 inches thick, carried upon rolled beams 18 inches apart between centres. At the first blush it would appear that reinforcing was quite unnecessary there, but so little information was given that it was impossible to check the calculations, and possibly there was some reason for it which the Authors had not stated. Coming, however, to the question of stresses, there was a little more to go upon. Taking, for instance, the steel, which the Authors said was to be stressed up to 18,000 lbs. per square inch, with an elastic limit of 55,000 lbs. per square inch, that was a higher class of steel than was customarily used for reinforced concrete in England, or even in France; but it had appeared to him for some time past that the use of such steel was a step in the right direction. For reinforced concrete a high-class steel was required, because it gave a higher elastic limit. In most reinforced structures—beams or floors—the limit of elasticity of the steel was really the limit of the safety of the structure, because once the steel began to stretch and exceed the elastic limit the beam invariably failed, even although the concrete was not stressed up to its ultimate strength. The stresses used in England ranged from 15,000 lbs. to 17,000 lbs., with an elastic limit of 34,000 lbs. per square inch, giving a factor of practically 2, taking the elastic limit of the steel as the point of failure of the beam, which was very near the mark. With regard to the concrete, the Authors gave the working limit on the outside fibres of the beam as 800 lbs. per square inch with a mixture of 1:2:4, but nothing was said about the ultimate strength of the concrete. It might be, as he had found, that a mixture similar to that gave as little as 0·53 ton per square inch, or the same mixture might give 1·64 ton per square inch, a variation in the ultimate strength of between 300 and 400 per cent. He thought that pointed to the fact that in all specifications for reinforced concrete there should be some statement as to what the strength of the concrete should be, because it must be apparent to anyone that if concrete could be made with such extreme variations the factor of safety was practically of no use. In connection with some reinforced-concrete work his firm had carried out at Swansea he had made tests of the compressive strength, and he had found out what had doubtless been known to a great many people, especially in America, that the heavier the concrete was per cubic foot, the higher was its compressive strength. He might say that, with regard to the figure he had quoted of 0·53 ton per square inch, as the ultimate compressive strength, that concrete weighed 126 lbs. per cubic foot. The concrete giving heavier stress of 1·64 ton weighed 149 lbs. per cubic foot. All the other experiments carried out showed that the strength increased with the weight, but of course in a far greater ratio. Since he made those tests he had had some more cubes made and tested; he had succeeded in obtaining a concrete weighing 158 lbs. per cubic foot, and he believed that in America they had succeeded in getting concrete which weighed 160 lbs. per cubic foot. The heavier the concrete, the denser it was; and the denser it was, the stronger it was bound to be. The blocks referred to were made of granite and sand, and if it were possible by improved mixing to make them as heavy as the granite of which they were composed they would presumably have the same strength. That would probably never be attained; nevertheless an endeavour should be made to obtain as heavy a concrete as possible. Heavy and dense concrete had the advantage of greater impermeability, which was of great importance in a material such as reinforced concrete. It would obviate a great deal of the risk, advanced by Mr. Elliott-Cooper and the last speaker, of moisture getting at the steel. The Authors stated that they preferred a wet concrete to a dry concrete and proceeded to give the results of some tests by Mr. G. W. Rafter. But unfortunately the tests did not bear out the statements of the Authors, because the record on p. 136 showed that concrete made of a dry mixture withstood 2,470 lbs. per square inch, whereas concrete made of a wet mixture withstood only 2,180 lbs. per square inch, showing that the dry mixture was the better of the two. His own experience was that a dry mixture was better. There had, of course, to be a certain amount of moisture, but provided that was sufficient to work, it was better to use a dry mixture than a very sloppy one. The more water there was put in, the less chance there was of getting a really dense mass afterwards. The Authors also made some remarks about plain bars as against corrugated and ribbed bars, and said that some form of ribbed bar was to be preferred to plain bars. He went into that question some little time ago and had some correspondence with Mr. Barclay Parsons, M. Inst. C.E., of New York, who told him that he was experimenting with bars and strongly advised the use of the ordinary plain smooth bar. Since then Mr. Parsons had given the results of his experiments in a Paper read before The Institution on the New York Rapid-Transit Subway. Mr. Parsons there pointed out that slightly rusted rods were better than clean rods, a conclusion at which Mr. Meik himself had arrived. The plain rods rusted stood 437 lbs. per square inch before being drawn out, twisted rods stood 509 lbs. and enlarged rods 637 lbs., showing Mr. Meik.

