Discussion.

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

Mr. C. S. MEIK remarked that, of the three Papers, Mr. Ball's Mr. Meik. was perhaps the most important, though unfortunately, as the Author did not give much information in the text, criticism was difficult. The only point in it to which he wished to refer was that of the test loads and how they were put on. No mention was made of the time that was allowed to elapse between the completion of the structure and the application of the test load, a point which was of the greatest importance in connection with reinforced-concrete structures. Such structures could not be tested in a similar manner to steel structures. A steel bridge when finished was ready for use; it would never get any better or stronger. But that was not the case with a reinforced-concrete structure, because, as was well known, the concrete improved with age. It was very much stronger 6 months after it was completed than it was 1 month after completion. If the test loads were put on 1 month, or even 3 months, after the completion of the structure, they were, in his opinion, very likely to strain it, and he had grave doubts whether it was advisable to put test loads at all on such structures. The test load might very easily strain the steel inside without producing more than minute cracks in the concrete, so that an injured structure might remain when the test load was removed. He was inclined to think, therefore, that unless a minimum interval of time was imposed—say 6 months after the structure was completed—before the tests were made, the structure had better not be tested beyond the actual working-load, for fear that internal strains might be set up.

With regard to Mr. Ellis's interesting Paper, he desired to call attention to the fact that the designers of the steel wharves at Kowloon had not chosen a very favourable steel section for their piles, namely, joists 12 inches by 12 inches, with very broad flanges. A large number of the steel joists which had been used in the East had, until quite recently, come from the Continent—though it was to be hoped that might not be the case in future—and he was afraid that the steel in them was not of first-class quality, nor was the rolling good; in any case, the surfaces of those joists were

Mr. Meik not suited to withstand corrosion. They had not a smooth surface—like the cast iron produced in the old days, with a really good skin on it—which afforded much better resistance to corrosion. While he was in Rangoon in 1913 he took the opportunity of examining some quays constructed of solid iron bars, 6 inches in diameter, on screw-piles. They were not protected in any way, and although they had been in the water for about 6 years, there was no sign of corrosion whatever on them. The resident engineer informed him that the only place where he had been able to detect signs of corrosion was where the steamers discharged their bilge-waters. He attributed that good result to the fact that the skin of the piles was smooth and much better than the skin usually found on steel, and also to the fact that they were iron piles. Of the river-water at Rangoon about 90 per cent. would be salt water and the remainder fresh. At another place on the Indian Ocean, not far from Singapore, he examined some hollow circular iron piles 10 inches in diameter which had been in the water for about 5 years, and could not discover any signs of corrosion. He had recently seen the manager of this undertaking, who informed him that, up to the time he left, no corrosion was visible. In both the cases referred to the ironwork above water-level was kept well coated with paint. With regard to the concrete coating that had been put on some of the work at Kowloon, he thought those members of The Institution who had experience of reinforced concrete would agree that that was one of the worst forms in which to combine steel with concrete. Encasing steel joists in concrete did not give the concrete a fair chance, because so many defined lines of cleavage existed. Reference to *Figs. 4* of Mr. Ellis's Paper showed that there could be very little bond in the concrete. It was quite different from reinforced concrete, in which the steelwork formed a very small percentage of the structure and was embedded in the concrete. He looked upon the work described by Mr. Ellis as steel protected by a concrete screen, and he thought it was not to be wondered at that the moisture got to the steelwork through the coating of concrete. Further, in his opinion 6-to-1 concrete, which had been used at Kowloon and was used in many cases for reinforced concrete under water, was too weak. Although good concrete nearly impervious to water could be obtained with a mixture of 6-to-1, it was impossible to get it in work carried out in the way in which reinforced concrete was made at the present time. Stronger concrete must be used, and it had been his practice never to use a weaker mixture than 4-to-1 for work in a tideway or situated where it was likely to be subjected to moisture in any degree. As both Mr. Ellis and Mr. Hammersley-Heenan pointed out, the first

place to be attacked in concrete used in a harbour or river was just Mr. Meik. below high-water level. At a level near low water the fact of the concrete being always in a moist condition protected the steel. The chief difficulty occurred where the concrete was alternately wet and dry, the alternate wetting and drying apparently opening the pores of the concrete and allowing the moisture to get into the steel, with the result that corrosion was set up; and once corrosion was set up, the concrete in square piles began to crack, so that unless remedial steps were taken immediately, the steel was ultimately destroyed. The difference in cost between using a 4-to-1 and a 6-to-1 mixture was very small. A reinforced-concrete pile which contained, say, 15 or 16 lbs. of steel per cubic foot as reinforcement, would probably cost in England 5s. per cubic foot, and the cost of the cement per cubic foot for a 4-to-1 mixture would be $4\frac{1}{2}d.$ If a 6-to-1 mixture were used, the cost of the cement would be reduced by $1\frac{1}{2}d.$, which represented in this country the cost of 1 lb. of steel. He thought it would be much better to have 1 lb. less of steel and use 4-to-1 concrete for its preservation, which was everything in a reinforced-concrete structure. In reinforced-concrete work cheap concrete meant trouble in the future.

So far as Mr. Hammersley-Heenan's Paper was concerned, he had had no experience of using salt in concrete other than using sea-water. He was not one of those who objected to sea-water being used in the manufacture of concrete, provided the water was clean and fresh, nor would he object to its being used in the manufacture of concrete in combination with iron or steel; but he certainly would not like to use even 2 per cent. of salt in making concrete to be used in combination with these materials. Quite enough trouble was experienced already in protecting steel from fresh water, and he thought it was the height of folly to put salt into concrete, because it simply meant that corrosion would occur much more quickly, and the structure would be seriously injured.

Mr. G. W. HUMPHREYS remarked that the effect of frost upon concrete was not of great importance in England, as the duration and severity of cold weather there was almost negligible so far as that matter was concerned. Some years ago he visited the Croton dam near New York one day early in January, when it was being built, the thermometer showing 10° to 15° of frost. Work on the dam, which contained about $\frac{3}{4}$ million cubic yards of masonry, was proceeding in a very expeditious and satisfactory manner, in spite of the frost. He remembered saying to the resident engineer that in England engineers would not think of proceeding with work when 10° of frost were recorded, to which the engineer replied that

Mr. Humphreys.

Mr. Humphreys. if they ceased work under such conditions in America they would never get anything done. The engineer rather ridiculed such fears. Although Mr. Humphreys did not remember fully the arrangements that were made, he noticed that most of those mentioned by Mr. Hammersley-Heenan for warming the materials, including the mortar, were adopted.

