"Recommended Technique for Making Fillet Welds in the Downhand, Vertical and Overhead Positions." (FE.5.) June 1944. (T.13.)
"Recommendations for Butt Welds." Dec. 1945. (T.15.)

4. T. Scott Glover, "Layout of a Welding Shop. Integral Factor in Modern Engineering Production." Trans. Inst. Welding, August 1945.
5. "The Control of Welding." Papers contributed to a symposium organized by the Scottish Branch of the Institute of Welding, 14th March, 1944, published by the Welding Research Council.
6. "Inspection of Arc Welding." Welding Memorandum No. 7. Advisory Service on Welding, Ministry of Supply.

Discussion.

The Author introduced the Paper with the aid of a series of lantern slides.

The Chairman observed that the Paper had broken new ground so far as the Structural and Building Engineering Division was concerned.

The recommendations made at the Glasgow meeting of the Institute of Welding should be carefully studied, as it was not too much to say that upon them rested the success or otherwise of welding.

It was noted that there was general agreement that control should begin in the drawing office, but that three divergent views were given as to how that should be brought about. He saw no reason why all three points of view should not be adopted, not as separate items but as general routine in any works. They were sound sense.

It had been claimed that welded work was more economical in material and in cost than riveted work. The Author had stated (p. 13, *ante*) that a gang consisting of a foreman, a welder, and five labourers erected an average of 5 tons of steel per day on a framed building. At present-day prices the cost of that labour on the site would amount to 25*s*. per ton for erection, and at that price it certainly was economical. Therefore, it seemed that some engineers were still chary of using welded work on load-bearing structures; possibly they were not quite satisfied over the human element which had perforce to enter into the making of a weld. Would it be possible to overcome that objection by eliminating the human element, making the weld by mechanical means? If so, even the most sceptical of engineers might have as much confidence in a welded joint as in a riveted joint. Had any research along those lines been initiated, and, if so, how far had it gone?

Mr. W. E. J. Budgen observed that whilst structural and building engineers had tended to hesitate about welding, to worry whether it was quite safe and how they should design for it, other branches of engineering had gone ahead with welding and had achieved quite satisfactory results. One reason for that hesitancy was that welding had not been well served by all its advocates. It was obvious from many articles and discussions that, whilst advocates of welding might know a great deal about welding, their structural knowledge was extremely limited and many of their statements would not bear analysis. If an engineer started even to think of the theoretical stress conditions over a simple end fillet weld he immediately encountered much more complicated things than the picture of designing by dividing the throat area by the load would tend to suggest.

Another factor which had held welding back had been referred to indirectly by the Author, namely, that the methods of design of comparable riveted structures, whilst giving quite safe results, were inaccurate theoretically, and so there was very little theoretical basis from which to start. Therefore, he agreed with the Author's view of the need for the development of what might be called accepted practice. He wondered, however, whether some of the Author's subsequent statements would help in the achievement of that end. For example, if an attempt were being made to persuade a client to change from a riveted job to a welded job, would he be helped by the Author's statement that when welding threw up problems, whether of metallurgy or engineering, the answer was nearly always well beyond the limits of present knowledge ? Would it be helpful if the client heard it said that in welding stresses developed in the weld and the material being welded when it was at a temperature near the melting-point and that that was a metallurgical problem with respect to which present day knowledge was either sketchy or non-existent ? Mr. Budgen felt that those statements would tend to put the client off rather than encourage him to build a welded structure.

He could not agree that structural and building engineers were now realizing that their present theory of structures was not only inadequate but also hopelessly incorrect. In his opinion, the trouble lay not in the theory of structures, but in the practical methods of designing them.

He questioned the Author's statement that it was natural and correct to regard the welded joint as essentially rigid. He agreed that it was easier to design a joint which was to be nearly 100 per cent. rigid with welding than with riveting ; but, on the other hand, it was equally possible to design a welded joint which was quite as flexible as a riveted joint.

With regard to Professor Baker's research into the load carrying capacity of rigid frame structures, particularly on the plastic theory, it should always be remembered, particularly with steel frame buildings, that if they were designed as rigid frame structures one of the great advantages of the steel frame building was immediately lost, namely, its adaptability and its capability of being altered in the future.