Mr. Meik. a slight advantage to the twisted rods and the enlarged rods; but Mr. Parsons made the following observation: [1]

"In all cases [of the twisted and enlarged rods] the concrete block was split, indicating a wedge-like action of the enlargements and the twists. If a mechanical bond is desired in addition to adhesion it can be better obtained by a square shoulder, such as a nut on the end of the rod, than by any shape that tends to split the enveloping mass."

With that conclusion he cordially agreed. He had never found any difficulty, provided there was a sufficient length of rod embedded in the concrete to get an adequate bond. Failing a sufficient length, it was necessary to rely on a mechanical device like a square shoulder or a nut.

Mr. Thorpe. Mr. W. H. THORPE observed that there seemed to be a considerable divergence of opinion about the use of a deformed bar or a plain round bar, but he thought it was largely a question of design whether the round bar would serve its purpose sufficiently well. If due care were not exercised to ensure that the grip required of the concrete was of moderate amount and that the maximum grip at the end of a bar in particular cases was not excessive, there might be some failures resulting. Taking the case of a simple beam of uniform depth, loaded in the middle, with bars parallel to the bottom edge, the rate of grip required of the concrete along the bar to hold it, would be uniform. If the load was distributed, the maximum grip required at the end of the bar was twice as great as the mean grip. In the case of a vertical wall sustaining water-pressure the maximum grip on the rod would be three times as great as the mean. This was quite obvious, and he was simply calling attention to it. If it should happen in any piece of work that less than sufficient care was given to the maximum stress which might be developed on a short length of the rod, some inconvenience might result. A deformed bar had the advantage that it would hold perhaps 50 per cent. better than the plain bar; thus there was a wider margin for carelessness. With proper design, and avoiding the use of large rods—which necessarily required a considerable length of enshrouding concrete to grip them—there should be no difficulty, as a rule, in ensuring a proper hold upon the bars. With regard to the question of wet versus dry concrete, the Authors stated that the advantage of dry concrete over wet concrete in point of strength was small; on the figures they gave it was about 14 per cent. He had looked up the experiments referred to, contained in the admirable volumes

[1] Minutes of Proceedings Inst. C.E., vol. clxxiii, p. 122.

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issued by the United States Government on Tests of Metals and Other Materials, copies of which were in the Library, and in the 1898 issue he found about 250 pages dealing with Mr. Rafter's and other tests. Looking through those tests in some detail, he concluded that, although the summarized result was to show that dry concrete had but a moderate advantage over the wet mixture, yet in particular series of experiments the advantage of the dry concrete over the wet might be as much as 50 per cent. He thought the conclusion of the Authors with regard to dry versus wet mixtures was not that which he would care to accept. With respect to the question of durability, he would refer to two structures of considerable age in England, the work of Mr. W. B. Wilkinson, of Newcastle-on-Tyne, whom he might be allowed to claim to be the pioneer, not only in this but in any other country, in the matter of reinforced concrete.[1] Mr. Wilkinson took out a patent, No. 2,293, in the year 1854, and in that patent showed a method of construction illustrated by the two drawings Mr. Thorpe had placed upon the table, tracings made about that time and in accordance with which the specification-drawings were prepared. They showed a method of construction which was reinforced concrete pure and simple. That Mr. Wilkinson had a knowledge of the principle underlying the work was shown by the statement in his specification referring to the reinforcement used: "The under edge of the same is set on the crown of centering, or nearly so, so that in this low position it may act with the more power as a tension rod to the floor." He clearly knew what he was about, and an examination of the drawings would show that his reinforcement was placed in a manner that it would be difficult to improve upon even now. He used wire-ropes, and Mr. Thorpe had been told that the reason was that at that time there was difficulty in getting round rods of sufficient length. Of the examples of Mr. Wilkinson's work referred to, still in existence, one dated back about 22 years, and consisted, on the authority of Mr. Hubert Todd, who made the working-drawings, of a floor about 14 feet in span, 12 inches thick, and loaded with 13 cwt. per square foot (by a baker's oven), to be found in Northumberland Court, Blackett Street, Newcastle-on-Tyne. The other case was a cottage in Wilkinson's storeyard, Ellison Place, in the same town. It was difficult to give the precise date, but it was probably built about

