Discussion.

The President. The PRESIDENT, in moving a vote of thanks to the Author for his Paper, said it was one that appealed to him greatly, because he had suffered from some of the defects which the Author pointed out, and which precise levelling aimed at remedying. In Ireland there was not the same datum as in England in the Ordnance Survey; it was not mean tide but an extreme low water, and the standard bench mark was fixed on the lighthouse at the entrance to the port of Dublin, with which he himself had been connected for so many years. It was in a very precarious position for a standard bench mark. He was not prepared to say whether it had moved, but he thought it was generally admitted that movement had taken place. From several check levels which had been taken in Ireland, it had been discovered that the bench marks had been placed on buildings which had been modified by outside authorities; sometimes they would repair the parapet of a bridge irrespective of the bench mark fixed by the Ordnance Survey, and the result was not desirable. The present was a specially useful time for such a Paper to come forward, because Geodetic Surveying was taking a prominent part in engineering education.

The Author. The AUTHOR explained that the Paper was conceived in 1914 and had been written very largely with a view of bringing about closer touch between those engaged in carrying out the levelling of the Ordnance Survey and the engineers who used their results. Unfortunately the outbreak of war had delayed the completion of the Paper, and still further delayed its consideration by The Institution. It also had had the effect of severing his connection with the Survey, and consequently he was not in a position to speak of the work done in the last few years or of the policy now being pursued. He was sorry to say that Sir Charles Close, the Director-General of the Survey, was not able to be present, but Major Wolff, who was now in charge of the levelling, was present and would probably say something about recent work. His experience while employed upon the Survey led him to the conclusion that there were many civil engineers who did not use the Ordnance Survey levelling to the best advantage. He had found people who thought that the Government mark must not only be accurate but necessarily remain accurate, fixed, and immovable. Unfortunately, that was far from being the case. He had also met people who thought the Ordnance

Survey mark was valueless, and went to unnecessary trouble in doing the work over again. He did not say that those were typical attitudes, but he had met with them. When he first went into the question of the instruments and methods to be adopted, he was not able to find anybody in this country who had studied the question of precise levelling, nor could he find any book published in this country giving particulars, and he had to go to foreign books. Mr. Lallemand's book was a very valuable one, and he had also obtained information from the publications of the Coast and Geodetic Survey of the United States, and of the Survey of India, and also from German sources. The only periodicals he could find dealing with current progress in survey matters were a German periodical and "The Surveyor," published in Australia, the latter dealing primarily with local topics. The Ordnance Survey had published for so many years such complete maps of this country that but little survey work had been necessary beyond bringing the maps up to date and adding special information that might be wanted for particular purposes. The natural result was that there had been very little development in survey methods and in survey instruments in this country for a good many years, and he felt that there was room for the establishment of some school or institute to give comprehensive training in all types of survey work. The ordinary engineering student was only given certain portions of it. Although there was not very much work of that sort to be done in this country, there was a vast amount of work to be done throughout the Empire, and a school or institute of that kind would form a connecting link between the scattered surveyors in the different parts of the Empire. It would be a great advantage also if a periodical could be published, dealing with all the latest developments and the difficulties met with in various parts of the world, and showing how they had been surmounted. It should not be necessary to rely on a German periodical for the latest developments in survey instruments. Through the courtesy of the Director-General of the Ordnance Survey he was able to show the three patterns of instruments mentioned in the Paper: the American pattern, which was rather large and heavy; the French pattern, which was full of little adjusting-screws which always required adjusting; and thirdly, the Zeiss level, which he was sorry to say was the best level for the purpose that he knew. It was radically different in various ways from the older types of levels. He also showed two small instruments which were engineers' levels, not precise levels, one of them being a "dumpy" and the other a small level following to some extent the most useful points in the Zeiss level. Both these

The Author.

The Author. levels embodied some of the points emphasized in Appendix I of the Paper. He was sorry he was unable to show an example of the staves, because they were all in use, but there were one or two photographs of them on the table, as well as a specimen of the secondary bench mark which was used in the work.