Mr. Budgen considered that the subject was one in which The Institution, and particularly the Structural and Building Engineering Division, would have to take an increasing interest in the future.

Mr. A. C. Vivian observed that, if he had interpreted correctly the figures given by the Author on p. 10, *ante*, they meant that 250 men had a work output of 23 per cent., but after procedure control was instituted—which no doubt also included the rearrangement of the lay-out of the shop —180 men had a work output of 45 per cent. The product of the number of men and the work output percentage was the actual work output of the shop, and the welding unit cost was inversely proportional to the work output percentage. Therefore, not only was there a unit cost reduction of 50 per cent. but also a work output of nearly 33 per cent. more. That seemed a very important consideration and a recommendation for instituting welding procedure control. Moreover, even with a greater work output, less floor-space would probably be required with 180 men than with 250 men.

During the past 20 years Mr. Vivian had done a great deal of research into the strength of materials, of the kind which consisted of studying technical reports and test measurements to find the reason why steel behaved as it did behave at high stresses, and in correlating stress with its components of strain—elastic and plastic strain. That study was very important in welding design. He congratulated the Author—who was the Director of the Welding Research Council—on having the courage to state that the present theory of structures was not only inadequate but also hopelessly incorrect. He agreed that it was very important to rationalize the design of welded structures to take advantage of the plastic deformation of welded metal and of structural steel, but he suggested that the first consideration was to rationalize the relation between stress and plastic strain. He had found it possible to do that from tensile measurements, provided the percentage elongation on two different gauge-lengths of the same diameter were measured. With those measurements, a maximum strength and a percentage reduction in area, he had found that it was possible to calculate a nominal stress-strain diagram which agreed with the measured stress-strain diagram above the yield-point. He had also found it possible to provide a rational explanation why, in terms of those mechanical tests, some apparently ductile steels were notch-brittle. The secret lay in the extent to which the steel would stretch before it began to neck. Realization of the importance of that measurement was not new. The late Professor W. C. Unwin, Past President, I.C.E., had pointed it out more than 40 years ago, in the British Standard Report No. 3, which contained many test results on tensile measurement. Professor Unwin had stated that he could only get that measurement from an autographic record, and that was obviously impracticable for check testing. Mr. Vivian had found from a considerable study of many results that it could be obtained by scribing a machined tensile bar at equal intervals along the gauge-length with equal circles pulling and finding the percentage elongation of two different gauge-lengths on the same bar. If the bar broke near the grips, it could be discarded and another pulled, because the measurement required was of an intrinsic property of the metal and not a surface defect. The strain to the ultimate tensile strength or, as Professor Unwin expressed it, the general elongation, varied with heat treatment, composition, and method of production, but it was approximately a constant for a particular quality of steel and method of manufacture.

To reduce high stress in a column or at the connexion, due to a bending moment transmitted from a beam welded to it, plastic deformation at the joint was required. The tests described in the first three interim reports covered by Reference 2 in the Bibliography showed that plastic deformation of the weld metal or of the steel adjacent to it could occur. Mr. Vivian wished to see research concentrated, firstly, on the evaluation of the safe plastic deformation of welded metal and of the steels commonly employed in welding, and secondly, on the evaluation of the rotation of beam end to stanchion for various types of standard welded connexions in terms of the plastic deformation of the steel.

The existing methods of design suggested that there was something doubtful about welded structures. The Author had taken the right line —not the salesman's line—in drawing attention to the inadequacies of existing design. It savoured of the fable of the fox and the grapes, but Mr. Vivian considered that the grapes—the welded structures—were all right, and that it was the fox—the present theory of design—which was sour.

Mr. H. V. Hill observed that he would like to know more about the work of Professor Baker, particularly in relation to what he considered to be the future development of the multi-storey building. Would the present method of construction with simple separated beams be continued, or would the continuous structure, as in reinforced concrete, be adopted ?

Mr. R. G. Braithwaite observed that his experience was that, despite the somewhat varying differences in fabrication technique as outlined by the Author, welding could be economically carried out in the structural bays provided they were properly equipped for the interchange of work. In fact, there was evidence in some of the designs now coming forward, and as emphasized by the Author in citing the cases of the Everall and Bailey bridge equipment, the parts for which were shop welded and site bolted or pinned, that welding would be mixed with riveting where economy or expediency required. That experience was borne out by a study of the lay-out of some American shops, where welding was regarded as a tool of fabrication rather than as a specialized method of construction when its economical use could be justified, and was confirmed in modern shipbuilding practice, where welding and riveting were used as most expedient and economical.

