Discussion.

Mr. TH. SEYRIG said he did not pretend to have sketched completely in his Paper the different modes of erection of iron bridges. It might almost be said that there were as many modes of erection as there were systems of iron bridges; and these had been very numerous, especially during the last few years. But he thought there was much use in classifying, as it were, the different modes of erection; and it was merely towards that point, and towards showing that theory might have a useful bearing on this essentially practical part of an engineer's work, that his efforts had been directed. He thought there ought to be more foresight or forethought in the getting up of designs for iron bridges than had generally been shown; and it would not be difficult to mention instances in which the erection of a bridge had been not only more costly, but also more difficult and dangerous than the work itself. It was this point to which he desired particularly to direct attention, that the design of the bridge should demonstrate the process or the theory of the way in which it ought to be erected. He might be permitted to exemplify what he had stated by the most recent example. The members had before them the successive stages in the erection of the Douro bridge, which he believed was the largest of its kind, though a larger one was now about to be built; and a few weeks ago there was a competition for another bridge near the same place of a considerably larger span. The bridge represented in Plate 10, Figs. 20 to 23, was of 525-feet span, and the new bridge was intended to have a span of 571 feet; and as every engineer knew, the difficulties with such large spans were not simply proportionately, but far more than proportionately greater as the length increased. A certain number of plans were given in for competition; the tenders were very different in price; he did not propose however to call attention to that point, but rather to the different ways in which the problem was proposed to be solved. The principal difficulty in this second Douro bridge was the same as in the first, that no intermediate staging was possible for spanning the river. Not only was the water deep, but the ground was insecure. The depth of the water was 40 feet or more, and the ground was very shifting. Moreover the tide came in twice a day to a certain height, which rendered it inconvenient to work there; and there were very high floods to be feared. All those conditions might make it difficult, if not impossible, to erect staging; and one of the other modes of erection had to be resorted to. He believed that all the plans proposed

Mr. Seyrig.

Mr. Seyrig.

bore evidence of this difficulty. He would sketch three of the proposed plans, and thus show how necessary it was beforehand to pay attention to this particular difficulty; and the different ways in which the problem was proposed to be solved would the better illustrate the necessity of forethought in design. Two roadways had to be provided, one above, and one below; one establishing a communication between the upper, and the other between the lower parts of the opposite townships. The lower roadway was to cross near the level of the river, and the upper about 160 feet higher. In one of the plans proposed it was evidently the intention of the designer to do the work by floating (Fig. 1). There was a semi-parabolic girder resting on the lower

FIG. 1.

abutments, divided into panels by verticals, as was usual in a bowstring girder; on this girder were erected standards to support the upper roadway. The girder was evidently intended to be erected somewhere up the river, and to be lifted bodily and brought into position by barges or pontoons placed underneath it. That plan was, he believed, one of the most costly in this case, owing to there being only one span to erect; although in consequence of the lightness of the girder, the firm proposing it were able to bring down the price to one of the lowest. Another plan (Fig. 2)

FIG. 2.

was this: the piers were to be first erected on the banks of the river; the roadway was to be constructed as far as the piers, and alongside of them was to be erected temporarily another kind of pier, consisting of a standard or strut braced to the first pier. A place for it would easily be found in front of the abutments on which the main pier rested. These constructions had evidently

stability enough to resist the wind and all other extraneous forces Mr. Seyrig. during the erection. It was proposed then to lower these huge struts, letting them turn upon their lower end as a centre, and at the same time to build up successively parts of the top girder, which after the lowering of the struts was to become a chief girder of the bridge. When once they had come into their required inclined position, they were already attached to the upper portion by a piece of girder having the form of a tie. It was not difficult to see how that part of the girder could be built up as the strut was lowered; and when once that point was reached, the upper part was stable in itself, forming a cantilever. The cantilever being sufficiently fixed to the abutment and to the roadway girders extending behind, it was evident that an arch could be built forward, piece by piece, so as to reach the middle of the bridge, and thus construct a true arch, and form, with the part built as a cantilever, a structure the resistance of which might be accurately calculated. The third plan, which was his own (Fig. 3), was very

FIG. 3.

similar to that of the first Douro bridge, with one slight difference. A difficulty had been experienced in that bridge from the arch resting on its abutments in a point; and one of the greatest difficulties, small as it might now seem, had been to support the first, second and third panels securely during erection. There was but a small space available for the staging employed for the purpose, and the plan now proposed for the new bridge to be built alongside the first one was to make the arch proper not with a pointed toe, but with its abutment ends deeper than its crown. It was thus evident that three, four, or more panels—the heaviest in the arch—could be got into place more securely, and probably at less cost, than even with the very little staging and the ropes which in the former bridge were made to support them. The form of the new arch might also perhaps be considered more elegant, and to some extent it might be regarded as an improvement. These three examples would show that the difficulties of erection in special cases ought to be as carefully considered as the question of the resistance and ultimate working strength of the bridge itself.