[1] Further inquiry shows that a near approach to reinforced concrete was developed about 1850–5 by a Mr. Lambot-Miraval, who constructed a boat 3·30 metres long by plastering Roquefort cement upon a skeleton network of iron and wire. See A. Delesse, "Matériaux de Construction de l'Exposition Universelle de 1855," Paris, 1856: to be seen in The Institution Library.—W. H. T.

Mr. Thorpe. 40 or 50 years ago. He was assured by Mr. Todd, and by Mr. Steele, the City Engineer of Newcastle-on-Tyne, that that building was in fairly good condition. Mr. Todd said that it showed absolutely no cracks, and Mr. Steele stated that there was little or no evidence of disintegration such as would be expected if rust were acting on the reinforcement under the concrete.

Mr. Steinberg. Mr. H. E. STEINBERG remarked that there was no engineering subject that needed discussion so much as reinforced concrete. At present in England attention to the matter seemed to be confined to two classes of people, those who had to practise it and those who wrote and talked about it; and although reinforced-concrete work to the value of probably a million sterling, was done in this country every year, the English text-books and discussions on the subject led one to believe that the question was still in its infancy. With regard to the Paper, he wished first to refer to the use of deformed bars. The Authors said that many American engineers did not look with favour upon the practice of using plain bars as reinforcement in concrete. On the other hand, many American engineers, to judge by American literature, did use plain bars in reinforced concrete, and practically all French, Austrian and German engineers did the same, and he hoped that all English engineers would do so. Deformed bars seemed to him quite unnecessary. Deformed bars such as those referred to in the Paper depended as much on adhesion for the transmission of their stress as plain bars did. If the adhesion were taken away, the little shoulders on the bars—which were said to be practically at right angles to the axis of the Johnson bar, but which in the examples on the table were practically at 45°—would have to transmit to the concrete a direct compressive stress of about 1,600 lbs. per square inch, a figure far in excess of anything which should be allowed. He wished to endorse what had been said already with regard to the reinforced-concrete arch shown in Figs. 2, Plate 5. It was not a reinforced-concrete design at all, and such arches had no need of reinforcement. The resultant of the dead load and the live load in any possible position would never pass outside the middle third of the section. The armouring could therefore never be in tension, and was quite unnecessary. A great deal might be said also against the design of most of the other work. For instance, in the culvert in Fig. 11, if the bars in the gusset were in compression, as presumably they were, then the concrete at the other end of a section taken diagonally through the corner, must be in tension, and no armouring to resist this effect was shown. The whole dimensions