Mr. Braithwaite considered that welding should be regarded as an alternative to riveting, but that an all-welded structure could be improved by special treatment. There was opportunity in ordinary riveted work for making use of various welded fittings. For instance, pieces cut for standard joists, could be much more economically and cheaply built up by welding two plates together in a T-section. There were many other details of that kind. The conversion of that view into practice was often hindered by the poor standards of detailing and the prolix regulations regarding its use. Mr. Braithwaite's shops experience in both forms of construction had shown that the assembly costs on welded frames compared unfavourably with riveted frames, as the absence of holes from which the work could be set out and accurately located had involved the use of skilled labour in the assembly gangs to set up and fix the parts in their correct locations. Designers should bear that difficulty in mind when designing units which had to be fitted at site. When the units were sufficient in number to justify the making of an assembly jig, the assembly costs could be considerably reduced. He could not agree with the Author's statement that there was little advantage to the steel fabricator in offering a welded building framework, on the principle that because there was less weight of steel and workmanship the total price should be lower. Any firm engaged in the production of steelwork was concerned, not with the ultimate cost, but with the ultimate profit, and, having regard to the cost of steel, would always be willing to entertain any method of construction which would cheapen the work. In doing so, due regard should be given to the lay-out of the works to suit the standards of construction prevailing and the customer's requirements. In many cases the latter insisted that no welding whatever should be permitted. At the present time a number of very large buildings were under construction in his company's works, for various authorities, and the specifications stated that no welding whatever should be permitted.

It should be borne in mind that riveted work had been standardized as a result of practical experience built up over a century, and that the standardization of riveted details, rivet pitches, clearances, and tolerances was the "A.B.C." of the detailing draughtsman and formed the basis on which an up-to-date shop was planned and organized. The introduction of welding was like introducing a trolley-bus service into a tramway system, the traffic control of which was modified by the absence of tramlines, necessitating the training of staff in a new system of control. That was why, in the modern days of research, welding had been made so difficult. The riveted details had sprung up from empirical practice, and they had withstood the stresses and strains of loading. People had never investigated the stress-distribution round a riveted joint to the same extent as they had investigated the stress-distribution round a welded joint, and the welded frame was complicated by that theoretical aspect.

Until a new code of design and detailing procedure was universally agreed upon, the process could not compete economically, and it was for that reason that fabricators and regulating authorities were loth to adopt the process. He had hoped that the Author would indicate some lines on which research could be conducted towards the building up of some empirical standards of cleat connexions and other details which could be standardized into ordinary structural work.

There could be no doubt that where structural work was rationally designed and the regulating and inspection authorities used up-to-date specifications, welding offered a speedy and economical alternative, and that was proved by the construction of the large number of Everall and Bailey bridge components which could not have been produced by the older technique.

He could not agree that buildings could be economically erected by in-situ fabrication. The question of in-situ fabrication and welding required considerable qualification. Whilst that method might be satisfactory for certain classes of work, it would not be satisfactory in any large building. Mr. Braithwaite had tried the system on a portion of an all-welded building some years ago, and had found that the lack of holes and correct dimensional lengths made the parts difficult to handle. It was difficult to locate a job in the air without any means of getting hold of it other than some form of clamp which slipped about. When the engineer came to line up the stanchions the wind was always blowing very hard; it was very difficult to hold the tape tight to get the correct dimensions, and it was difficult to line up the building. He had found as a general rule, that irrespective of the loads to be carried, at least two temporary bolt-holes were required at each end of a unit to enable it to be landed safely and located accurately to adjacent steelwork.

Pre-fixed clamps and glanding attachments devised to overcome such difficulites were costly to make and required skilled supervision, which often made the work more costly to erect, whilst they did not, as a rule, result in the accuracy and standard of work undertaken by reputable firms.