Mr. Martineau. Mr. WILLIAM MARTINEAU said as he had been concerned for one of the parties tendering for the original Douro bridge (the only English firm, he believed), and had seen all the designs submitted, he might be permitted to supplement the remarks of Mr. Seyrig by saying that there was another design from a French house, which was composed of two slight curved arches, representing as it were a Gothic arch, forming two flat curves falling together in the centre. No very clear explanation was given as to how that bridge was intended to be erected, but he should infer that it was in the way which Mr. Seyrig had illustrated—by building upright struts and gradually lowering them together. The design submitted by the firm for which he was concerned was a semicircular arch for the centre, and two side arches, also semicircular. They were intended to be erected as cantilevers, half on one side and half on the other, counterbalancing each other until arriving at the centre. The width of the bridge was about 18 feet at the top, spreading out much wider at the bottom. There was one ponderous plate-girder bridge which he presumed was intended to be raised by hydraulic pressure.

Mr. Lloyd. Mr. S. ZACHARY LLOYD wished to give a few particulars of the erection of a bridge in Spain, over the river Esla, with which he had been connected some years ago on the Palencia and Ponferrada railway. Nothing of the kind, he believed, had been mentioned in the Paper. It was a peculiar mode of erection, which, he presumed, would not be frequently employed. The bridge (100-feet span) was riveted up complete at the railway terminus, and a double bogie truck, with four ordinary wagons, was run under each end. The bridge was thus carried down the line a distance of 50 miles, run over a temporary bridge, and then lowered into place. It was a simple arrangement, and answered very well; but in most cases a temporary bridge would probably be far more expensive than was desirable. Another bridge on the line had been erected much in a similar manner, under the superintendence of Mr. Oudry, a French engineer. Of course there were no bridges across the line, and no tunnels; and there were very few cuttings, and in one only of these was any difficulty experienced. Each span was 150 tons in weight.

Mr. Wawn. Mr. C. WAWN had listened to the Paper with considerable interest, having been concerned in the erection of several bridges. He could have desired, however, that some more of Mr. Seyrig's examples had been taken from this country, such, for instance, as the Clifton suspension bridge or some of the bridges over the Thames. He observed that in the Königswart bridge the scaffolding was

strained 10 tons to the inch. He considered this rather a severe strain even for a temporary purpose. His own experience was that temporary works, which were not generally so carefully considered in detail as permanent structures, were occasionally exposed to unexpected shocks from accidents to cranes, &c., and a strain of 10 tons to the inch (too much in itself) certainly left no margin for such contingencies. It was stated in the Paper that, in rolling out a bridge, considerable side strain was thrown upon the piers. That might be obviated by taking a tie from the top of the pier exposed to the thrust, and attaching it to the press or crab, or whatever was used for giving motion to the bridge, so that the strains might be self-contained. There was another method of rolling bridges to which reference had not been made—a compromise between rolling over and floating. The girder was first thrust out about a third of the way across, a vessel was brought under the end, which was lifted by taking advantage of the rise of the tide, or by pumping water out of the vessel to get flotation. The girder was then drawn over, one end supported by the vessel and the other by the pier. It had been stated that it was necessary in rolling out that the girder should be continuous. This was not necessary in all cases; indeed he had been considering the question lately, and a scheme had suggested itself by which, in the case of a single opening crossed by three girders (say for a double line of rail), the centre girder could be made to carry over successively the two outer ones. Two girders were built on opposite sides of the opening, and each rolled halfway out, meeting in the centre, as shown in dotted lines in Fig. 4, and being temporarily fastened together they were drawn over as shown in Fig. 5. The attachment was made preferentially by a pin or

FIG. 4.

FIG. 5.

hinge, in order to provide for the slight vertical motion due to the camber of the girder. As the girders advanced, the weight to be carried by the supporting girder of course increased, but was more

Mr. Wawn. than balanced by the greater leverage of its inner end. A girder rolled over in this way, being cantilevered for only half its length, must be less subject to injury than if thrust out for its whole length, counterbalanced by a temporary tail-piece. After the two outer girders were in place there could be no difficulty in getting the third over. The system of rolling over, which he had sketched, though not universally applicable, might in a modified form be of use in many situations.