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of the structures were too large for reinforced concrete. The Authors spoke of slabs 3 feet thick. In a slab of that thickness four-fifths of the armouring was carrying the slab and one-fifth was carrying the live load. All the figures as to cost were, therefore, as a basis for comparison, in his opinion, quite valueless. Reinforced concrete would certainly never have justified itself or become so popular if it were designed on lines such as those shown by the Authors. With regard to formulas, it was said that the parabolic formula of Professor Talbot was used. Parabolic formulas were very cumbersome to work with, and the extra accuracy, in the second place of decimals, might be considered unnecessary. It was almost impossible in reinforced-concrete work to design precisely; the utmost that could be done was to design by a kind of guesswork and then check the design to see whether it came out correct. There was a graphical method of working out directly the quantity of steel required, but its use was not widely known. The percentage method, mentioned in the Paper, was also very cumbersome to work with. With regard to the steel girders reinforced by bars placed alongside them, it would be quite impossible to calculate them by any formula. In the second Appendix, on p. 146 a Summary of Building Regulations governing the use of rėinforced concrete in the United States was given: the point he wished to touch upon related to the bending-moment of continuous beams. In New York, Buffalo, and San Francisco it was $w\,l/8$ and in Cleveland $w\,l/10$. It was quite permissible to legislate about the stresses to be allowed. One State might fix 16,000 lbs. and another State 15,000 lbs. per square inch on the steel; but no State could legislate directly about bending-moments. Once the span and the loading were fixed the bending-moment was fixed. In a simple case of an ordinary beam resting on two supports it would be absurd for New York, Buffalo, and San Francisco to say that the bending-moment should be $w\,l/7$, and Cleveland to say $w\,l/9$; it would still be $w\,l/8$, whatever they might decide. When the span was continuous it was still quite impossible to govern bending-moments by legislation. The monolithic nature of reinforced concrete rendered every slab and girder passing over supports a continuous beam, and although continuous beams were very troublesome to calculate, it was necessary, if the armouring was to be properly arranged, to recognize that property of continuity and to calculate the armouring accordingly. Referring to the regulations of different countries, in Germany it was stipulated that continuity should be recognized, and only if the beam could not be calculated exactly according to theory as perfectly

Mr. Steinberg. continuous should $wl/10$ be taken in the span and $wl/8$ in the supports. In the Report of the Royal Institute of British Architects it was stated that the bending-moment in the span was $wl/24$, and over the supports $wl/12$. At Buffalo they gave $wl/8$, which was probably in the span, and Cleveland gave $wl/10$. It seemed to him the whole thing was quite unnecessary. If the methods suggested in the German regulations were adopted, and the moments were calculated as accurately as possible, according to the accepted laws of mechanics as applied to continuous girders, or if, when the problem was too complex for this to be done, then high fixed values for the bending-moment were taken, it would meet every case.

Sir H. Tanner. Sir HENRY TANNER remarked that his experience of reinforced concrete was limited to buildings, and therefore his remarks would hardly bear upon the matter from the railway-structure point of view. His attention was first directed to reinforced concrete about 6 or 7 years ago, and arose mainly from considerations of economy. He went to see a building put up by Messrs. Hennebique, through Mr. Mouchel, at Newcastle, and it struck him as being a very economical building, while taking up very little space, the walls being so thin that very little floor-space was lost inside, which was, of course, a great advantage. He went into the matter and persuaded his Commissioners to allow him to carry out the Post Office in reinforced concrete, and the result that a saving of about £60,000 was effected on that building. The carcase cost about 2*d.* per cubic foot, whereas, if done in steel it would have cost 4*d.* The other things, of course, were practically the same. There was some stone in the street fronts, but the greater part of the structure was concrete. The walls were 7 inches to 8 inches thick. If the building had been of brickwork he believed the thinnest walls would have been 18 inches and at the bottom the walls would have been about 3 feet 6 inches at least in thickness. The piers were no larger than they would have been if they had been of steel, and probably smaller, because it would have been necessary to encase the steel in concrete. So far his experience had been extremely satisfactory, and he had gone on to other buildings. He had found the concrete to be quite waterproof. In the basement there were walls 25 feet high and 7 inches thick against the earth, but no water came through, and the place was perfectly dry. The floor was only 5 inches thick and the water-level was about 18 inches below it. The only place where water came into the basement was where the levelling-pegs were left in; wherever a wet spot appeared in the floor it was known that a levelling-peg was there. As to the mixture, he thought that rather depended on the amount of reinforcement. Where the reinforcement was heavy, the mixture had to be thinner, but in course of time that corrected itself. So far as he had noticed, the dry mixture became harder more quickly and bore a load at an earlier date, but the wet mixture quite made up for it and probably surpassed the dry mixture in strength eventually. With regard to rods, he always preferred round ones, which he thought could not be beaten. He did not care for corrugated rods of any sort. The extreme tension which required deformed rods to prevent slipping should not be reached. He did not think there was any fear, if the concrete was properly made, of any rusting occurring. The rods he had used had been taken generally out of the yard, where they had stood in all weathers for a considerable time, and all that had been done was to brush off the rust and anything that was loose. He had had holes cut in the concrete and had always found the steel to be as blue as if freshly manufactured. He thought the great point about reinforced concrete was economy, which governed everything. Sir H. Tanner.