He had seen under construction the building in Brussels which the Author had illustrated by a lantern slide. He had not been able to go over it with a gauge and a plumb, but it had appeared to him that not so much concern was paid to dimensional accuracy as would be shown by British engineers. With regard to the standards of workmanship permitted, when he had arrived on the site he had found men engaged in welding up one of the flange beams which had been broken into three portions through being dropped from the slings; the edges were being bevelled and butt welded. He did not think that kind of standard would be tolerated in Great Britain.

Major R. J. Ashby observed that the details which he had obtained of a number of failures of Bailey bridge equipment and other engineering equipment in active operations indicated that, having regard to the quantity of equipment used, the percentage of failures was almost negligible. However, with practically only one exception, the failures had been through the welds. Some had obviously been due to fatigue, and one or two due to impact. Even in the latter cases the failure of the weld had not resulted in failure of the structure as a whole. No military engineering structures had failed suddenly and disastrously, with one exception, where someone had very stupidly driven on to it a vehicle which was much too heavy for the bridge in question. The vehicle had reached the middle and no farther!

For military purposes everything came out of the shop, where the vast number of similar parts made possible the use of jigs and very accurate work. Then it went into the field, and was usually put together by the use of pins, bolts, or some other mechanical fastening. Occasionally, however, it was necessary to do some fabrication on the site. In many cases the site was such that the standard equipment provided was not suitable as it stood and some form of improvision had to be undertaken. Quite a large quantity of welding at site had been done, and he understood that no failures had occurred where it had been undertaken.

Another point which was rather apt to be overlooked was that bridges built in active operations were nearly always damaged at some time in their career and had to be repaired. The fact that bridges seemed to stay in position day after day did not mean that no maintenance work had been done on them. Usually the maintenance was exceedingly heavy, but in spite of the fact that the material was usually high-tensile steel welding was done very successfully indeed. It should be realized that in the Army the skill of the welder at the bridge site was not of the highest order. Nevertheless, the results obtained were quite good. Moreover, weather conditions were not always those of sunny Italy; in North-west Europe, at all events, welding was done in the worst of weather. It had to be, and it was.

With regard to inspection, equipment could be tested very accurately when it came out of the shop, with the exception of one or two minor parts. There were always awkward components which were difficult to test. Those were the parts which gave trouble, and broke. Visual inspection alone was not good enough. It was necessary to find whether the method of X-ray inspection could be improved, so that not only would it be possible to test a shop-fabricated small component by the million, but also when, in the field, an awkward shape somewhere up in the air had to be dealt with, something more than just a visual inspection would be possible.

Mr. J. R. Pinkerton observed that, having learned that the Italians welded their members as soon as they were erected he had come to the conclusion that the explanation of the leaning tower of Pisa had now been provided!

What type of sections did the Italians use in order to get the pieces into position? The ordinary H-section did not lend itself to that kind of thing. Did they make box sections, so that the beams could be slipped in sideways? In Great Britain it was not possible to erect beams into the webs of stanchions without displacing the latter quite considerably, but that could not be done if the job had already been welded up.

In his reference to the influence of organization in the shops upon the form of technique and the way in which it could be used to improve the output per man, the Author had jumped from an output of 60–80 feet per welder per day to one of 200 feet per welder per day. The latter figure appeared to border on the astronomical. Was the day the same in each case, and was manual or automatic welding being used? Mr. Pinkerton would be very glad to receive some indication of how such an increase in output could be achieved, as it worked out to 25 feet laid down per hour; that might be all right for one hour, but in his opinion it could hardly be carried on for 8 hours.

*** **Mr. A. H. Beckett** observed that it seemed surprising that some doubt still existed in certain circles as to the efficiency and reliability of welded steel structures. Apparently certain authorities still regarded structural welding as bad practice. They were satisfied that welded connexions might be all right if they were closely watched and sufficient and elaborate control of workmanship were employed; but they always had the feeling that the work might come unstuck. It seemed fairly certain, however, that they could not be aware of the developments in technique that had taken place during the past 6 years—developments that made it possible for girl labour with only a few months' training to produce welded equipment capable of passing the highest tests both in the shop and in service.

Service requirements were rigid in the extreme. Not only was lightness in weight an obsession, but also structural failure could not be tolerated. Service requirements also called for prodigious production of interchangeable components in a ridiculously short period of time.

Practically all military structural steel equipment subjected to the most rigorous service conditions relied on welding for its connexions, and it was produced by indefatigable structural shops using a very large proportion of diluted labour.