He was not quite clear from the earlier sentences of Mr. Ellis's Paper why the use of screw-piles was inapplicable; it appeared to him that the use of cast-iron screw-piles would have overcome all the difficulties that had been encountered. Many engineers were very familiar with the corrosion of steel. Since the advent of steel for ships the corrosion of the hulls of vessels had been a source of great annoyance and perplexity to those who were concerned with them. He quite agreed with Mr. Meik's remark that the remedy that had been adopted at Kowloon, of casing the steel in concrete, was one of the worst that could have been applied. It was difficult to see what considerations had led the designers of the pier to adopt the form of structure that had been built. He imagined that, as the piles were 12-inch by 12-inch 80-lb. joists in single unspliced lengths up to 78 feet, and they had been brought to the place, some question connected with difficulty of construction must have weighed with the designers. Hong-Kong was a difficult place in which to get things done, but it appeared to him, looking at the section, that a cast-iron cylinder, or other similar form of construction, should have been adopted for that wharf. Obviously the corrosion was greater in a tropical climate than in England, but he had recently had occasion to look at some travelling stages made of comparatively light 4-inch by 4-inch, or 3-inch by 3-inch, angle-bars of $\frac{1}{2}$ -inch metal, which had been in use in the sea at Whitby for the last 5 or 6 years, and had found that they were practically eaten away. The corrosion was not only below water-level but also above it, owing to the spray, the sea in the neighbourhood being very rough. On the other hand, he remembered being connected, in 1887 or 1888, with the construction of a pier on the Clyde, near Gourrock, in which the piles forming the legs of the pier were 4-inch iron bars let into the surface of the rock, cast-iron sleeves, forming the structure of the pier and carrying the bracing rods, being put over them. When he saw the pier 2 years ago, after it had been in service for 25 years, it was apparently in as good a condition as when it was built.

Passing to Mr. Ball's Paper, he desired to ask whether the Author had built any reinforced-concrete bridges underneath running-roads on the Great Central Railway. Referring to the

actual cost of the works, he noticed that the first work was carried out for about 29 per cent. less than the estimated cost of a steel structure; the second one for 16 per cent. less; the third for 20 per cent. less; and in the case of the pits for the engine-shed, which was a peculiarly favourable type of structure for the use of reinforced concrete, for 42 per cent. less. The people that engineers were responsible for advising were very anxious to take advantage of such reductions of cost, and it was the main duty of the engineer to make up his mind when he would or would not use reinforced concrete for such structures. In one or two bridges which had lately been under his notice in London the costs had come out almost exactly the same as those given by Mr. Ball, the estimated saving being 29 per cent. in one case and 16 per cent. in another. Reinforced-concrete work in a London thoroughfare was a very difficult thing to handle, and the consideration Mr. Meik had urged, as to the time that should elapse before reinforced structures were tested, militated against their use in such a position.

Mr. MAURICE F. WILSON thought that in the large main-line bridge described by Mr. Ball the working-stresses used (700 lbs. per square inch for the concrete and 16,000 lbs. per square inch for the steel) were rather higher than usual. In the other bridges described in the Paper working-stresses of only 550 lbs. per square inch for the concrete and 15,000 lbs. per square inch for the steel were used. Why had those different stresses been fixed for the two classes of bridge?

With regard to Mr. Ellis's Paper, it would be very alarming to think that all steel structures might be pitted and eaten away in the manner of the corrosion that had occurred at Kowloon. He thought there must be some reason, other than the fact of the structure being in a tropical climate, for the trouble that had ensued. Either the steel was not quite of the quality it ought to be, or the shell-fish might have had some effect in causing the corrosion, as suggested in the Paper. He did not know whether Mr. Ellis had ever examined the wrought-iron jetty just opposite Kowloon which was designed by his (Mr. Wilson's) firm. Five or 6 years ago he was on the jetty and examined it in a general way, though not in the detailed manner adopted by Mr. Ellis, and then it was apparently in perfectly good condition; he could not see any signs of deterioration or rusting. His firm had been concerned in the construction of many other jetties, in South Africa, West Africa, and in the East. All of them had been constructed of wrought iron, braced, and they were in very good condition. His partner, Mr. A. T. Coode, M. Inst. C.E., examined in 1913 such a jetty at Port

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Mr. Wilson.

Mr. Wilson. Elizabeth, which had been built 40 years, and found it in perfectly good condition. He examined one himself about 5 years ago at Calabar, in West Africa, and another at Secondee which had been built for many years, and in both cases no signs of corrosion were visible. The structures to which he had referred were all of wrought iron, but he could not think that the difference between wrought iron and mild steel such as was now used could be the sole cause of the soundness of those works and the corrosion at Kowloon. Nowadays steel was used almost entirely in shipbuilding, and he believed Lloyd's accepted either iron or steel for such important forgings as stern-posts. He did not think such a difference existed between wrought iron and steel, when in salt water, as to fully explain what was described in the Paper. He agreed with Mr. Meik that the design of the structure at Kowloon was not at all good, but he presumed it was arranged before Mr. Ellis went out there, and that, the materials being already on order, he had to make the best of them, and therefore encased the structure with concrete in order to preserve it to some extent. That seemed to have been effective so far as the steel below low water was concerned, but above low water the corrosion seemed to have gone on much as before. It was a curious fact that in nearly all the reinforced-concrete work where corrosion had been found in connection with sea-water, it took place chiefly between a little below high water and the level of the deck. The prevalent idea was that where concrete was continually wet some sort of deposit formed and prevented the percolation of water through it. Above that level, if the concrete was not perfectly sound and solid, moisture got through small cracks or irregularities in the concrete and caused corrosion of the steel. He agreed with Mr. Meik that with 6-to-1 concrete, as used at Kowloon, it would be almost impossible to make a sound concrete which would prevent percolation of water. The large plain face which occurred in a design where rolled joists were used was a bad arrangement from the point of view of adherence of the concrete, and was likely to result in cracks and splitting. Again, any springing in the joists would be much more likely to cause dislocation of the concrete under those circumstances than springing which occurred in properly-designed reinforced concrete, as opposed to joists simply buried in concrete. After the occurrence at Kowloon to which Mr. Ellis referred, a reinforced-concrete lighthouse in the Malacca Straits was examined, and a considerable amount of rusting was found to be going on at about the same level as Mr. Ellis indicated. But in one or two cases, although part

of a member had rusted badly, the rest of it was perfectly sound, the latter part being where the concrete was so good and solid that no percolation of water had taken place. That seemed to show that corrosion was due to percolation of water through the concrete, which would not take place if the concrete were really solid. Some means were required to ensure making the concrete perfectly solid, and if such a process could be discovered, it would be of the greatest advantage in connection with all reinforced-concrete work.

Mr. Hammersley-Heenan's Paper was very interesting as showing what was done in Canada, where concreting had to be carried on during very frosty weather; but such work had not to be done in this country to the same extent. He presumed the Paper referred almost entirely to light concrete work for buildings and similar structures, the thin walls of which could be kept warm, and not to solid work such as the Croton dam, which could not be kept warm in the same way. With regard to what the Author said as to the frost not actually injuring the cement, but merely stopping the setting for a time, Mr. Wilson had a similar experience at Southampton during the very cold winter of 1894-95. The concrete walls of the dock were being pushed on as fast as possible, in spite of the severe weather, in order to allow the American liners to use the quays. Steaming was tried, but eventually it had to be discontinued, and as soon as the thaw came a great deal of the concrete which had been put in went absolutely soft again, to a depth of 6 to 9 inches below the surface. It was intended to cut it all out, but later on it began to set again—he presumed in its natural way. It set perfectly hard, and was afterwards found to be quite sound.