Mr. W. Dunn sympathized with a great deal of what had been said with regard to the examples shown not being very economical structures. They seemed to him to have been designed by an engineer who desired to try a new method of construction, but who was not prepared to go so far as a specialist in reinforced concrete would go. In Paris a little time ago he had occasion to examine a bridge over the canal St. Martin, which had a span of 27 metres. The arch had three semi-articulations, and the thickness was 0·45 metre. That was in marked contrast to the arch shown in the Paper. As had been rightly said, the concrete in these arches would be amply sufficient to do all the work, and the steel could only have been put in to resist cracking due to temperature-stresses or other causes. It was said that a very high stress was allowed—up to 800 lbs. per square inch—in the concrete. Looking at the sections of the arches he quite failed to see how such a stress could possibly be developed. He thought it was coming to be more and more the custom to limit the stress in the steel to 16,000 lbs. per square inch. There was a good reason for doing that, because if the stress in the steel was very high the concrete tended to open. If the stress in the steel was 18,000 lbs., the stress in the concrete at the same level was approximately about 1,200 lbs. per square inch, and any concrete would crack at that. The stress in the concrete 2 or 3 inches below the steel was even higher. Therefore there was a strong reason for keeping the stresses in the steel at a low limit. He agreed with previous speakers that it seemed peculiar to use high-carbon steel with an ultimate stress of Mr. Dunn.

Mr. Dunn. 105,000 lbs., and yet keep the stresses as low as 18,000 lbs. Naturally engineers feared to adopt a material about which there was some question as to its permanence. In many cases it was a much more permanent material than steel could possibly be. In Paris he had seen, in bridges over a railway, steel girders side by side with reinforced-concrete girders, which had been in for 12 to 14 years. The steel girders had been frequently painted, and yet had rusted very badly. The reinforced concrete, he was assured by the engineer in charge, had received no attention, and, as far as could be judged, it required none, being in perfect condition. With regard to the artistic effect of a bridge, a large mass of plain concrete in a wall had naturally a rather unpleasant colour, but when it was put into a bridge, whether an arch or a plain girder-bridge, there was a chance of making it much more artistic and agreeable than a lattice girder or other form of steel girder. He was only sorry the members had not an opportunity of seeing illustrations of a number of charming bridges that had been built in France and Germany, mostly arched bridges, which structures to his mind offered a splendid field for the use of reinforced concrete. One speaker had mentioned the Report of the Joint Committee of the Royal Institute of British Architects, and stated that the bending-moment should be $wl/12$ in the span and $wl/24$ in the support. He thought the speaker was wrong in that. The Committee suggested that $wl/12$ would be a fair allowance to take in a continuous beam in the centre of the span, and naturally the allowance differed with the distribution of the live and dead load. What the Report did say was that when continuity was calculated, every proper provision must be made for the moment at the support, which seemed a very natural thing to say. It did not lay down what the bending-moment over that support should be.

Dr. Brightmore. Dr. A. W. BRIGHTMORE remarked that it had already been pointed out by more than one speaker that advantage had not been taken of the reinforcement in the designs to reduce the dimensions. It was not quite clear in Fig. 3, Plate 5, why a reinforced abutment should be adopted for a plate-girder bridge. In Fig. 8 plain concrete abutments were adopted for a reinforced girder; also the two piers were shown as being reinforced. That presumably was a reinforcement for compression, because the girders were not shown to be continuous. It was questionable whether any advantage was gained by that reinforcement. It seemed a logical thing to introduce steel bars where there was tension in concrete, but it was not so clear why steel bars should be introduced to assist in the compression. A good many experiments had been made which showed that there was more uncertainty about benefit being derived from reinforcement in compression than in tension. If the unit stresses referred to in the Paper were actually adopted, the factors of safety would be reduced considerably below what were considered desirable in ordinary engineering practice. It was mentioned that the working-stress in the concrete in compression in cross bending was taken as 800 lbs. per square inch—rather over 50 tons per square foot, and he thought that was a stress which in an ordinary engineering structure would not be looked upon with complacency. It was also stated that for direct compression it was reduced to 600 lbs. per square inch; but even that worked out at about 38 tons per square foot. No doubt a good deal of the saving that was obtained by using reinforced concrete with such unit stresses was at the expense of reducing the factors of safety beyond what was considered desirable in ordinary structures. Dr. Brightmore.