The Author had mentioned the widely versatile work of Lt.-Col. W. T. Everall, involving 200,000 tons of military equipment designed for use by the Army in railway bridging, port construction, and amphibious assault operations. From intimate knowledge Mr. Beckett was able to state that in all cases welding was used as the method of shop fabrication of that equipment, and that not a single instance of failure under service had been recorded.

Mr. Braithwaite had stated that much of the objection to welding was based on the very complicated technical investigations and calculations that seemed to go with it, whereas the good old riveted structure was comparatively free from such troubles. Commercial design of riveted structures was simplified by codes of well accepted simple rules, but strictly speaking it should be subjected to the same exact investigation as was applied to welded structures. Mr. Beckett considered that the lack of a similar code was probably responsible for most of the objections to the use of welding for everyday structures.

He understood that much of the Author's efforts were being directed to the preparation of similar simple and generally accepted design rules for

*** This and the following contributions were submitted in writing.—Sec. I.C.E.

application to welded structures. If such rules would enable a junior engineer to produce a satisfactory competitive structural design in the same time as was now required for the equivalent riveted product, Mr. Beckett was certain that many of the objections to the use of structural welding would evaporate.

Mr. O. Bondy observed that the Author's description of recent experience with welded steel structures in Italy was of considerable interest. For the past 5 years or so very little engineering information had been available from the Continent, but technical literature recently received indicated that welding progress abroad had been considerable, particularly in some of the neutral countries, such as Switzerland and Sweden. Reports based on observations on the spot should form a background against which the tremendous achievements of war time welding in Great Britain could be seen in a new perspective.

The Author had indicated some of the advantages derived from the greater rigidity of the welded structure in comparison with the riveted and bolted structure. Whilst experimental results were still awaited, it might be useful to collect and publish information on how welded structures behaved under air attack, for example, against blast from bombs.

In judging the working efficiency of a welding shop the "operating factor" had been rightly recommended as a guide, giving the average proportion of welding time to total working time of the welders: $\alpha = \frac{T_w}{T_t}$. Similarly a "weld weight factor" could be introduced as a very useful index to the quality of the design, namely the ratio of weight of welds to total weight of steel: $\beta = \frac{W_w}{W_s}$. That ratio varied with the type of structure, but within one group of structures, say welded plate girders, or welded lattice roof trusses, the variations were very small, provided that the design was economical.

Mr. Bondy concurred with the Author's remarks on future policy with regard to welded steelwork, and he agreed that under present conditions "there is little advantage to the steel fabricator in offering a welded building framework. The weight of steel is less and . . . the total price should be less." But why should the steel fabricator determine future policy? Should not the saving in steel and in total cost form the best argument in favour of welded construction? It was the consumer who mattered. The demand should come from him, as in other fields of sound economy. A good deal more information was required for the consumer and for his architects, designers, and consultants. If they realized the very marked advantages of certain types of welded construction they would insist on having their demands satisfied.

Mr. J. S. Henzell observed that welded construction was quicker, cheaper, and better than riveted work for the long spans and light loadings of industrial buildings, workshops, hangars, and auditoria. The steel scantlings could be delivered direct from the rolling-mill to the site, the parts assembled with minimum of cutting and accurate fitting, the holing of main scantlings could usually be avoided, and the easiest of welding could be used. No riveted work could compete with welding in that field. Naturally, light welded fabrication would not appear to be competitive when done in obsolescent shops cluttered with heavy equipment so unsuited to light work that excessive fixed charges resulted. Given a fair field, welding would always oust riveting for light loads and long spans. When normal conditions returned, however, and timber and plywood became available for shuttering, welding might face competition from shell concrete roofing, especially when thermal insulation and low maintenance cost were factors.

For the heavier loads of multi-storey buildings, the position of welding was less assured. A dozen multi-storey structures had been erected in the United States, and a few in Great Britain, in which welding simply replaced riveting, the free-span beams being connected to the columns upon welded seats with " flexible " or rather plastic welded connexion-plates at the upper beam flanges. The weight of beams and columns in that design was thus the same as for riveted work, with a small saving in the details, and the plastic upper flange connexions were considered adequate as wind bracing for heights up to ten or twelve storeys, the beams being designed for full free-span positive moment and the columns for wind moment only, in the same way as for earlier American skyscrapers with plastic riveted joints. That form of welded construction had not been applied to heights in the skyscraper class, however, and was not likely to be used in the future. Nor was there any future for the barbarous proposal claiming partial relief for positive beam moment on account of an arbitrary " semi-fixity " of the flexible connexions to the columns, with or without the co-operation of concrete casing.