Sir Alexander Kennedy. Sir ALEXANDER KENNEDY, Past-President, remarked that unquestionably geodetic surveying was one of the most interesting and most precise of any of the measurements which an engineer could have to make. At University College, years ago, it had been a source of pride to measure to $\frac{1}{10,000}$ inch in a length of 10 inches, which was a matter of $\frac{1}{100,000}$ of the length measured, but according to the Author's statement it appeared to be possible to measure to about $\frac{1}{40}$ foot in 25 miles, which was about 1 in $5\frac{1}{4}$ millions Engineers were not accustomed in any of their ordinary operations to measure to that degree of accuracy, and it spoke immensely for the men engaged in the work, and for the instruments they used, that such extraordinary accuracy could be reached not only in one place but all over the country. It was not necessary to say anything as to the importance to an Empire like the British Empire of having accurate measurements of the surface of its land, and The Institution had recognized this by making Geodesy one of the most important subjects in its Associate Membership Examination. If the School of Geodetics which had been alluded to could be established in connection with one of the Universities, he was sure it would be of very great service to the progress of one of the highest branches of engineering work. He was glad to think, especially from what the President had said, that there could be no doubt The Institution would do everything that it was possible for engineers to do in helping to promote such a result. He did not know how it was going to be brought about, but it had been spoken of for a good many months past, and he hoped something of the kind would ultimately develop. Certainly it was at least as important as a good many other branches of engineering work which were already being specially provided for in the Universities, and more suitable for handling by a University than most other branches. Personally he would feel that it was a matter of great advantage to have such a school formed, also in view of the help which it might give to a hoped-for liaison between Royal Engineers and those who called themselves "Civil" Engineers, because close connection between the two, he thought, was very desirable in the interests of the whole country. He had seen in the war areas a good deal of work the Royal Engineers had to do, and he had found them one and all very anxious to get into closer connection

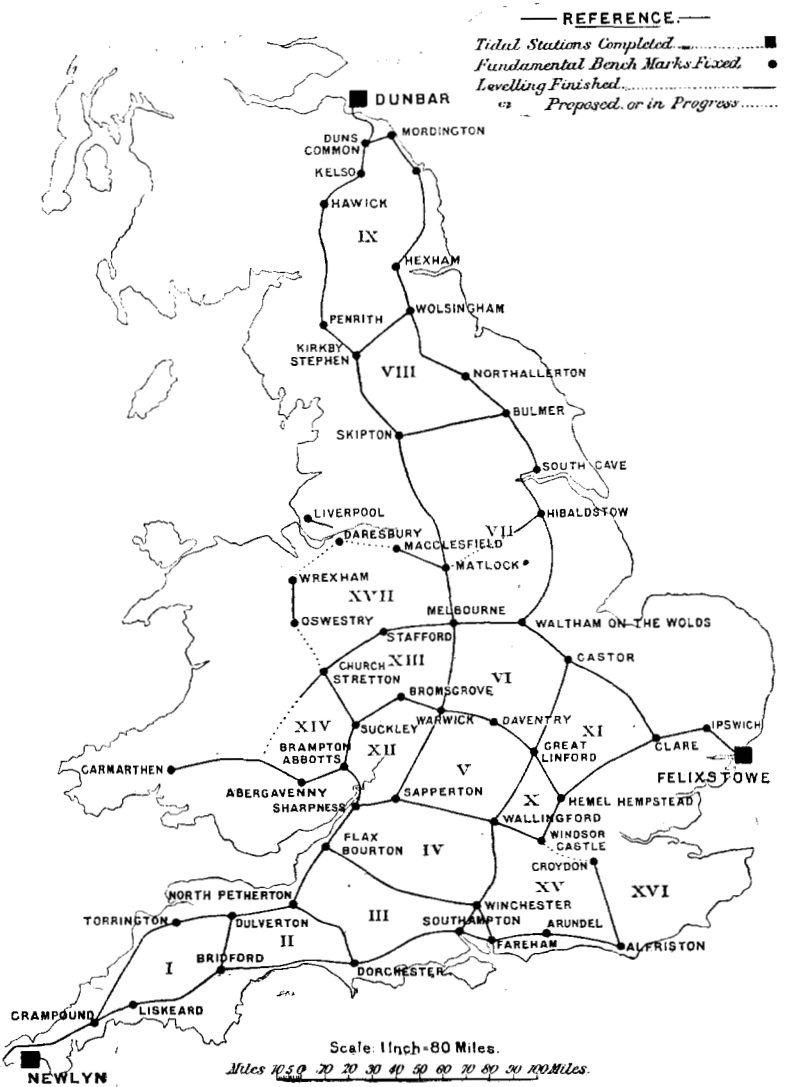
with The Institution. He trusted that in future the old distinction between Royal Engineers and Civil Engineers would be, if not abolished, at least reduced to the minimum. He was sure that would be to the advantage of both, and, what was more important still, of great advantage to the country, especially when another war came, if it ever should come. Everyone knew that there had been very close working between the Civil Engineers and the Royal Engineers for the last 5 years, and that the results of the mutual co-operation had been most advantageous. Sir Alexander Kennedy.