Mr. C. F. MARSH thought it was a pity that the Paper should have been selected to show what could be done in reinforced concrete, because there was hardly a fair example of that material in the whole communication, and he thought it would have been much better if a Paper showing what could really be effected by the use of reinforced concrete had been brought forward for discussion. With regard to the remarks that had been made comparing reinforced concrete with brick and concrete, he hardly thought them fair criticism. Reinforced concrete was reinforced with iron or steel, and it was not the mixing of the concrete which gave strength; that only gave strength in compression. Mr. Elliott-Cooper thought that if any water soaked through the concrete it would attack the steel and cause rust. Even if a certain quantity of water did go through—and Mr. Marsh did not think it would, in properly-constructed reinforced concrete—unless carbonic acid gas and oxygen also gained access to the steel, no rusting could occur. The stresses of 800 lbs. and 600 lbs. per square inch, given in the Paper, were altogether beyond what ought to be allowed, and were very high for American practice. He thought the use of the compressive stress of 800 lbs. per square inch on the concrete must have arisen from the fact that Talbot's formula had been used and 18,000 lbs. per square inch assumed for the stress on the steel; and that on working out the formula for 1 per cent. of reinforcement it had been found that a compression of 800 lbs. per square inch on the concrete was required, and therefore this stress had been assumed. The shearing-stresses were extraordinary. It was assumed that if the concrete was reinforced with steel against shearing—and presumably the Authors took the steel into account in their calculations for the shearing resistance—more stress could be allowed on the concrete in shear. Taking what the steel would give as an addition to the Mr. Marsh.

Mr. Marsh. shearing resistance of the section, he did not see how any more resistance could be allowed for the concrete. With regard to high-carbon steel, he was entirely at variance with the Authors. Mr. Dunn had said very much what he himself would say on this question. It was extremely dangerous to use steel under high stresses on the tension side of the concrete. With regard to corrugated and other deformed bars, there was no doubt that they did give additional bond resistance; but the question really was whether plain bars were sufficient for the purpose, and he thought it had been clearly shown time after time that plain bars, secured in a proper manner at their ends, gave sufficient resistance against slipping. As to the mixing of concrete, he thought it best to mix it neither too wet nor too dry, and to have a medium mixture. With reference to the arched bridge, he thought that it would have been much better if some of the reinforcement had been taken out of the arch and put into the parapets to reinforce them against temperature-stresses, which had a marked effect on long lengths of concrete.

The President. The PRESIDENT, in calling upon Mr. Matthews to reply, remarked that he thought the discussion had been very interesting, notwithstanding the last speaker's deprecation of the reading before The Institution of a Paper which was the subject of vigorous criticism. He quite understood that there were finer examples of reinforced concrete, and he would suggest that Mr. Marsh might offer a Paper upon more advanced specimens of reinforced-concrete work. The Institution was always glad to have descriptions of works, particularly in other countries, and to have the experience of people who were groping their way, because all engineers had to do that in some degree. Therefore he congratulated the meeting on a very interesting discussion on a subject which was exercising the minds of a large majority of the members and was interesting to all, and a subject upon which the Council were spending a great deal of time and money in investigation and in carrying it farther than perhaps anyone in the room that evening knew.