Mr. Matheson. Mr. E. MATHESON said as reference had been made to the Kentucky bridge, described in a previous Paper by Mr. Clarke,¹ he might be permitted to say a few words about it on the question of erection. It was, he believed, the longest length of building out ever attempted, having been built forward 196 feet. He had recently brought with him from America, and now exhibited, photographs showing the state of things when the building out was at its greatest. The girders were not pushed forward. A suspension bridge, towers, and anchorage had been constructed, and the anchorage was made use of to hold down the girders, allowing the extreme building out. The height over the water was 275 feet, so that a staging below was almost impossible. A light trellis however was put up to carry the point of the bridge when it got to 196 feet, and it was then thrust forward to complete the span of 375 feet. One strange point was that no advantage had been taken of the towers, as in the Douro bridge. No suspension was attempted; the ends of the girders were merely anchored down, and the building carried out from them. He did not know of any other bridge built out so far in that way.

Mr. Reeves. Mr. F. W. REEVES observed that, although the Author had classified the different modes of erection in a somewhat arbitrary manner, his Paper would be of great service to those who might have anything to do with similar kind of work. It had been stated that when the bridges were rolled over they were liable to injury; two cases of that kind had come under his own notice; but in no case had there been anything more than a temporary delay. The first instance was that of a bridge with a continuous girder and two spans of 170 feet. The bridge was not strengthened for rolling, but, in order to give it a sufficient vertical stiffness during the rolling, temporary struts of wood were introduced. When the girder, which weighed about 350 tons, was nearly at the central pier, the struts yielded, and some of the hinder bars were bent beyond the limits of elasticity, and had to be taken out and

¹ *Vide Minutes of Proceedings Inst. C.E., vol. liv., p. 182.*

straightened. The work was carried on however with very little delay, and was ultimately successful. The other case was that of a bridge across the Tagus, consisting of nine spans of 130 feet. While one of the spans was being rolled, the boom was not only damaged but fractured, and a temporary pier had to be erected to support the end of the girder while the broken piece of boom was cut out and replaced. There was a delay in that case of about three months. Where floating could be resorted to, he believed that was the cheapest way of getting bridges into their places. It might be expensive to make special plant for a few spans; but if they were not very large, ordinary craft, lighters, barges, or even ships might in most cases be used for the purpose. He had seen two or three accidents in the lifting of ironwork, and he would recommend the use of iron links where they could be employed. It would have been interesting if the Author could have given the approximate cost of the erection of the Douro bridge.

Mr. G. WELLS OWEN having, in conjunction with Mr. G. W. Keeling, M. Inst. C.E., carried out the large bridge over the Severn, wished to say that, from the first moment of the inception of the project, careful attention had been paid to the manner in which it would have to be erected. The whole of the scaffolding and the mode of erection had been designed and arranged by themselves. The bridge consisted of several spans varying from 134 to 171 feet, and two spans of 327 feet. The difficulty only arose, of course, in reference to the large spans where the bed of the river was tolerably deep, and contained a considerable amount of sand. As the Bill passed Parliament, the intention had been to build the two large girders as a continuous girder, of about 650-feet length, on the masonry viaduct that connected the main bridge with the shore, and to roll them over the one small iron span that intervened between them and this viaduct; it was found however, on careful calculation, that the extra amount of iron necessary to brace the girders in order to roll them across such large openings without crippling them would have involved so great a cost that the idea had to be abandoned. The consent of the conservators of the Severn was afterwards obtained to build two temporary piers somewhat similar to those shown in Fig. 16, carrying a timber superstructure upon which the girders were built up *in situ*.

Mr. H. N. MAYNARD had been a good deal connected with bridge-making, and had given much attention to the question of rolling-over bridges. His firm had constructed the Crumlin viaduct, and, calculating the size required for the girders, they adopted a span of 150 feet, and had the girders lifted from the

Mr. Maynard, valley. The height of the bridge was about 200 feet, and it consisted of ten spans. The ordinary mode of lifting by a crab and pulley blocks had been adopted. The girders were erected at a cost of about 10s. per ton for labour alone, and a considerable sum was spent in the preparation of tackle. A girder was lifted by a gang of twenty men to the height of 200 feet in one day, and it required the same men double that time to prepare the tackle and build up the girder. The cost of the entire erection was about 30s. per ton, excluding the cost of tackle. The cost of the tackle was divided over the whole work. Had there been only one span, the cost per ton would of course have been larger. In another case, where the bridge was a single span of 150 feet at a considerable height, weighing a little more than half as much again as a span of the Crumlin viaduct carrying a similar load, the girders were rolled forward singly to overhang 70 feet, a floating stage taking the overhanging end, and the bridge was erected partly by lifting and partly by flotation. Here the tackle had cost as much per ton erected as the entire erection of another bridge of a similar span, because it had to be divided over one span only. He agreed with Mr. Seyrig and Mr. Owen as to the importance of following out the design of the bridge from the beginning to the end. If the plan of rolling over had been adopted for the Crumlin viaduct, it would have been necessary to use girders 50 per cent. heavier than those employed. The actual rolling over might in some cases cost very little; but then it was necessary to consider also the additional iron required to be put into the girders to make it possible to roll them over. The cost per ton in the case of the Stadlau bridge was stated to have been from 1s. 8d. to 2s. 6d. per ton; but nothing had been said as to what additional iron was required to make the bridge capable of being rolled over, or as to the cost of the necessary tackle. In some of the examples cited the cost of the staging was excessive, while in others it was perhaps very low. In the case of the Znaïm viaduct the cost was said to have been £3 12s. per ton. He had himself erected in Italy two viaducts, one being 95 feet, and the other 140 feet high, each with five spans of 120 feet, with continuous lattice girders, weighing together 422 tons. The scaffolding was similar to that described by Mr. Seyrig. The cost was £1 9s. per ton. Allowing the timber to be worth half the original cost, the use and waste of it amounted to 7s. 6d. per ton more, so that the total cost was but little more than half of that for the Znaïm viaduct. Of course there was a great difference in the cost of the erection of similar structures in different parts of the world, and it was impossible to state what constituted