Major A. J. WOLFF remarked that, irrespective of any use which might be made by a future generation of the new precise levelling of Great Britain for scientific investigation, such as movements of the earth's crust and relative movements of land and sea, the precise levelling was absolutely necessary for ordinary working purposes, and the ordinary provision of heights of bench marks could not have gone on satisfactorily much longer on the old basis. The old initial levelling had been adjusted by least squares, but a least-square adjustment could not get rid of mistakes; it merely distributed them over larger areas, and masked them so that they were not apparent for local work. Each revision tended to bring the mistakes into evidence, and several such mistakes appeared to be indicated in the old levelling. As stated by the Author, the new values of bench marks would no doubt be arranged so as to disturb the old values as little as possible, but he thought the Author might be rather understating the case when he said that changes in the heights of bench marks due to errors in the original work would probably not exceed a few inches, as in certain areas it was becoming evident that the changes might well reach a foot. Those changes would probably clear up many of the large discordances in the mean-sea-level observations made in 1859 at various points along the coast. It should be remembered that those values of mean sea-level were all compared with the Liverpool value through the initial levelling, and it appeared probable that the larger discrepancies were mainly due to the fact that the accuracy of the initial levelling of 70 years ago was inadequate for comparing mean sea-levels at tidal stations several hundred miles apart. He did not wish to imply that the mean sea-level of the North Sea was the same as that of the Atlantic. That was one of the questions which would be fully investigated when the field-work of the new precise levelling was completed, which would be in a few months' time. The programme indicated by the Author had had to be considerably curtailed owing to various causes. The Royal Commission on Coast Erosion recommended in their Report that the Ordnance Survey Major Wolff.

Major Wolff. should make investigations as to the relative movement of land and sea. The new precise levellings would be of great use for the investigations. Double levelling lines were being run near the coast in suspected districts, and those lines would be tied on the fundamental bench marks. Flush brackets were being placed at intervals on those coast lines, and some flush brackets, marked in a different way from those on geodetic lines, would in future be fixed at important junctions in the secondary levelling. He agreed with the Author that in England it was better to run important lines of levels along roads rather than railways, owing to the large amount of traffic on English railways, but at the same time there was a good deal to be said for the American method of using railways. The best levelling was obtained by rapid work and by avoiding steep slopes, and a railway was ideal for that. By making use of rail motor-cars and trolleys, and taking long sights with their heavy but powerful instruments, the Americans attained the high speed of about 10 miles a day; and they kept their cost per mile low and got a fair standard of accuracy. The standard of the new precise levelling of Great Britain was considerably higher than the American, and in fact was about as high a standard as could be obtained at the present day, but the cost per mile was high, in spite of the fact that the length of a sight might now be 400 feet instead of 300 feet. It was fortunate that the Director General of the Ordnance Survey decided when he did that a new primary network of levelling was necessary, as it had enabled the bulk of the field-work to be carried out before the rise in prices. With regard to the systematic error and the fact that it was nearly always of one sign, no really satisfactory explanation of that had so far been obtained. If it were due to the movement of intermediate supports between fore and back sights, as the Author suggested, the Ordnance Survey method was better than the French method, as the error would be largely eliminated by removing the supports between the two runnings of a line. The adjustment of the relative heights of the fundamental bench marks would be made in terms of orthometric and not dynamic heights, though both orthometric and dynamic heights would probably be given in the published results. As the heights of the fundamental bench marks in England were low in comparison with those of France and America, the orthometric correction would always be small; between Newlyn and Dunbar it was not likely to exceed 0·1 foot. With regard to the instruments, the Zeiss level and Cambridge staves had proved very satisfactory. The Zeiss level would probably be used in future for all Ordnance Survey levelling, instead of the Y level. The