Mr. Matthews. Mr. MATTHEWS, in reply, stated that his co-author and he were not in agreement with regard to the whole of the structures mentioned in the Paper. He certainly thought that in some of the structures there was far too much material. The thickness of concrete in the arch of the Sangamon River bridge, for instance, was probably greater than it need have been. But the object of bringing the Paper forward had been to show that in America, in railway engineering, reinforced concrete was being used because

Mr. Matthews.

it was considered that it resulted in a marked saving. On the Wabash Railroad it had been used extensively. With regard to Mr. Meik's remarks, he was quite sure that the necessity for a high class of steel for reinforcing bars was very apparent, and he did not agree with some of the other speakers' remarks on that subject. There had been a good deal of discussion on dry versus wet concrete. He preferred wet concrete, for the reasons advanced in the Paper. He had carried out a good deal of reinforced-concrete work—walls, flat roofs and beams—and his opinion was that a better and denser concrete was obtained by making it wet, and, what was more important, the reinforcement was better embedded than with a dry or even a plastic mixture. With regard to the particular bars shown on the table, he was not committed to any particular system of reinforcing bars, but, as stated in the Paper, in America engineers looked with some disfavour on plain bars, preferring some form of deformed bar, such as a bar with a ribbed device, or a twisted bar, or the Thacher bar. With respect to the question of economy, he had himself effected a saving of 30 per cent. by using reinforced concrete in the construction of retaining-walls at Bridlington instead of brick or monolithic concrete, and was aware of experiences of other engineers which corroborated such economy. As to the durability of reinforced concrete, which had been referred to by several speakers, none of them had questioned the durability of properly-gauged concrete; and with regard to the possible corrosion of the steel in the concrete, experience had shown that, if a dense mixture was formed, and the aggregate was suitable, there was no fear of corrosion taking place. He had occasion, some little time ago, to remove a portion of a concrete-in-situ sea-wall at Bridlington which had been constructed 25 years previously, and in doing so he laid bare several chains which had been inserted in the wall when it was built. He found that the chains were quite bright to within ½ inch of the face of the wall. He also removed recently a concrete roof constructed 18 years ago, and partially reinforced by 6-inch by 4-inch tee-bars. He had found the tee-bars perfectly bright. In further support of his view he would refer to the results of tests carried out by him in 1908[1] in order to ascertain whether corrosion of steel reinforcement in concrete took place. The advantage of using reinforced concrete in the construction of bridge-floors was

[1] "The Corrosion of Steel Reinforcement in Concrete." Transactions of the Society of Engineers, 1909, p. 61.

Mr. Matthews. that corrosion of the floor-plates was avoided. He did not agree with Mr. Hudleston that very few experiments had yet been carried out with reinforced concrete.

*** Mr. Cunningham's reply will be found at the end of the Correspondence.

Correspondence.

Mr. Colman. Mr. S. M. COLMAN, having watched for some years the struggle for recognition which reinforced concrete was making, wished to notice some conditions of its use. First, the methods adopted by specialists could not be protected. If a monopoly or close ring of practitioners were formed, or if legislation requiring severe testing and substantial guarantees were introduced, the unqualified engineer would soon abandon its use. Its intrinsic merits would then raise it to the level which it undoubtedly deserved. Then, it was a material which lent itself too readily to imitation; the apparent simplicity of some of the great works accomplished in reinforced concrete had led many men of doubtful ability to emulate experts by producing ridiculous or over-bold designs which had been a factor in the high percentage of failures. Again, its efficiency depended to a very large extent on perfect workmanship; this perfection often being required in details known only to the designer, the least relaxation in the duties of supervision perhaps meaning failure. This dependence on workmanship, rather than on any factor of safety, was a good reason why the designer should himself take charge of the construction and not depute this all-important task to a subordinate. The failure of a structure, due to its faulty design by a self-constituted expert, tended to destroy confidence in good work by specialists. The direction which discussions on reinforced concrete took showed such want of confidence in each other among its most sincere advocates, that an impartial engineer was justified in condemning them all for that reason alone. Then again it had its legitimate and its illegitimate uses, and examples of the latter were the more frequent. This was undoubtedly due to the fact that those who had arrived at or assumed the position of experts were inclined to recommend its use in all places where it could be, rather than in those places only where it should be, employed. The former being much more numerous than the latter, many costly