the elements of difference. A large margin had to be allowed for Mr. Maynard. contingencies which could not be described. In the centre of Africa, for instance, all sorts of difficulties would have to be contended with, and labour would be more costly than near the coast.

Mr. JOHN DIXON remarked that each bridge should be specially Mr. Dixon. devised for the circumstances to which it was adapted. The Douro bridge was perhaps the most striking of any of the examples cited; but the drawing gave a very inadequate idea of the extent and imposing character of the work. Considering that the span was 525 feet, the height above the river 180 feet, and that the bridge with its approaches was carried across the ravine for £49,000, the French engineers deserved every credit for the skill manifested in the design, and for the strikingly imposing lines of the structure. Those who had watched it from inception and through the various stages of erection, as he had done, could not but accord to Mr. Seyrig, who had had the chief control and design of the entire work, great praise and credit for the manner in which it had been carried out. It had often struck him, looking at the examples of bridgework on the continent, that they somewhat reflected the popular idea of the different types of national character. The French works, for instance, were of a light and airy character, as contrasted with the more substantial works to which English engineers were accustomed. The latter did not design such light structures, but they could not fail to admire them when executed. He might be permitted to suggest that the Author should add to his Paper a few more statistics as to the cost of the erection of the bridges with which he had been connected. He would also draw his attention to the well-known viaducts on the Orleans line, where the girders had been rolled across high piers in a very economical way. In every instance of rolling girders forward that had come under his own notice, the work had more or less suffered by the excessive strain thrown on the different parts of the lower members, which were not especially calculated to bear it. In many cases absolute injury had been sustained, and he did not think the system should be followed if it could be avoided. The Institution was greatly indebted to a member of the French engineering profession (which had carried engineering science to a state of such perfection) for coming to England to read a Paper on so interesting a subject.

Mr. A. BUCHANAN, like other speakers, felt a debt of gratitude Mr. Buchanan. to the Author for having brought the matter before the members in the way he had done. He agreed with the statement that the Paper exemplified the fact that almost every bridge should be

Mr. Buchanan. treated in accordance with what the circumstances of the case would admit of. He believed that, as a rule, English engineers recognised the necessity of considering from the beginning how a bridge should be erected. In erecting a bridge, at all events in a foreign country, an engineer should do the best he could with the labour and materials at hand; and it was not always possible absolutely to determine the best plan until arriving on the spot. He might design a bridge at home, in the expectation of finding many things in the country to which he was going, but which were not to be found there. Generally speaking, he believed the differences in the cost of erection were not so great as some persons imagined. In the centre of Africa the difference might be considerable; but in most semi-civilized places the cost of labour was much less than in civilized countries; so that by using a greater proportion of labour very nearly the same result might be attained. Some of the viaducts to which reference had been made would appear to have been built in countries where timber was tolerably cheap. In countries like England an endeavour was generally made to economise in timber structures, in order to secure a lower cost. It would not however be right to be too critical, because the best might have been done under the circumstances. The Douro bridge was peculiarly interesting; and the way in which every advantage had been taken of the structure itself, in order to erect it, might be taken as a model. In the erection of heavy work, especially away from home, it was of great importance to consider the joints by which the various portions of the bridge were put together. If they were not thoroughly and fully considered, immense trouble would be occasioned in the erection, and there would be great risk of the structure getting seriously damaged during its transit. If there were long overhanging light pieces, which were difficult to pack and protect satisfactorily, they would be pretty sure to arrive at their destination to some extent damaged, when it might be found impossible to replace them; and the bridge might consequently be put up in a crippled condition. In such cases, perhaps above all others, the advantage of erecting on a staging was realised. Of course in such a case as the Douro bridge a stage ought not to be used; but where it could be employed it was very desirable. In the Moerdyk bridge, the use of pontoons to float the girders across combined the advantage of building upon a stage with pushing over. The principal gain in building upon a stage consisted in making it possible to preserve the exact "camber" of the girder, and so to avoid the enlarging of holes and other alterations of the