micrometer attachment was excellent for precise levelling, where the level was always midway between the staves. Before using it Major Wolff.

Fig. 7.



for intermediate sights, he thought the question of how the weight of the attachment at the object glass end of the telescope affected

Major Wolff. the adjustment of the level should be considered. With the attachment on, it was not possible to test the level adjustment in the usual way, as the attachment prevented the telescope from being turned upside down. In order to test whether the micrometer reading was the same as a direct reading without the attachment, he had made several tests, and had found that the fact of removing the attachment not only altered the reading on the staff, but threw the bubble out. It was possible that that point had been considered by the makers, and that the dislevelment might be counteracted by an index correction to the zero of the micrometer; but that was a matter for discussion and further investigation before he would care to use the attachment for sights of unequal length. He had brought a diagram (*Fig. 7*) showing the state of the network of the precise levelling of Great Britain at the end of 1919, as modified from the original scheme.

Mr. Grierson. Mr. T. B. GRIERSON remarked that nothing could be more important than accurate levelling. With regard to levelling along railways, as an old chief engineer of railways he could say that instructions were given that the work must be done along the rails. In Parliamentary work it was the level of the rails that was required, and it was only where the work had to be done across public roads of great importance that it was essential to level along the roads. Although it might be the case that there was not a great deal of levelling to be done in this country, there was a great deal yet to be done in the Colonies, and it was also essential that the levelling done in this country should be exceedingly accurate. He remembered a case in which a Bill for a new railway to be made to form a junction with the railway with which he was then connected was thrown out owing to an error of 14 inches in the level of the proposed point of junction. And in another case a certain local authority served the railway company with a writ to connect a railway-station lavatory with a main sewer the bottom of which was 2 feet higher than the level of the lavatory. The Paper would be of great value to young engineers. He commended it to them as a good Paper, well put together, and worthy of The Institution.

Colonel Lyons. Colonel H. G. LYONS said there were several points in the Paper which appealed to him particularly, some of special technical interest, and others of more general application. If he had understood Major Wolff correctly, the field-work was on the point of being completed, and if that was so, he hoped the Ordnance Survey would issue an early interim report, without waiting for the adjustment of the circuits. As has been said, there were numerous sources of error in high-grade levelling, any one of which might,