Mr. R. ELLIOTT-COOPER, Past-President, remarked that, having seen the use that Mr. Ball had made of reinforced concrete in the work he had carried out at Immingham, he was glad that his Paper gave definite information both as to the cost and as to the loads which the structures would carry. As a rule Papers upon the subject of reinforced concrete went deeply into the scientific and technical side of the matter, but gave very little information as to the actual results, so far as the carrying-capacity was concerned. It was very satisfactory to learn that the bridges described in Mr. Ball's Paper, two of which were of considerable magnitude, had fulfilled not only all the requirements of the Board of Trade, but also the much more onerous requirements of the road-authorities, besides effecting substantial savings. When actual costs of construction were compared with estimates, some doubt often arose

Mr. Elliott-Cooper.

Mr. Elliott-
Cooper

whether the engineer, quite unintentionally, had not looked upon the dark side so far as the steel structure was concerned, and had perhaps designed it upon a scale rather larger than he would have done if he had been going to build it. He did not say that was so in the present case, but he knew that when an engineer had made up his mind that a certain form of construction was the best, and he wished to compare it with another form, he did not minimize the estimate of cost of the latter. Mr. Humphreys, however, had removed any suggestion as to that having been so in the instances referred to by Mr. Ball, by recording practically the same experience. When the subject of reinforced concrete was discussed 2 or 3 years ago, he remarked that he had found no cause to change his view that the success of a reinforced-concrete structure depended very largely—in fact almost wholly—upon the care with which it had been constructed. As a rule, the members heard only of the successes in reinforced concrete, as in other engineering work, very little being heard of the failures and their causes. But that there were failures in reinforced-concrete structures was unquestionable, and it had been generally found, he believed, that they were caused by insufficient care in the preparation and putting together of the two materials which formed structures of that kind. The question therefore naturally arose: if reinforced structures became more usual, would there be any relaxation in the extreme care which had to a very large extent made the use of the material so popular? As people became accustomed to a particular type of work they were apt to take a great deal for granted, whereas when it was altogether new the inspectors as well as the engineer took very good care that, so far as human eyes could see, there should be no flaw in the structure. Bearing in mind what reinforced-concrete structures really were, particularly when their walls were very thin, it was clear that disastrous results might occur if there were any diminution in the care with which they were built. When there were only perhaps $2\frac{1}{2}$ inches or 3 inches between the steel portion of the structure and the outer surface it was obvious that the greatest care must be taken.

He was sure all the members would agree with Mr. Meik's remark that the wharf at Kowloon could not be called a reinforced-concrete structure; it was a steel structure encased with concrete for protective purposes. Mr. Ellis's Paper was useful as indicating how a structure which showed signs of deterioration could be protected, but there was one remarkable thing in connection with steel structures abroad, particularly in some of the Colonies, that was very difficult to account for. Some years ago he visited Jamaica for the

purpose of reporting on a certain work there. He found that in the north of the island the corrosion was enormous—he could use no other word. Rails laid along the northern coast corroded to a degree which made them unsafe in 2, 3, or 4 years, whereas rails laid on the south side of the island remained for many years without any appreciable signs of corrosion. There were, as far as he could see, only two explanations of that, apart from the fact that in the former case the rails were much nearer to the sea; either the moisture in the northern part of the island had for some reason a very exceptional effect upon the steel, and the moisture in the southern part had not that effect, or else the cause was some difference in the chemical composition of the steel. In the cases mentioned in the Paper, corrosion appeared to be very irregular, some parts showing signs of corrosion very quickly and other parts showing no signs at all; therefore it must be assumed that the cause lay in the steel itself. No one could say what the future of reinforced concrete would be. Everyone hoped that corrosion would not occur in the interior of such structures to an extent that would in any way affect their strength, but no one could feel sure. That was particularly the case in structures under water; it was impossible to say whether the concrete surrounding the reinforcement would or would not be affected in years to come. In some cases where examination had been made the reinforced concrete had been found to be badly affected, while in others it had been found quite satisfactory; and there must be some reason for the difference. Considering the economy that appeared to result from the use of the material and its usefulness in many ways, it was to be hoped that it would be as successful in the future as it was known to be at present.

Mr. Elliott-Cooper.

Sir WILLIAM MATTHEWS, K.C.M.G., Past-President, wished to refer to two or three points in connection with the Papers by Mr. Ball and Mr. Ellis. He did not propose to discuss Mr. Hammersley-Heenan's Paper dealing with the carrying out of work under extreme conditions of cold, of which he had little experience. Mr. Ball referred to the saving effected by the use of reinforced concrete, amounting to 30 per cent. in one case, 16 per cent. in another, and 20 per cent. in a third, on the estimated cost of corresponding steelwork bridges, and showed that the results of the adoption of reinforced concrete had been thoroughly satisfactory. It should not by any means be assumed, however, that similar savings—or even any saving—could be effected in all other cases, as compared with the cost of carrying out works in steel. He had had opportunities, where his firm had been consulted as to heavy wharves for the accommodation of

Sir William Matthews.

Sir William
Matthews.

ocean-going steamers, to prepare comparative estimates of the cost of carrying out such work by the two methods, and had found that in some cases reinforced concrete would effect practically no saving, while in others it would cost more than steelwork. The work referred to by Mr. Ellis could scarcely be regarded as of reinforced concrete. The steel was in the form of joists, and the concrete had not been added until it became necessary to protect the joists in consequence of failure due to corrosion. About 35 years ago the late Mr. Thomas Ormiston, M. Inst. C.E., the engineer of the Bombay Docks, referred to pitting of exactly the same character as that described by Mr. Ellis, and, as far as Sir William Matthews could make out, of the same shape and size, which pitting, Mr. Ormiston said, occurred on the sea side of one of the caissons at the entrance to a graving-dock at Bombay. That was the first time Sir William Matthews had heard of pitting of that character in connection with iron or steel work. He did not know whether Mr. Ellis had met with such pitting anywhere else. [Mr. ELLIS replied in the negative.] His only personal experience of it had been at Colombo, where his firm had had to carry out three long breakwaters, one of which consisted of a rubble mound tipped from temporary staging. For two reasons wrought-iron piles were adopted for this temporary staging. The first reason would be evident from the piece of timber he had placed on the table, which would be seen to be riddled with large holes by the action of the teredo, as the result of being in the work at Colombo for only 2 years, notwithstanding the fact that the timber was creosoted with 14 lbs. of creosote per cubic foot. When he came into possession of that piece of timber 30 years ago the creosote in the worm-holes could still be smelt: the great activity of the teredo, as shown by the specimen, was therefore not due to deficiency of creosote. The other reason for using wrought-iron piles was that on the completion of the mole it would be possible to draw several of the piles and cut off others and use them for the construction of permanent jetties; but when the piles were withdrawn it was found that they were pitted in the manner described by Mr. Ellis, there being oval holes about $1\frac{1}{4}$ inch long and $\frac{3}{8}$ inch deep, not sufficiently numerous, however, to interfere seriously with the structural strength of the pile, and extending for a length of 2 or 3 feet in the vicinity of low-water level. The rise of tide at Colombo was only 2 feet, and the resident engineer protected the piles, as he thought, at and about low-water level, by scraping off the shell-fish and marine growth, and coating the surface with hot tar. His own experience was that to apply anything in the nature of tar or paint to a wet surface was