In a multi-storey building, in which continuity was accepted and taken advantage of, the positive moments at mid span of the beams were about 40 or 50 per cent. less than for free beams (depending on the ratio of unbalanced loads), for which a steel joist of about 25 or 30 per cent. less weight could be used. At the columns, ignoring wind, negative moments were about 30 per cent. less, for which a joist of from 10 to 20 per cent. lower weight could be used, depending in particular cases upon the stepped scale of properties of standard sections. Some of that saving in the weight of beams might be offset by the extra weight of shaft necessary to resist the additional column moments induced by continuity, but there could be no doubt that columns could safely withstand heavy moments, far in excess of those permitted by the building code, in addition to the direct load over the short zone near floor-level where those moments are of importance. In a continuous building frame, therefore, an appreciable saving in weight resulted if the beams were designed for the negative moment at support, and an even greater saving if designed for positive moment at mid-span.

A few buildings had been erected on the Continent, and a few in the United States, with straight beams site-welded to the columns, the welding being designed for full negative moment. The preparation of the parts for that construction was simple, as was the erection, but the site welding at points of maximum moment was not an agreeable feature and it was not easy to develop the full strength of a joist in welding at the face, particularly if, as seemed probable, the building code permitted an increase in flexural stress for beams of from 8 tons to 10 tons. That construction, however, showed a definite saving in weight and in cost. It was also very rigid to lateral forces, although the column connexions, limited to beam-depth (or nearly so) would be much too shallow for tall building wind moments which would necessarily, for a structure now elastic to initial lateral deflexion, require to be added to the negative gravity moments from the beams.

The full weight saving of continuity could be achieved only by proportioning the beams for moment at mid-span, with some form of local strengthening for the maximum moments at the columns, such as fully flanged flares of extra depth. (Brackets added to the straight beam flanges were not a solution.) Not a single multi-storey building of that type had been erected in Great Britain or the United States, and very few elsewhere, except in Belgium, where a few excellent examples were reported to have been tested with good results. The beams were strengthened by curved flare sections shop-welded to the columns, the site welding to the straight beams being done at points a certain distance out into the span where the most unfavourable combination of moments was much below the negative maximum at the column and might even be less than the positive maximum at mid span. That construction would be ideal for earthquake regions and for sky-towers, especially if, as research would prove, increased stresses approaching the elastic limit could be permitted at the wind-bracing connexions where local plasticity would not lead to collapse. The curved flares required labour, and increased welding, both in forming the flares and in making the extra vertical joints, but the overall saving in weight was sufficient to show large economies in countries where steel was expensive in comparison with labour. In the United States, where steel was cheap and labour expensive, riveting was not likely to lose the skyscraper field for some time to come, but in Great Britain frames of up to ten or twelve storeys could be welded at lower cost. An advantage of the continuous frame was that the depth of beams at mid-span was reduced, and that might be of importance where spans of 30 feet or more were required for department stores, warehouses, and garages. As for settlement, the alleged danger of unequal footing movements endangering the continuous beam framing above, long experience of reinforced-concrete construction had proved that to be a factor only where the foundation design was bad.

The Author's description of Italian building frames welded up piece by piece in situ was interesting, and even if the labour estimate quoted was a special rate for transients, a sort of *carnet de tourisme*, the description suggested that welded erection could be carried through by almost any kind of human, supermen and riveters being unnecessary.

Whilst welding had made colossal strides in shipbuilding, in the construction of oil and gas lines, and in industrial fabrication of all kinds, steel building construction by welding had been limited. In the United States, by far the greatest application of welding had been to bar joists. Since 1927 the industry expanded rapidly until, in 1940, no less than 50,000,000 square feet of roof and light concrete floor construction was manufactured. Still greater expansion was now under way. Welded bar joists were applicable not only to light concrete floors and roofs but also to the lighter sheeted claddings of industrial buildings, hangars, and workshops. The savings of steel, cost, and time in bar joist construction were well known to American engineers. Even greater relative savings were possible under British conditions of material and labour cost.