under diverse conditions, increase or decrease. Information as to the extent to which each of those errors had affected the work in this country would be particularly valuable to those who had high-grade levelling to do in other parts of the Empire. He did not quite grasp from the Paper what improvement in the work was due to the invar staves. They certainly saved the determination and application of a correction. Invar staves were first designed 15 years ago in Austria, and were used there, but, so far as he knew, they dropped out of use in that country. About 1906, when he was starting the precise levelling in Egypt, he discussed with the late Colonel Keeling whether invar staves should be obtained, and at that time they did not see that they were going to gain very appreciably by adopting what was then an expensive form of staff and one difficult to obtain. They were content to use Colonel Goulier's French pattern rods with certain modifications. He therefore looked forward with interest to such a report, which he hoped would be published, showing exactly how far and in what way the use of invar staves—other than for mere temperature correction—did materially increase accuracy. It was not always the same factors which gave trouble in various parts of the world. In Egypt in one case very good results were obtained in the morning, but the afternoon levelling was distinctly inferior; it was certain that the errors which appeared in the afternoon work were due to personal factors and were such as could not be eliminated by any mechanical arrangement. If he had understood Major Wolff correctly, levelling was now being carried down to the coasts. He was sorry to see from the diagram that the primary bench marks would be only inland, because they had all to be set on rock, and consequently some of the distances to the coast would be considerable. Where friable soil and alluvial deposits had to be dealt with, it was difficult to get a thoroughly reliable primary bench mark, but he conceived it to be of great importance in the neighbourhood of cities on alluvial flats and near important harbours that there should be a few bench marks of high reliability for controlling the work in the neighbourhood. That problem had arisen on the southern shores of the Baltic, where there were a large number of such special bench marks. The screwing down of iron tubes 100 or 120 millimetres in diameter to a depth of sometimes as much as 15 or 20 metres, had provided, it was said, bench marks in alluvial soil of a much higher stability than any that could be set on the abutment piers of even large bridges. The practical value of high-grade levelling, apart from controlling the secondary or tertiary circuits, might come up at any moment as

Colonel Lyons.

Colonel Lyons. soon as the permissible errors in other relations got wrong. Ten years ago the Irrigation Service in Egypt asked for a first-order levelling of the Delta, and since then they had asked the Survey Department to carry out the secondary levelling. They found they had not the time to lay out the levelling with such high accuracy as they required. With regard to the necessity for a School of Surveying at a University, he would like strongly to support that proposal, because high-class surveying was not a half-time job but a life profession. At the present day nearly every Crown Colony had registration of title for land, and there would be a demand for a considerable number of men well trained in the higher branches of surveying work. There were before the war something like three hundred posts of from £300 to £1500 a year, but he doubted whether the majority of those were filled by men who had been trained for a life profession of surveying. In Egypt, where the survey had to be started both as a cadastral survey and as a topographical survey, the only way of providing qualified men was to get men with a university training in mathematics and physics, and then to teach them their surveying in the country; and the results certainly justified the employment of men of a high grade of scientific education. With regard to the need for a periodical devoted to the subject, he made inquiries as to the possibility of that 6 or 7 years ago, but it was a little difficult to see how it was going to be done until a school had been formed and a profession built up which would want such a periodical.

Professor Dixon. Professor STEPHEN M. DIXON remarked that the Paper was on a fascinating subject, and was also intensely practical. Nearly everyone had begun his engineering as a surveyor, and probably one of the first jobs a young engineer had to do when, say, a large railway-tunnel was being constructed, was to check bench marks. The very fact that the engineer had to check bench marks showed that something was wanting, and when a young engineer found a discrepancy he naturally hesitated to think that an error had been made by the Ordnance Survey Department and put it down to his own want of accuracy, or to bad instruments, or the chain-man; and thus a great deal of time was wasted. He thought it would be possible with secondary levelling to make the bench marks much more useful. In searching one never knew where to find a bench mark; sometimes it was underneath a bridge and sometimes on a gate-post. There was a bench mark in Kensington Gardens on a flagstone which covered a well. That was the kind of thing which he supposed was going to be corrected. The bench mark should always be on the same kind of thing. If the secondary bench

Professor Dixon.