useless, and was a waste of time and money. As a result of his experience of sea work he had always held that wrought iron resisted the corrosive action of sea-water better than steel; he must admit that he could not absolutely prove it, but he might state some of the grounds for his opinion. When he was at Colombo several years ago, a rail which had lain on the bed of the harbour for a considerable period was lifted in the course of carrying out the works, and on examination it was found that corrosion in the finer fibrous portion of the rail had been much more rapid than in the harder and coarser crystalline portion. Another case occurred at Hong-Kong, opposite Kowloon, the spot referred to in Mr. Ellis's Paper. About 14 years ago a wrought-iron jetty was built there by his firm for the accommodation of passengers. Mr. Ellis, who had been on the jetty on several occasions, had informed him that this jetty, which was only a mile from the wharf described in Mr. Ellis's Paper, was now in a state of good preservation, or at least it showed no evidence of being corroded or of having had its strength impaired. It was built of wrought-iron piles, and might be considered to be a wrought-iron structure, except for some small details such as cast-iron steps, landings, etc. His firm had also carried out some very extensive jetty-work on the coast of South Africa, probably extending in the aggregate to over 2 miles in length. The first jetty was put up there 35 years ago, and Mr. R. H. Hammersley-Heenan, M. Inst. C.E., the father of the Author of the third Paper, was allied with his firm in the work, and was well acquainted with the conditions. On examining the first of these jetties about 15 years after it was built, he could find nothing wrong with it. Between wind and water, and in the vicinity of low-water mark, and for some distance below it, the piles were coated with marine growths which apparently had protected the material effectively, but the structure, which was exposed occasionally to heavy seas, showed no signs of deterioration. All these jetties were of wrought iron. Another case was a pier at Malacca. On examining that pier 23 years after it was built he found the tie-rods and the structure itself covered with small oysters about the size of a five-shilling piece, and they were so encrusted on the ironwork that their shells formed a complete coating of carbonate of lime. He had a tie-rod scraped at about half-tide level, and found that to all intents and purposes the iron was as good as on the day it was placed in the work. At Penang he had personally examined a heavy pier which was put up in wrought iron, and found the same growth of small oysters and no pitting or deterioration. He mentioned those facts to

Sir William
Matthews.

Sir William Matthews. show that works in the sea had been built in wrought iron, under climatic conditions apparently similar to those which prevailed at Kowloon, without showing any such deterioration as Mr. Ellis had found. In consequence of the pitting experienced at Colombo

Figs. 1.

in the vicinity of low-water level, his firm had in later works provided what they called "sleeves." These consisted of an outer casing which extended 1 foot 9 inches above low water and 2 feet 9 inches below low water, sometimes more. Figs. 1 showed the form

of sleeve generally adopted. The piles consisted of four sections riveted together, or of solid rounds 6 inches in diameter. When the piles were driven or screwed they were filled with concrete, after which the sleeves put on and the space between the pile and the sleeve was filled with 6-to-1 concrete. Such sleeves, of wrought iron, gave effectual protection to the vulnerable part of the work, which could not be easily renewed. The clips, etc., above and below the sleeves could be easily taken off and renewed, whereas the piles could not be renewed without considerable inconvenience and cost. He had not known one of them so far that required to be renewed. He had found that to be a simple device for checking corrosion. Mr. Meik had already pointed out the comparatively small additional cost which would be entailed by the adoption of 4-to-1 concrete instead of 6-to-1; and in Sir William's opinion the advantages of 4-to-1 concrete for such small masses of concrete in sea-water amply justified the $1\frac{1}{2}d.$ or so per cubic foot difference in cost which would result from using the extra cement for reinforced-concrete work. With regard to the condition of the concrete, Mr. Ellis pointed out that where the situation and arrangement of the steel members permitted of the concrete being thoroughly rammed into place, it was found to be in better condition. The success of work of that kind turned on the thoroughness with which it was carried out. His own experience showed that for such finicking work Chinese labour was admirably adapted. An interesting point referred to by Mr. Ellis was the excessive corrosion occurring above high-water level. At first sight those who had not had to do with such cases might consider that that was above the level at which the corrosion would be a maximum, but he could bear out what Mr. Ellis said on the matter, and it had been confirmed by Mr. Meik. The lower bracing members of the wharf, Mr. Ellis said, were found to be entirely unaffected by corrosion, although they were in the sea.

Mr. J. MITCHELL MONCRIEFF asked whether the piles in the Kowloon wharf were driven for any length of time before the coverings were put on.

Mr. ELLIS replied that there were two distinct sets of wharves. In one case the piles had not been coated at all, and it was in those that the pitting had taken place. The piles in the other wharf were coated immediately after driving, and, so far as he could tell, no corrosion had occurred there.

Mr. MONCRIEFF remarked that he had met with the fine black powder spoken of by Mr. Ellis, not only on steel, but also on wrought-iron cylinders in river-water. He had not, however, come across

Sir William
Matthews.

Mr. Moncrieff.

Mr. Moncrieff.

Mr. Moncrieff. shell-fish or marine growth causing any local corrosion. In each case the fine black powder could be rubbed away with the fingers, and the iron or steel was perfectly clean and bright underneath, so that no actual corrosion was going on. Judging from Mr. Ellis's experience, something more was required to protect steel piles than the concrete covering described. It appeared evident that if the steel piles were eaten away to the extent Mr. Ellis described, and the pittings were so close together, even a cylinder put round and filled with concrete could not last for any length of time. The concrete filling could not be regarded as a protective coating at all once the protecting cylinder had gone, particularly below low water. Was it quite clear that the corrosion occurred only in the members of the bracing? He noticed that corrosion took place in the upper parts in the neighbourhood of high water, which seemed just the part of the wharf which received blows from vessels, and would be the first part to suffer in the way of the concrete parting from the steel, when corrosion would naturally occur. A few years ago he himself noticed an instance of corrosion which had occurred in a river in this country. There were two reinforced-concrete wharves, in one of which the reinforced concrete was perfect, with no sign of corrosion whatever, and in the other exactly the kind of corrosion occurred that was described by Mr. Ellis, due to the parting of the steel from the concrete. It was a real reinforced-concrete structure, not one of steel protected by concrete. The cracks in the concrete occurred along the lines of the bars which reinforced the structure. There must have been something, in the cement or in the workmanship, or in the conditions under which the wharf was used, to cause this corrosion, or it might even have been due to electrolytic action. Many of the difficulties and troubles which occurred with reinforced-concrete structures and other structures opened a wide field for investigation, and were worthy of more attention than they received: more could be learnt from one failure than from twenty successes. It was a curious fact that in Canada the same troubles had occurred from moisture combined with cold as had occurred at Hong-Kong from moisture combined with heat. There might be some mechanical cause, other than that arising from frost, or heat, or moisture, and he again suggested bumping by vessels, and possibly differences in workmanship, causing differences between structures. He had been extremely interested to hear from Sir William Matthews that wrought-iron structures stood so well in the East, because Mr. Ellis's account of the failure of steel structures had rather disconcerted him. He thought, however, the view that