The Author, in reply, observed that the Paper had been intended to be, to some extent, provocative, and to invite discussion, and the discussion had been extremely interesting.

Referring to the remarks of the Chairman, welding was applied mechanically in shipbuilding to a great extent, particularly in America. Machine welding was practised in Great Britain also, but that in itself introduced its own problems. The accuracy of set-up needed to be much closer and the whole organization had to be tuned up to work with the welding-machine. In Dr. Scott-Glover's shop—illustrated by the lantern slides—there was one automatic welding-machine to probably forty or fifty hand welders. The Author believed that in the future most shops would wish to have a limited number of machine welders, but the bulk of the welding would continue to be done by hand.

The development of the use of welding should not be made to await further research on the control of welding. The necessary information for controlling welding satisfactorily was available, but some shops would not make use of it. There were shops properly laid out and organized and with competent engineers in charge who were getting the most out of their welding, but such shops were the exception rather than the rule. The question of organization and supervision was paramount in welding.

The Author agreed with Mr. Budgen that it was unfortunate that the introduction of welding into structural work had been left to the amateur efforts of the manufacturers of welding materials, instead of being taken up by consulting engineers and professional steel designers, on whom the country should have been able to rely for the development of an economical method of construction which had become standard practice in other countries. The tendency of the consulting engineer to play over-safe was not going to help in the fight for overseas markets.

The Author had not stated that "structural and building engineers" were now realizing that the present theory structures were inadequate. He had said that, "in the realm of the indeterminate structures it is now being realized that the present theory is inadequate" and that experimental evidence had "established that the actual load-carrying capacity of a column member in a building framework bears little or no relationship to the load as calculated according to the elastic theory." He had not intended to accuse the structural and building engineer of modernistic tendencies. The Author should, perhaps, have made it clear that the metallurgical problems did not arise in welding the mild steel of building construction, which was not susceptible to alteration under the welding heat and was sufficiently ductile to accommodate any shrinkage stresses set up, but rather with high-tensile steels likely to come into use in the future. The fact that the armour of all recent British tanks was welded suggested, however, that even with the intensely air-hardening steels a practical solution had been achieved.

The Author welcomed Mr. Vivian's contribution on the effect of the plastic behaviour of steel, to the possibilities of which engineers as a whole were not yet sufficiently alive.

The Author had been much interested to hear that Mr. Braithwaite had found that welding and riveting could comfortably be accommodated in the one shop; but Mr. Braithwaite had gone on to say that he had found that the cost of welded frames compared unfavourably with riveted frames. As that was usually the class of work for which welding was found especially favourable, could it be that the equipping of the shop to enable it to be used for the dual purpose was affecting the cost of the welded work?

With regard to the in-situ construction of buildings, the Author could only say that he had seen it being done and, whilst the approach was certainly unconventional, it was obviously satisfactory and undoubtedly economical. He gathered that Mr. Braithwaite had attempted to erect a building with rather long columns and wide spans without connexion material, and he could appreciate that there would be difficulty in that case which would not arise in a simple building framework. In the building he had seen under construction in Italy no connexion materials other than the welding was used and the erectors did not consider they were doing anything unusual or difficult.

In reply to Mr. Pinkerton, in the case of the buildings which the Author had seen under construction in Italy, H-sections had been used throughout. It was necessary to lean the columns out to let the beams be inserted, but, as the building was built outwards from one corner, that could be achieved. It would be an advantage in that respect to use box sections.

The increase in the speed of welding referred to was due partly to using larger electrodes, the deposition of metal from a $\frac{1}{4}$-inch dia. electrode being four times as great as that from an 8-gauge electrode, and partly by increasing the operating factor or the time the arc was actually running, by setting up the work accurately and making conditions as comfortable as possible for the welder. The figure of 200 feet of welding per day was by no means an outside figure. On work done in jigs an output of 260 feet per day of 8 hours was maintained in some shops.

The Author particularly appreciated the written contributions to the discussion from Messrs. Beckett, Bondy, and Henzell, which constituted a valuable addition to the Paper.

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