marks were figured like the primary bench marks, people could easily find them, and should also find the reduced level marked on them. On a large post there was no trouble in screwing in a plate. If bench marks were to be of use they should give the reduced levels, as in most of the secondary levelling in France and Germany. There was another difficulty, he thought, in regard to the secondary bench marks shown, the frame put round the plate in order to protect the point prevented a man from holding a level staff on it unless he had a special support, and as he probably only wanted to use that support once in 6 weeks, it might in some cases be left behind. The point of reference should project a little from the face of the bench mark, so that it could carry the staff. He agreed with all the remarks made about the Zeiss level; it was incomparably the best level for working quickly, and saved a great deal of time. He would like to know whether any difficulty had been found in levelling during frost. In America, if levelling had to be carried out when the ground was frozen, the difficulty was overcome by digging away the frozen surface. The question of the variation of the points on which the staff was held would be greatly complicated if the work had been carried out on frozen ground. He would like some information with reference to the speed of levelling, because that was closely connected with the cost and with the accuracy. The accuracy of the new surveys in the United States was very high, and nothing better was wanted. He believed that in the line from San Francisco to New York the error was just a little over $\frac{1}{2}$ foot when they joined up. Standards had been set up by the International Geodetic Association, and for high precision work it was plus or minus 1 millimetre in 1 kilometre, and for tolerable work plus or minus 3 millimetres. Work of that kind was now always obtained, he believed, by the United States Coast and Geodetic Survey. Another difficulty that occurred when one tried to work rapidly was the limited length of sight. If limited to 150 feet, it was necessary to have twice the number of sights to a mile compared with the average number allowed in the United States Surveys. The cost in foreign countries ranged from £3 10*s*. to £1 a mile. He wondered how the cost of the English survey would compare with that. The lowest cost he could find was given by the Geological Survey in the United States, but in the case recorded the survey was not carried out with the same accuracy as some of the others. There was a special course in geodetic surveying at the Imperial College of Science and Technology, South Kensington. The course was established before the war, and it was only owing to the war that it had not been appreciated. There was plenty

Professor Dixon. of scope for men trained in that work. Many of the Colonies, however, preferred to train their own people. In Canada a man educated at an English college and without colonial experience would not have the same chance of getting such work as one who had been trained at a good college in Canada. Climatic and other conditions of life made survey work in Canada difficult for a man trained only in Great Britain.

Mr. Warren. Mr. P. D. WARREN observed that he had the pleasure of Sir Charles Close's acquaintance when he was at the War Office, and frequently used to consult with him on subjects in connection with levelling and surveying and the lithographic reproduction of maps, and he had taken a lifelong interest in those subjects. Mr. Warren started what was called initial levelling across the Island of Ceylon, and he believed that was now very nearly completed. He could quite see that the work that was being done by the English Ordnance Survey would result in a very high degree of accuracy —higher than the original survey was able to obtain. He hoped that in Ceylon they would have the advantage of using modern instruments, and, if so, it would be interesting to see whether the old work that he had the honour of starting would compare favourably with the new. The work in Ceylon was done with non-commissioned officers of the Royal Engineers, men trained partly at Southampton. His civil assistants were selected by him and sent to Southampton for training, and after a year there they came out to take charge of parties in the fields. Two of the Royal Engineers' staff were specialists, who received their final training in Colombo. Those levels had been carried practically all over the island, and he believed it was possible now to obtain accurate heights for any part of the island where engineering was required. Mr. Warren expressed his great appreciation of the contents of the Paper and the interesting remarks thereon by the previous speakers. It was, however, nearly 10 years since he gave up work, and his information and ideas might be rather out of date.

The Author. The AUTHOR, in replying, expressed his thanks for the way the Paper had been received. He would feel very gratified if it assisted in any way in the establishment of a School of Surveying, or of a Geodetic Institute, or if it in any way promoted closer touch between the Civil and Royal Engineers. He very much appreciated Sir Alexander Kennedy's remarks on those points. He had long felt that closer touch between these two branches of engineers would be to the advantage of both, and was very glad to see signs that the authorities both of the War Office and The Institution were taking this view. The adoption of the low-water datum in Ireland was a