wrought iron was better than steel required to be adopted with a Mr. Moncrieff. certain degree of caution. While Sir William was speaking, Mr. Moncrieff had in his mind a picture of a large washer which he once picked up on the top of a bridge-pier, where it had been lying for 30 years. It was a wrought-iron washer 5 inches square and $\frac{5}{8}$ inch thick, and at one corner it had corroded and opened up like the leaves of a book, until it was $1\frac{1}{4}$ inch thick, while the opposite corner was still $\frac{5}{8}$ inch. If the washer had been of steel it would have lasted just as well, and probably it would not have shown such a destructive form of corrosion.

With regard to Mr. Hammersley-Heenan's Paper, it would be interesting to have particulars of the few cases, and to know how the conditions in which very serious deterioration had occurred owing to frost differed from those in which such work had been carried out successfully.

He did not quite understand the use of the word "tests" in the title of Mr. Ball's Paper. Only one test was referred to in it. In these days, when engineers were so anxious to get information about reinforced-concrete work, which had come to stay, the word "tests" raised hopes that some valuable information might be given. Ordinary contract tests did not help much, and personally he had never placed much reliance on them, because they told very little beyond the fact that on the day of the contract test a structure carried the prescribed load. The real question was: how long would the structure carry that load, and under what conditions would it be loaded in the future? Taking the first bridge described by Mr. Ball, it would be extremely difficult to get, under the ordinary conditions of such a bridge's existence, working-loads which were anything like the load under which it was tested, and, that being so, it was not possible to say whether the assumed working-stresses were justified. But in regard to the third example, railway-bridges with small spans, probably Mr. Ball could give some information, which would be very valuable, as to how those bridges behaved under railway-traffic presumably near to that contemplated in the calculation of the stresses. He had a great fear himself—and he believed other engineers had the same fear—of reinforced concrete under intermittent or reversed stresses. He did not believe it was suitable for such conditions; but that was only belief, and proof was required. Mr. Ball's railway-bridge with small spans might or might not have cracks in it, and it would be interesting to know whether there were cracks in this case, and whether the bridge had been stressed to anything like the original intention. In practice it

[Mr. Moncrieff. was difficult to get a structure loaded to anything like the test load. Much mathematics had been applied to reinforced concrete, until engineers were rather tired of mathematics in that connection and would like to hear of some practical experience of the structures in actual work. A great deal of calculation was expended on things which did not "come off" in practice. He had in mind a case where great care was taken over the calculations, and yet a thing happened that was never expected. In some large reinforced-concrete beams of 22 feet 8 inches span, 5 feet 3 inches deep, and 14 inches wide, he had recently discovered cracks almost the full depth and close to the point of support. However carefully the reinforcement might have been considered, and however carefully patentees might have gone into the matter, no one could have foreseen that those cracks would occur just where they were not wanted—where the shearing stress was greatest. What was the good of calculations for a material which cracked in that manner as compared with a steel beam which did not crack? An engineer who received from a maker a steel beam with a crack extending three-fourths of its depth would not accept excuses. In making comparisons between reinforced-concrete structures and other structures endeavour should be made to compare like with like as far as possible.

Mr. Trench. Mr. E. C. TRENCH observed that all three Papers were very interesting, but to British railway men Mr. Ball's Paper was of special interest. Mr. Ball had helped to remove the reproach which was sometimes levelled at British railway-engineers, that they were not sufficiently progressive and did not with sufficient alacrity take up the most recent and fashionable form of construction. Mr. Ball, however, had boldly adopted new methods, and by relating his experiences had rendered railway-engineers a service. The one fault Mr. Trench had to find with the Paper was that there was not enough of it; there were many things other engineers would like to have known. A good deal was expressed in a single line, but if Mr. Ball had filled in the details a little more fully, his Paper would be even more valuable than it was. For instance, engineers would like to have been told the composition of the concrete, the matrix used, the properties of the cement used, how soon the tests were made, whether the Author used any waterproofing over his bridges, and so on. After all, however, the main points were given—the design, the ratio of steel to the mass, the system of reinforcing, the tests, and, most valuable of all, the cost. There was considerable reticence in many Papers read before The Institution with regard to the latter point, and admiration must be expressed

for Mr. Ball's courage in giving the figures. That they should Mr. Trench. have turned out so well, as compared with the figures for other forms of construction, had perhaps made it easier for him to take the members into his confidence. With regard to the tests, on the first structure the deflection given for all the spans was the same, although the spans ranged from 36 feet to 84 feet. That was remarkable, and as they were all given to the thousandth part of an inch, they had presumably been taken with great accuracy. Was it possible that 0.062 inch was only another way of expressing $\frac{1}{16}$ inch, and might it mean that $\frac{1}{16}$ inch was the smallest division on the 2-foot rule of the man who held the staff? Lest it should be thought that the Great Central Railway was the only company experimenting in that particular direction, he would like to give a few details of some work which had been carried out on the London and North Western Railway. One structure completed a couple of years ago was a reinforced-concrete viaduct. It was, he believed, one of the first examples in England of a viaduct in that material carrying a railway; it carried a group of sidings leading to a coal-gantry, and had been constructed on the Hennebique system. It consisted of reinforced-concrete beams under the rails, supported on reinforced-concrete columns, with a reinforced-concrete deck over all. The ratio of steel to the mass was 2.05; the working-stresses were 500 lbs. per square inch in compression for the concrete, and $6\frac{1}{2}$ tons per square inch in tension for the steel; and the cost of the viaduct, 260 feet long, was £2,656. This, compared with the estimate made for a similar structure in steel, showed a saving of 22 per cent., thus bearing out Mr. Ball's figures to some extent. When the test loads were applied, 6 weeks after the completion of the structure, the deflections varied considerably in the various beams, but the maximum deflection, measured with an accurate instrument, was $\frac{3}{16}$ inch. The North Western Railway had built foot-bridges of the ordinary type with reinforced-concrete columns and beams, and there was some trouble at times in constructing them, owing to the difficulty of erecting the falsework over running-lines. In order to get over that difficulty some foot-bridges had been constructed on a plan which he had not seen elsewhere. They were arch bridges of three-hinged type, a hinge at each springing and one in the centre. The reinforced-concrete ribs, having been cast at some convenient place, were lifted into position by a crane on a Sunday, and formed the basis for the laying of the floor, the steps, the parapets, and the covering of the bridge. He had expected rather more saving than was obtained, but still the bridges were satisfactory, and the cost was slightly less than if they