structure due to loss of "camber." This seemed to point to the Mr. Buchanan. great advantage of using a stage where it could be employed with anything like economy. Equal advantages could hardly be expected to arise from the pushing-over plan, especially with girders which were not continuous. The plan of putting a bridge together at a railway terminus, and conveying it to its destination in one piece, was a very nice one when it could be carried out; but this was seldom possible. A number of pieces might be carried on successive trucks for hundreds of miles (as had been done in Russia), and the whole span could be put together on arriving at the site, the trucks being used as a stage. When the bridge was thus firmly put together it was pulled over a temporary structure at the place where it was to be finally deposited; and when the trucks were removed, it was lowered into place by tackle.

Mr. G. H. PHIPPS said that, having had to consider the same Mr. Phipps. subject as the present Paper in some lectures which he delivered seven years ago at the School of Military Engineering at Chatham, he could quite appreciate the great trouble to which the Author must have been put in preparing so excellent an account of works as his Paper contained. He should have been glad however if the Engineers who at early periods had executed some of the works in question had been mentioned. He should like to mention the name of his friend, the late Mr. J. M. Heppel, M. Inst. C.E., who, in 1858, 1860, 1867, and 1870, employed the pushing-over principle on the Palar river, the Cauvery, the Chittranutty, and the Ganges, at Cawnpore. In the last case the rollers were caused to revolve by mechanical power; and in order that all the rollers, ten on each pier, should take an equal bearing, they were kept up by hydraulic pressure all in connection, so that no one roller could have more than its due share of pressure, and this he thought was a very great improvement. He might also refer to a bridge that had been put up in the Mauritius by Mr. Longridge. He had previously remarked upon the beauty and arrangement of the Fribourg bridge:¹ not only were the girders pushed over the piers, but the latter were built in place from the extremities of the girders when overhanging the abutments. He might also allude to Mr. Berkley's Mhowke Mullee viaduct, the girders of which were lifted bodily into place by hydraulic apparatus. An admirable Paper had been read by Mr. Leslie on a bridge over the Gorai river;²

¹ *Vide* Minutes of Proceedings Inst. C.E., vol. xxv., p. 250.

² *Ibid.*, vol. xxxiv., p. 1.

Mr. Phipps.

which was partly floated and partly pushed into position. Nothing had been said in the Paper about the erection of suspension bridges; but perhaps the Author thought that was too wide a range to take. Great credit was, he thought, due to the late Mr. Price Prichard Baly, M. Inst. C.E., who had arranged, under Mr. Brunel, the system of wire ropes for erecting the Hungerford Suspension Bridge. When it was removed to Clifton by Messrs. Hawkshaw and Barlow, wire ropes were also successfully used. He thought that more use might be made of them in erecting bridges than had hitherto been done.

Mr. Barry.

Mr. J. WOLFE BARRY did not understand why such large spans as 227 feet should have been used in the Königswart viaduct. The water-level evidently was sufficiently low to admit of temporary piers being erected, and he wished to ask why permanent piers had not been adopted there also. A similar question might be asked in reference to the Znaïm viaduct, where the spans on each side of the water-channel were 164 feet. Perhaps some calculation had been made to prove that they were more economical than smaller spans; but at first sight it appeared that, while one of the centre spans of 197 feet was correctly proportioned, the side spans were not economical. He also desired to direct attention, in the case of the Znaïm viaduct, to the extremely rough system of triangulation which appeared to have been adopted with the scaffolding, and to say how important it was that the triangulation of such structures should be carefully and systematically carried out. In several parts of the scaffolding there appeared to be quadrilateral bays without any triangulation at all. Anyone who had had much to do with scaffolding would know what a radically important point it was to have all the parts rigidly triangulated. In listening to the Author's interesting account of the designs for the new Douro bridge, and the plan of turning forward one of the temporary struts adopted in the second design to which he had alluded, he had been forcibly reminded of the fact that in so many of these large structures no advantage was taken of their great height in order to get long diagonal struts supporting the girders and reaching down to the piers. Examples of that plan were to be found in the beautiful viaducts of Mr. Brunel on the Cornwall railway, where there was a system of fan-like struts resting on the piers, and reducing the spans into manageable proportions. That sort of construction was peculiarly available in all cases of great height of road above the water-level; and in many of the examples exhibited, he should have thought that something of the kind might have been done with advantage.