legacy from the charts. A sailor naturally wanted to know the least depth of water he might expect, consequently soundings below low water best met his requirements. Early levelling work by Mr. J. A. Lloyd,[1] F.R.S., and Mr. T. C. Bunt,[2] showed that much greater accuracy was obtainable by spirit levelling than by "trigonometrical" determination of heights. This led to a network of lines being levelled in Ireland in 1839–1843, and at the same time an investigation was carried out in conjunction with Sir G. B. Airy, F.R.S., the Astronomer Royal, into the levels of high and low water around the coasts. The results showed conclusively that the level of low water varied considerably at different places, and that the height of mean sea-level was approximately constant, and therefore a far more suitable datum. There was much discussion as to whether the datum for the Irish map should be changed from low water to mean sea-level, but as many maps had been published, it was decided to adhere to the old datum. The English levelling was only then starting in the Liverpool district, and the assumed height of mean sea-level at Liverpool was taken as the datum. Sir Alexander Kennedy's method of stating the accuracy obtained, although flattering, was somewhat misleading. Although it was possible to measure the difference in height between two points 25 miles apart with an error of the order of $\frac{1}{40}$ foot, it was not possible to measure the distance between such points with anything like the same accuracy; an error as small as an inch or two might be obtained if the work were done regardless of expense, but an error of a foot would be much nearer that actually obtained in ordinary first-class work. He entirely agreed with Major Wolff that the new levelling was necessary for the ordinary provision of heights of bench marks. In all measuring work errors were inevitable, and no one who had not had to try to reduce, into a concordant whole, the discordant results of a network of ordinary levels, could realize fully the necessity for the provision of a certain number of heights that could be accepted as accurate, or as nearly so as it was possible to get them. The new levelling should reduce some of the discordances in the old mean sea-level determinations around the coasts, but much, possibly the bulk, of the discrepancies were due to the extremely short duration of the old mean sea-level observations at any one place. Mean sea-level observations extending over a month (the old observations mostly extended only over a fortnight), might easily show discrepancies of more than a foot between summer and winter at the same place, due

The Author.

[1] Phil. Trans., 1831, Part I.

[2] British Association Report, 1838, and Phil. Trans., 1839, p. 151.

The Author. to meteorological conditions, and this quite apart from the tides having periods of 5, 40, and possibly 240 years, which existed, though it was not possible at present to give their amplitude. He was so fully impressed with the advantages of the American practice of levelling along railways, that he carried out much of the earlier work in this manner, but was forced to the conclusion that the traffic in this country was far too dense for this to be possible. Undoubtedly, good levelling must be quick levelling, and the American method of using rail motor-cars and trollies for transport was excellent where it was possible, but it was not possible in this country. Long sights had obvious advantages in regard to both speed and accuracy, but they could only be used in flat country, and then only when the conditions were such that refraction errors did not become excessive; which was seldom the case in this country. Unless the man in charge of the party was capable of judging which conditions were safe and which were dangerous, it was necessary to limit strictly the length of sight allowed. The best and quickest work could only be done if every facility was granted to the parties to get to their work with the minimum of time and fatigue; this meant considerable extra expense per party per day, but whether it would increase the cost per mile levelled was another matter. Placing the micrometer attachment on the telescope could hardly fail to alter the adjustment of the instrument. The instrument could, however, be fairly adjusted by putting up a staff and determining the correct reading in the usual manner without the attachment, then placing the micrometer in position and tilting the telescope till the correct reading was obtained. If the bubble was then made to read correct the instrument should be in adjustment with the micrometer fitted. At the same time, the full advantage of the micrometer attachment would be obtained only in precise work with the instrument equidistant from the two staves. Work entailing many intermediate sights would never be of the highest accuracy, neither was such accuracy required for the intermediate sights themselves. For such work the attachment was hardly to be recommended.

As to invar staves three factors came in: (1) Evenness of graduation, (2) correct total length, (3) constancy of total length with varying temperature and humidity. In flat country (2) and (3) were of less importance than (1), while in mountainous country the position was reversed. The error due to (1) increased as the square root of the number of settings-up, and was independent of the difference in height of the terminal points. The error due to (2) increased directly as the difference in height of the terminal points.

The Author.