Mr. Trench. had been built in steel. The same remarks applied to five bridges completed recently on a branch line near Coventry, where the depth was not quite sufficient to allow of a brick arch, and the alternatives were either a reinforced-concrete arch or a steel girder bridge. There was a bed of rock at about rail-level which offered facilities for springing an arch, and it was thought that bridges economical in first cost and maintenance would be obtained by adopting reinforced concrete. The bridges were built, and he believed they were an improvement on the ordinary steel-girder bridge from the point of view of appearance, but the saving in cost was very small. It rather looked, as Sir William Matthews had said, as if every case had to be examined individually before deciding whether any substantial saving would result from adopting reinforced concrete. For bridges it usually had certain advantages. It was probably cheaper in first cost and in maintenance, but against that had to be put the fact that it could not be brought into use so soon; moreover, on railways many changes were probable as time went on, and it must be remembered that a reinforced-concrete bridge was exceedingly difficult to remove, and when it was blown up, or removed by other means, the pieces were of very little use; whereas a steel-girder bridge could generally be utilized somewhere else.

Mr. Grierson. Mr. W. W. GRIERSON proposed to confine his remarks to the Papers by Mr. Ellis and Mr. Ball, for although the possibility of continuing concrete work in a severe frost was a matter of considerable moment in a country like Canada, in Great Britain severe frosts of long duration were uncommon, and he would prefer to delay the work and eliminate one possible risk of an unsuccessful result. The most interesting and perhaps most important point in Mr. Ellis's Paper appeared to be his conclusion that concrete was not an effective protection against air saturated with sea-water, especially in tropical climates. It was recognized, Mr. Grierson thought, that the effect of sea-water on reinforced concrete had not yet been determined. In 1897, in a discussion on a Paper by the late Mr. Harrison Hayter at The Institution, Sir Francis Fox stated that so far as above water-level was concerned he was content with it, but below water-level its history had yet to be written; and that the effect of sea-water on piles driven into the bed of the sea and exposed to sea-water was a matter on which opinion must for the time being be held in abeyance. Mr. de Vesian, in the same discussion, stated that there was no special sensitiveness to corrosion in the case of concrete piles submerged in sea-water, always assuming, of course, that there was no flaw or defect in the outside skin. It would be seen that Sir Francis Fox's fears applied to concrete below sea-

level, whereas Mr. Ellis had pointed out that serious injury was found above high-water level: and on the other hand it appeared that, in the opinion of Mr. de Vesian, if the concrete was without flaw or defect there was no risk either above high tide or below it. On the Great Western Railway a good deal of concrete work, in the form of piers and piling, had been carried out during the last 13 years on the south coast of England, not perhaps from any conviction that the life of reinforced concrete had been altogether demonstrated, but on account of the teredo. Twelve months ago the Divisional Engineer reported on the condition of the structures, and the result of his examination went to show that the concrete was sound and good above water, and also, as far as could be seen, below water. He did not put that forward as being necessarily in conflict with the deductions Mr. Ellis had drawn, because although there were no signs of rust or discoloration on the surface of the concrete, it was, of course, not possible to discover what was the actual condition of the reinforcement. To his mind it was as piling and piling-supports that reinforced concrete was perhaps of greatest value, and he would be sorry to think that sea-water acted seriously upon it. There might have been other influences at work at Kowloon besides the climate and sea-water, and one or two speakers had rather suggested that that was the case.

The inference to be drawn from Mr. Ball's Paper appeared to be that in the design of a reinforced-concrete structure the stresses to be borne could be safely calculated, and that the cost of such structures was less than that of masonry and steelwork. It went without saying that a saving in first cost did not necessarily imply an economical structure. The life of the structure was a vital point, and at present that was generally regarded as an unknown quantity in the case of reinforced concrete. With regard to maintenance, there was no doubt that a saving could be effected as compared with steel or other material, which required periodical painting. On the Great Western Railway there were several reinforced-concrete bridges built over the railway, carrying roads, and also two which carried railway-sidings, over which locomotives passed. In every instance but one there was an estimated saving, but it was nothing like as large as Mr. Ball had found to be the case, and in one instance the reinforced concrete cost considerably more. The structures, which had been up for several years, were standing well and had given no trouble. He had been invited to write a Paper to be read at Berlin in 1914 on the use of reinforced concrete by railway-companies in Great Britain and in the Colonies, and he had been surprised to find, from the answers

Mr. Grierson. to his inquiries, to what a small extent reinforced concrete had been used by British engineers. It was an important question whether the tardy adoption of that material was due to want of enterprise or to a well-grounded fear that the behaviour of the material had yet to be learned. His Paper went to Brussels, and probably came prematurely into the hands of the Germans.

Mr. Shelford. Mr. FREDERIC SHELFORD remarked, with reference to Mr. Hammersley-Heenan's Paper, that the addition of a little lime to concrete was a common practice in England among bricklayers, who, in building an arch-ring or a piece of work in cement, were fond of putting in a little lime in order to make it work easier. He thought the placing of manure in proximity to cement in process of setting must be attended with considerable danger. The same might be said with regard to the addition of sodium chloride, which the Author said lowered the freezing-point of water; but it could only lower the freezing-point of water so long as it remained water, and not when it began to enter into chemical combination. Properly-made concrete allowed to set in the usual way would never suffer from frost. He had occasion 20 years ago, in the north of Scotland, to build bridges of concrete, which in those days was a novelty. They were soundly built and were allowed to set in the usual way, and when he saw them last, a year ago, every one of them was as good as the day it was built. When concrete showed signs of deterioration under the action of frost, he thought it was often due to trouble not having been taken to make up the concrete with a good face in the forms. The result was that when the form was removed the face of the concrete was rather rough, and a little cement was put over it. This added cement was liable to come off. Trouble with concrete piling in frosty weather was due to fine cracks in the concrete. In a pile standing in tidal waters the concrete was subjected to a low temperature when the water was low, and when the tide rose, the water being warmer than the frosty air, the concrete expanded. By constant repetition of that process the concrete became finely divided with hair cracks, the water got in, and when frost came expansion took place and the concrete was split. In the north of Scotland a certain Scottish contractor—not a very scientific man, but one of the best—told him that he had built a concrete platform-wall 200 yards long in which there was not a crack from start to finish. He offered to bet that gentleman a sovereign that he would show him a crack in the wall at every 25 or 30 feet. The bet was made, and a few weeks later, on going to the place, they found that the wall was cracked from top to bottom at every 25 or 30 feet, by expansion and contraction,

though it was none the worse for that. His contractor friend was Mr. Shelford. so horrified that he forgot to pay the sovereign!