Sir JOHN HAWKSHAW, Past-President, said it might be taken almost as an axiom that those who designed bridges should have reference to the mode in which they proposed to erect them. The Author appeared to think that in some cases that had not been done with sufficient care; and that was possible. Engineers were perhaps not always as careful as they ought to be in such matters; but he thought that every engineer worthy of the name did consider the mode which he thought would be necessary or best for the erection of a bridge which he had designed. The various methods of erection illustrated in the Paper were very numerous, and it was quite impossible for anybody to stereotype any special mode. Each mode must depend upon situation and upon other circumstances which had to be considered at the time; nevertheless it was always useful to those engaged in such matters to have laid before them the methods that had been successfully adopted in different places. As to what was possible, he would be a bold man who would undertake to say what was or what was not possible. For instance the Author appeared to think that the system of rolling over was applicable only to continuous girders. On that subject he should say that, if it were the best thing or a proper thing to be done, he knew of no girder that might not be rolled across the place which it was intended to span. If it were a single girder, it might be necessary to make a temporary tail-piece, and a temporary provision for strengthening the girder during the time in which it had to act as a cantilever. That was practicable where it was a proper thing to do: though of course it might be an expensive method for a single girder crossing a single opening. If a number of single girders had to be rolled forward, the work could be done in the way described; so that it was not right to say that the rolling process applied only to continuous girders. Whether the process of rolling should be adopted, or of floating, or of erecting upon a stage, each case would have to be decided for itself and by itself. All therefore that could be derived from descriptive papers was the advantage (a very important one) of having cases brought forward, in which the different methods in question had been successfully applied. Latterly bridges had been extended to a degree far surpassing the notions of old engineers. When he was in the United States some time ago, American engineers were talking of girders of 800-foot span; they seemed to think there was no difficulty in constructing them, and in that view he was disposed to agree. He therefore fell back upon the proverb, "It is no use prophesying unless you know." Some years ago it was gravely considered in this country

Sir John Hawkshaw.

Sir John Hawk- whether a suspension bridge of 1,500-feet span could be built; and shortly afterwards, while the subject was under consideration, the work was being done in the United States. He had lately seen the bridge, which was very nearly completed. Such questions were interesting; and he thought the members were much indebted to the Author for the trouble he had taken in bringing so much information before them.

Mr. Seyrig.

Mr. SEYRIG, in reply, said that Mr. Martineau had alluded to one of the designs for the new Douro bridge (his own) being a complete arch, joined to two side arches at either end of the bridge. He remembered that that design had struck him as being perhaps the most easy mode of erection; but it was also the most costly, the tender being about three times the amount for which the present Douro bridge had been made. The tender for the present Douro bridge was about 960,000 francs, and that for the design in question about 3,000,000 francs. He thought that one of the reasons for so great a difference in price must have been a large quantity of metal introduced merely for the purposes of erection. Mr. Lloyd had referred to a bridge which was riveted complete at a railway terminus before being run into its place on wagons. Unfortunately the railway was not always in existence before the bridges were built; and the plan referred to by Mr. Lloyd, admirable as it might be for small bridges on certain occasions, could not often be adopted. He regretted with Mr. Wawn that more examples had not been taken from this country; but he had not sufficient materials at his disposal. He might be permitted however to express a desire that the Paper should be supplemented by Mr. Wawn or some other member, so as to bring before their continental friends some of the most striking examples of English bridges. With regard to the strain at Königswart bridge, he should not have admitted such a strain for a permanent bridge; but he thought it was allowable, notwithstanding the accidental strains that might occur, to admit so high a strain for metal which was only to serve for a few months, and was not exposed to continuous vibration. That high strain was admitted by the Germans, who were perhaps bolder than French or English engineers; but it should be remembered that their calculations were made with the greatest care and nicety, and that they adhered very closely to the practice of deducting for rivet-holes. He did not know how far this was customary in England, but in France it was not done at all; at any rate, the government regulations did not require it, whatever engineers might do in practice. Perhaps he had gone a little too far in saying that a continuous girder was necessary for rolling