As regarded (2) and (3) Colonel Goulier's staves (with iron and brass rods up the centre, forming a metallic thermometer) were satisfactory, and replacing the iron and brass rods by one invar rod, as in the case of the later French staves, merely simplified the construction of the staves and the readings necessary in the field for determining their change in length from day to day. The French staves had the divisions painted on the wood face. It seemed to the Author that it would be more accurate if they were cut on metal by a dividing engine. If this were done invar was practically necessary, as the temperature of an exposed metal slip was rather indeterminate. There had been considerable difficulties in cutting the divisions on the invar, but these had been eventually overcome. While the temperature coefficient of invar was sufficiently small to be negligible in this country, it was for consideration whether it would be so for a country with extremes of temperature. The question of placing special stable bench marks in alluvial districts was hardly considered by the Ordnance Survey while the Author was there. It appeared to him that the main framework should come first, and that it should have its marks founded on rock. It was undoubtedly desirable to have marks as suggested by Colonel Lyons, but it was largely a matter of cost. The whole question of bench marks was rather a difficult one. The first secondary marks put up on the new levelling were of French pattern, with a projection to support the staff. It was found that these were liable to damage, small boys climbed on them, and their elders knocked them about or removed them for the sake of the metal. It was, therefore, considered that a type of mark that could not easily be damaged or moved without the fact being obvious, would be better, and the Author designed the mark shown in *Fig. 3* (p. 120). There should be no special difficulty in marking these with the heights when they had been finally determined, but it was doubtful whether it would be worth the expense involved, as the heights would be shown on the 6-inch maps, even if they were not published separately. A multiplication of marks similar to the fundamental marks, as advocated by Professor Dixon, and of special marks in alluvial districts, as advocated by Colonel Lyons, was doubtless desirable, but it seemed improbable that funds would be available for the purpose. If it were the general desire of engineers to have more such marks it might be possible to provide them gradually, but this would involve either greatly increased expense, or a considerable curtailment of the amount of tertiary levelling carried out. The Director-General of the Ordnance Survey had to decide how the funds at his disposal could best be allocated to meet the demands of the various users of

The Author. the maps. The present demand for economy in all Government departments, combined with the all-round increased cost of material and labour, had not made this task easier. As regards levelling in frost, the danger arose when there was a thin layer of frozen, but thawing, ground; both instrument and staves were, in such conditions, liable to erratic movements. The same applied to roads thickly tarred, or with a bituminous surface which became soft under a hot sun. He had traced serious errors in the tertiary levelling to the latter cause. Professor Dixon's remark as to the Colonies preferring to train their own surveyors was true of the Dominions, but did not apply with so much force to the Crown Colonies. The Dominion Colleges had in many cases far more comprehensive courses in surveying than any of the colleges at home, and a knowledge of the local land laws was essential to a land surveyor practising in the Colonies. The Crown Colonies had not the same educational facilities available as the Dominions, and their surveyors had to learn their work as best they could.

Correspondence.

Mr. Dyce Cay. Mr. W. DYCE CAY regretted that in recent Ordnance Survey maps the heights of bench marks were not given to two places of decimals, as for many works tenths of a foot were not sufficiently accurate. Also he regretted that many more levels were not marked on the plans, so as to make them more useful for projecting and carrying out works. To achieve this by precise levelling might be too expensive, but much might be done with sufficient accuracy by the systems of work in ordinary use by engineers and surveyors. By such systems a level could be run by an expert leveller and two staff carriers for, say, 9 miles per day over rough country, leaving bench marks on the way. With reference to the sea-level, he would suggest that records of the height of every tide had been kept for years at dock gates and harbour entrances—at Aberdeen Harbour, for example, for upwards of half a century—and by taking averages from them, e.g., for H.W.O.S.T., the three highest consecutive tides in each full and change of the moon, and dealing similarly with the intermediate tides for the neaps, and also using the low-water records, where available, the mean sea-level could be economically and quickly determined. Due account must, of course,