With regard to the subject of Mr. Ellis's Paper, he might refer to works carried out in West Africa, such as the bridge at Lagos, $\frac{1}{2}$ mile long, founded on steel piles in tidal waters, which was built and finished in 1897. For 17 years that bridge had stood, and to-day it was free from pitting or trouble of any kind, as far as he knew. The last time he saw the bridge it was covered with small mollusks and vegetable growth. The question raised by the Paper was of considerable importance, as if reinforced concrete could not be depended upon in the tropics, the sooner that fact was known the better. He could not help thinking that the cause of the trouble at Hong-Kong was that the concrete had been too poor, not sufficiently mixed, and not properly applied.

Mr. A. C. AUDEN remarked that Mr. Hammersley-Heenan Mr. Auden. referred to Mr. John Kennedy doing work in Halifax with a covering of wood about 2 inches in thickness; but unless that wood was creosoted, frost would have almost as bad effects as if it were not used at all. Soft wood, uncreosoted, absorbed water and formed a sponge or poultice. He would take the liberty of going even farther than Sir William Matthews, and advocate a mixture of $3\frac{1}{2}$ -to-1 for coating steel. He believed that would be found distinctly advantageous, and quite worth the extra cost. As to difficulty in properly coating horizontal and diagonal steel bars with concrete, if a rendering coat were applied first of all, put on by hand with a steel or wooden flat, the coating would be perfectly impervious, and it would be exceptional to find even a hair crack. A little well-hydrated lime was by no means a disadvantage in the preliminary coating, and after that the concrete could be placed round in casings. With reference to the saving in cost, it might be interesting to mention that he had designed a "mushroom" raft instead of a beam raft on reclaimed land that was constantly flooded; owing to its form it had obviated a great deal of excavation, and the saving in cost had been 56 per cent. on a contract actually submitted for steelwork. That was an exceptional case, but where excavation in bad land was concerned, the use of a mushroom raft in reinforced concrete certainly seemed to result in a remarkable saving.

Professor STEPHEN M. DIXON remarked that he read the results of the observations on the corrosion of the steel wharves at Kowloon in quite a different manner from that in which Mr. Ellis had read them. Mr. Ellis described the attempt to preserve steel sections by encasing them in concrete, and said that on cutting into the

Professor
Dixon.

Professor concrete a very unsatisfactory state of the steel was revealed; and he regarded that as affording an indication of the life of reinforced concrete under the same conditions. It had been pointed out by Mr. Meik that the wharves at Kowloon could not be considered as reinforced concrete, and Mr. Ellis had admitted that reinforced concrete constructed in the usual way gave excellent results when subjected to the trying conditions of a fluctuating water-level in a warm climate. Mr. Ellis stated that the corrosion was probably due to the fact that at Kowloon there was a large amount of salt in the water, but he also said that the greater part of the corrosion occurred above high water. He described two methods of concreting, some parts being concreted on shore and others in situ. The large beams concreted in situ were encrusted with wet rust, while the lower horizontal bracing, concreted ashore, was found to be entirely unaffected by rust. That would seem to show that even steel sections, if embedded in good concrete, would be completely protected from corrosion, even when exposed to the action of a moist, warm atmosphere, provided, of course, that care was taken to see that the concrete came into intimate contact with the steel while concreting. Whenever engineers like Mr. Ball claimed that there had been a large saving by the use of reinforced concrete the opponents of reinforced concrete said that a great deal of care in inspection was necessary if the concrete was to be a success. That point was laboured to such a degree that it would almost be thought that no inspection was required when steel and masonry structures were being erected. If he expected a saving of, say, 30 per cent., the engineer might certainly spend a little extra money on the inspection necessary to ensure that the concrete was put in properly. Opinions with regard to reinforced concrete were of very little use; facts were wanted. The time must come soon when there would be collaboration between engineers in practice and engineers in charge of testing-laboratories. The time for the testing of materials alone had passed. Such testing must go on, but what was really wanted was the testing of structures. Tests of cement, concrete, and steel were all necessary, but tests of reinforced-concrete members were essential, and they involved expensive machines and expensive work. Engineers who were engaged in constructional work should make beams and posts exactly in the same way as the beams and posts to be used in their structures were made, and should send them to testing-laboratories to be tested under the same conditions as would exist in the bridges. With large testing-machines it would be not only in reinforced concrete that engineers would obtain valuable results.

Professor
Dixon.

On the 300-ton testing-machine at the University of Birmingham he had had opportunities for more than 4 years of testing steel sections—struts, ties, and beams—of all kinds, and, besides getting much useful information, he had obtained one very important result, namely, that a large majority of the pieces tested failed to bear the breaking-load calculated by the designer. That showed how important it was to test structures and not merely materials. With regard to reinforced concrete, it might be considered that 3-to-1 concrete was better than 6-to-1; but if 6-to-1 was good enough, why use 3-to-1?

Mr. CHARLES HAWKSLEY, Past-President, remarked that some of the observations made in the discussion on corrosion applied to steel structures and others to wrought-iron structures, and he thought it was important to distinguish between these two materials when considering liability to corrosion.

Mr. BALL, in reply, remarked that he ought perhaps to apologize for presenting a series of notes in the form of a Paper, but when he put them together he did not contemplate more than that they might be worth printing in the Proceedings; and he was sorry he had not had time to elaborate them. From the experience he had gained in experimenting with reinforced concrete for about 10 years, he was of opinion that the Ashton bridge, with three spans, was about the limit for that type of design, and he would not like to put up another as large, because the bridge was exceedingly heavy, the heaviest girder weighing about 74 tons. The accompanying sections (*Figs. 2 and 3*, p. 170) showed the area of the reinforcement in the top and bottom booms of two of the girders. The bridge was in a coal-district, where there was liability to settlement. The superstructure was entirely independent of its abutments; each span was distinct, and rested on the mass abutments at either end and on the two intermediate reinforced piers. The paving of the bridge was also independent of the concrete structure. Between the concrete which carried the pavement and the bridge-decking there was a layer of asphalted felt which prevented any cohesion between the surface of the concrete and the decking. The test load was very heavy, but he did not agree with one speaker that such a load would never come on the bridge again. In that district very heavy loads of armour-plate, boilers, and guns were usual, and the bridge was designed to carry the load of the district. In the next bridge he tried an experiment. It was a road-bridge carrying a double tramway-track. Three months after the centres were struck he placed on it four 30-ton locomotives with a 12-foot wheel-base, and the result was a perma-

Professor
Dixon.

Mr. Hawksley.

Mr. Ball.

Mr. Ball. nent deflection of $\frac{1}{8}$ inch on the beam in the 37-foot span. There was no permanent deflection in the 31-foot span. The experiment

Fig. 2.

Cross Section of Girder No. 3.

Fig. 3.

Cross Section of Girder No. 5.