over. He had himself rolled girders which were not continuous: Mr. Seyrig. where for instance there was only one span, and a temporary staging had been erected in the river a third or half-way. He had selected examples specially to illustrate the theory, and not the modes in which different plans might be combined. The two methods of rolling over and floating bodily might no doubt, as had been observed, merge into each other, so that a bridge might be half rolled and half floated. This also had given him very good results. It required, however, greater precautions, quieter water, and greater expedition than either floating or rolling alone. Mr. Matheson had remarked that the longest overhang was that of the Kentucky bridge, 196 feet. That bridge however was not pushed forward. One of the viaducts on the Orleans railway, the Sioule, had about the same length of overhang, namely, 190 feet. In that case, for the first time to his knowledge, no additional staging was used with the ties that were till then commonly employed. Nearly all the bridges rolled over up to that time had been supplied with a gantry and chains or ropes, on the principle of the wooden stage of the Regoa bridge. The fore end of the bridge was connected with its hinder end by chains or ropes going over a temporary trestle. One of these, erected on the Orleans line, very nearly came down, owing to one of the ropes breaking. It was difficult to estimate exactly, in all the different positions which a bridge took during rolling, what would be the strains on the ropes. When the bridge had nearly reached the opposite pier, one of the ropes broke; the girder turned a little on one side, but happily nothing further occurred. After the accident, the Sioule viaduct of the same design having to be erected, the company's chief engineer proposed to do away with the ropes altogether, and the plan was most heartily adopted, because it gave much greater security. A little more metal was put into the booms, and a little more into the diagonals, and that addition remained afterwards to strengthen the bridge itself. That was also the occasion on which the set of four combined rollers (Fig. 14) was used for the first time. The largest span crossed by rolling the girder without staging or ropes was, to the best of his knowledge, one he had himself designed and erected near Tours, over the Cher, which had two spans of 202 feet each. Many bridges had been rolled over in France, where that was the general practice, without an accident. One accident however had occurred, with serious results. It was in the case of a two-span bridge. On arriving near the abutment, it toppled over; that however was not the fault of the mode of erection, but arose from

Mr. Seyrig.

an error in the calculations. Rolling over certainly required more minute calculations and more care than erection on staging, but it possessed many decided advantages, especially that of economy. It had been stated that no one knew what was the condition of the booms after rolling, especially the lower booms; and the occurrence on the Tagus (Portugal) had been referred to by Mr. Reeves. Some overstraining might have been very near occurring when the bridge got over the sixth or seventh support, so that a temporary staging had to be erected. In a bridge of ten spans which he had built, with middle spans of 192 feet, there was some difficulty on coming to the tenth span. The lower boom had to be strengthened a little, but the last span was safely got over and the injury was really very slight indeed. He therefore contended that with proper precautions, even with so large a number of spans as ten, the rolling over might be accomplished with safety. As to the cost of erection by building out, it would be difficult to give a precise figure. He might say, however, that the total cost was not so much as might be supposed. In a bridge similar to the Douro, about to be erected in France, the span being 15 feet larger, but considerably higher, the government engineers had consented to pay for the erection of the large central span £12 a ton more than for the erection of the side spans. He thought the estimate for erecting bridges of that sort should be considerably lower. He made that statement from the result of the last tenders for the second Douro bridge, the total cost of the iron in a bridge like that being only about £22 per ton. The tenders varied from £21 to £24. Mr. Maynard had referred to the Crumlin viaduct, the girders of which were lifted by means of crabs and pulley blocks. The cost of that lifting was in Mr. Seyrig's opinion extremely low. Mr. Maynard added that the viaduct would have had to be 50 per cent. heavier had it been rolled over, on account of the additional quantity of iron that would have been necessary. Mr. Seyrig was not of that opinion. He had often designed bridges on different systems, and had had occasion to compare different kinds of continuous girders with others, and he believed that continuous-girder bridges could be made much lighter than single-span bridges, and that the additional metal necessary to carry them over with safety would not equal the difference between the weight of continuous spans and single spans. By properly combining the depth of the girder and the arrangement of the diagonals, more economy could be obtained by using continuous spans. In his opinion the objection to them lay in another direction—the unknown strains coming upon the girders

on account of possible variation in the level of the supports. Mr. Seyrig. The Crumlin viaduct, he believed, was originally built with pins; and certainly the cost of erecting bridges on the American system with pins was much lower than that of riveted work. That, he thought, was the only advantage of the American bridge system as compared with the European systems; and he should willingly adopt it in cases where the difficulties of erection were very great. Africa had been spoken of as a country where it was possible bridges might have to be erected, and he hoped they might be. Labour would be very dear, and perhaps the climate might render it necessary to remain on the spot the least possible time. In such cases bridges with pin connections might be the best to adopt, so as to get the advantage of the lowest cost of erection; but only in such cases would he adopt that system. In the case of the Stadlau bridge he had given the cost of labour in rolling over, but he could not get at the cost of the tackle. The tackle might serve many times over when once a firm adopted the system of continuous girders for rolling over or lifting bridges. The tackle made more than twelve years ago for the Sioule viaduct, above referred to, had hardly ever stood idle since then. Mr. Maynard had said that his Italian work was cheaper than that of the Znaïm viaduct; but it was necessary to take everything into account. Timber was not dear in Austria, and carpenters' work, especially of the kind employed at the Znaïm viaduct, was very cheap. The connections between the different timbers were made on the Austrian system, with cramps driven into the wood, instead of bolting the pieces together; and he ventured to think the staging of the Znaïm viaduct was one of the most economical that could be made. Attention had been called by Mr. Dixon to the light appearance of French as compared with English structures. That observation was perfectly just; but the Author believed that the difference was often the result of their proportions, more than of their absolute lightness. Where an Englishman would often prefer an appearance of massiveness or solidity, a Frenchman might lay more stress on proportions that gave a light and elegant character. But engineering works, and more especially iron bridges, were not mere architectural structures; they had to undergo the tests of calculation in every one of their details, even the smallest. The closer observation of theory, and the dislike of anything that resembled rule of thumb, had certainly been the principal causes why French engineers had attained that lightness in their designs. The viaducts on the Orleans railway, mentioned by Mr. Dixon, had already

Mr. Seyrig.

been spoken of, more especially the Sioule viaduct. The Author could not quite agree with him as to the constant bad effects of rolling, but rather believed that only from sheer neglect of the necessary precautions had the iron been permanently injured in any such cases. Mr. Phipps had spoken of the Cawnpore bridge, where the rollers had been each supported by hydraulic pressure, so as never to bear more weight than their share. That plan seemed at first very simple and effective; but the Author had heard of occasions where it had again been tried with but very indifferent results. At all events it was expensive, and he thought no more effective than the simple contrivance shown in Plate 9, Fig. 14. He had not spoken of suspension bridges, these being happily considered in Europe as things that ought to be avoided. Replying to Mr. J. Wolfe Barry, the Author thought the spans of the Königswart viaduct were well proportioned. A rule which ought not to be considered as absolute, but which in many cases gave at once the most economical proportion of the spans for a bridge, was to make the spans nearly equal to the height of the piers. In other words the openings between the piers, ground, and roadway, ought to be nearly square. According to this rule the subdivision of the total length of the Königswart bridge into three large openings appeared justified. They were all three made equal for the sake of simplicity in the ironwork. The same rule was nearly applicable to the Znaïm viaduct; but there, the girders being continuous, it was natural that the middle spans should be about a quarter larger than the side spans. As to the triangulations of the scaffolding of that viaduct, it was an instance of the boldness which Austrian engineers would exceptionally venture upon. It must be remembered that the piers themselves served effectually in steadying the scaffolding, and that in Plate 8, Fig. 2, the transverse triangulation could not be shown. It was however somewhat of a similar description to that existing lengthways. Sir John Hawkshaw had gone rather further than the Author in saying that he knew of no girder which might not be rolled across the space it was intended to span. Surely that could not apply to certain classes of girders, such as semi-parabolic girders on the prevalent Dutch system (Plate 8, Figs. 3 and 4, for example), or to any system with flat tie-bars for the lower booms. In erecting girders the motto ought to be: first, safety; next, cheapness; third, rapidity. Special cases might change the order of these aims and their value; but such cases would be exceptions. The best mode of erection would result from the happy combination of the three, including, if possible, a fourth—elegance of method.

Reverting to the first words of his Paper, the Author believed that Mr. Seyrig's progress lay in this direction, namely, the right and proper combination of the design with the most judicious mode of carrying out the work, having in view not only the excellence of the permanent structure, but also the art of getting it into place. The Author wished to express his thanks to Mr. Alfred Bache, who kindly consented to translate his Paper, and to whose lucid and careful English wording of foreign expressions a great part of its interest and worth to English readers was due. He begged in conclusion to thank the members of the Institution for their kind reception of his Paper, and he could only wish that it had been more worthy of the Institution.

Correspondence.

MR. ALFRED BACHE, referring to the observations made both in the Paper and in the discussion, with respect to the risk of girders being permanently injured by the strains in rolling them over their spans, remembered an instance of a girder bridge carrying one railway obliquely over another, where the extent of overhang and consequent strain upon the girders had been diminished by pushing them across at right angles to the lower line, and then slewing them round afterwards into the oblique direction of the upper line. That expedient depended however upon having sufficient clear space in the rear of the abutment for manœuvring the girders at the level of the upper line.

From the drawings shown of the rollers, it was evident that, where these were used, the lateral guiding and steadying of the girders had to be provided for by some other means. But in the ball apparatus of Herr Weickum¹ (Fig. 6, p. 202) it would be seen that the lateral guiding was effected by light angle-irons riveted along the top and bottom of each side of the live plate. The H iron, forming the trough in which the balls ran, was carried on ordinary flat-footed rails; a pair of these were spiked down alongside each other, whilst a third rail inverted was placed between them; the three, together with the H iron, made a very firm path for the load to travel along. The balls were $4\frac{5}{8}$ inches in diameter, running loosely in circular holes in the flat live plate.

The extensive replacing of timber bridges on Hungarian and Austrian lines, referred to in the Paper, had its counterpart in this

¹ *Vide Mémoires de la Société des Ingénieurs Civils*, 1880. "Note sur quelques cas spéciaux de montage des ponts métalliques," par T. Seyrig.