REINFORCED-CONCRETE OVERBRIDGE, ASHTON-UNDER-LYNE (see Figs. 1, p. 124).

consisted in building the wings entirely independent of the abutments, and the movement that took place was interesting; the

wings moved forward slightly until the bank became consolidated; Mr. Ball. the joints were then pointed, and there had been no further trouble. The third example, a four-track bridge, was designed without the mass-concrete invert in the first instance, but owing to the rottenness of the ground when the embankment was tipped, the subsoil was forced up about 4 feet between the abutments. Owing to some defective work and improper inspection, the whole bridge slued round several feet; but it did not collapse, and now it carried every day engines of 110 tons weight. For the test, two engines of 110 tons were used. There were seven other reinforced structures, which were giving every satisfaction. He quite endorsed what Sir William Matthews had said with regard to cost. He was not a strong advocate of reinforced concrete for all structures, and the idea that a large saving could be made on every structure was quite wrong. In the engine-shed (*Fig. 7*, p. 132), in particular, covering $1\frac{1}{4}$ acre, a very large saving had been effected by using reinforced concrete. The structure was on made ground, and on the top of the reinforced portions there were brick walls carrying the roof. There had been a gradual settlement of about 3 inches. The cracks were of no consequence. For that type of structure reinforced-concrete construction seemed to be ideal. He agreed with Mr. Meik that one of the most important points in connection with reinforced-concrete structures was the time that should be allowed to elapse between the erection of the structure and the application of the test load. In the case of the public road overbridge at Ashton-under-Lyne 2 years, and in the case of the four high-level railway-bridges at Immingham, periods ranging from 2 to 3 years, elapsed between their completion and the application of the test loads. The reason for these long periods was that approaches had to be tipped, and a considerable amount of other work had to be done, before the loads could be brought on to the bridges. The bridge carrying the new road and tramway over the Grimsby District Light Railway was completed in May and tested in August, so that 3 to 4 months intervened before the first test was made. The Board-of-Trade test of this bridge was not made for another 2 years, when the electric tramway over the bridge was completed. Another reinforced-concrete bridge with which he had had to do (not referred to in the Paper) was tested 3 months after completion, and proved entirely satisfactory. He was of opinion that where it was possible a minimum period of 6 months should elapse before the test loads were applied, although a bridge might be opened for traffic at the expiration of, say, 3 months. With reference to Mr. Humphreys's question, whether there were on the Great Central Railway any reinforced-concrete bridges under

Mr. Ball. running-roads, the four high-level bridges mentioned in the Paper each carried four lines of railway, over which, as previously mentioned, engines weighing 110 tons were continually passing, and, so far, these bridges had been quite satisfactory. No reinforced-concrete bridges had yet been built by Mr. Ball carrying passenger-lines. With regard to the working-stresses, the higher stresses allowed in the case of the bridge at Ashton, as compared with the railway-bridges, were due principally to the difference in the design, and to the fact that while the one was an ordinary road-bridge the others carried heavy locomotives: undoubtedly the stresses due to constant application of heavy rolling loads were much more severe than those which usually obtained in bridges carrying ordinary road-traffic. With the experience gained in carrying out these bridges he would be disposed to limit the stresses in reinforced-concrete structures, whether for road- or railway-bridges, to 14,500 lbs. per square inch for steel, and 550 lbs. per square inch for concrete. Mr. Elliott-Cooper had, he thought, put his finger on the whole point of reinforced-concrete work—subject, of course, to the design being right—and that was, the question of inspection. There was no doubt that the entire safety of structures of this character must depend upon the closeness with which the inspection was maintained. He had already referred to a failure in one of the high-level railway-bridges due to improper inspection and defective work. With reference to Mr. Moncrieff's remarks, the test loads to which the various structures were subjected were not abnormal. To the Ashton bridge he had already referred; and as to the bridge carrying the new road and tramway over the Grimsby District Light Railway and the high-level railway-bridges, in the former case the test load referred to in the Paper consisted of the actual tramcars regularly passing over the bridge, and in the latter case it consisted of engines similar to those passing daily over the structures. Electric tramcars had now been running over the road-bridge since November, 1913—that was, for more than 12 months—and the high-level bridges had been in constant use since October, 1911, and, so far, no ill effects had been produced. In each case the test load applied was practically the same as that used in the calculations. Mr. Trench had referred to some of the disabilities of reinforced-concrete construction for railway-bridges. In the case of bridges under and over existing railways, time and facility of construction were frequently factors in favour of ordinary steel structures. In addition to this, as pointed out by Mr. Trench, the question of alterations and extensions had to be considered.

Generally speaking, a steel bridge was more adaptable. As to the Mr. Ball. life of reinforced-concrete structures, having regard to vibration and frequent application of the live load, this of course remained to be proved, but so far as experience went up to the present, the results appeared to be favourable, and certainly the material used was such as to warrant reasonable anticipation that that would continue to be the case. He agreed that tests such as those referred to by Professor Dixon were very desirable, but the expense of carrying them out was the deterrent in such matters. Where actual tests to destruction had been made on structures, or on portions of a structure, the results so obtained had been of considerable value. In conclusion, he wished to thank the members for the kind way in which they had received and discussed his Paper.

Mr. ELLIS, in reply, desired in the first place to acknowledge the Mr. Ellis. vote of thanks passed to him, and to express his appreciation of the very instructive remarks made during the discussion, particularly by Sir William Matthews and Mr. Moncrieff. He regretted that some apparent misunderstanding of the scope of the Paper had led Mr. Meik and Mr. Humphreys to discuss the design of the wharves. He had not been, in the first place, responsible for the design, and so had had no intention of submitting it to criticism, but had rather meant to set forth certain facts which had come under his observation as to the corrosion of steel under varying conditions. These conditions came under two distinct heads. The first was the case of the two steel wharves called Nos. 2 and 3 in the plan (*Fig. 1*, p. 134), which were left as bare steel. It was in the piles of those wharves that pitting was found under water—not between wind and water, as some speakers had suggested, but entirely below low-water level, where the incrustation was much more defined than above. The plaster cast which he had placed on the table showed the actual condition of a length of 6 inches of a pile. A European diver hammered a thin sheet of lead on the face of the pile after scraping off the incrustation of shell-fish, and then the cast was made from this template. Probably it had been taken at the worst place the diver could pick. The actual quantity of metal eaten away represented 4 cubic inches on one side of one flange of the pile, on a length of 6 inches. The content of the whole flange over that length was 54 cubic inches, so that $7\frac{1}{2}$ per cent. had been eaten away from one side of the flange, and it might be concluded that at least 12 per cent. had been lost from the whole section in a period of 6 years. He was not disposed to attach too much importance to this corrosion of bare steel under water. It might quite well be a phenomenon peculiar, in its severity, to the

Mr. Ellis, neighbourhood of Hong-Kong, though he could vouch for the fact that it occurred over many of the steel wharves in that colony; but the general impression of engineers, including himself, had been that the incrustation of shell-fish, which occurred on steel in all tropical waters, was, as Sir William Matthews had said, a protective coating to the steel; and it seemed to him an instructive fact that in certain instances these same shell-fish introduced an independent source of rapid corrosion. It would be interesting, for instance, to learn whether the wharves and jetties which Mr. Wilson had mentioned as being in perfectly good condition had ever been scraped and examined below water-level, or whether the state of that portion (as in Hong-Kong harbour previous to 1906) had been taken on trust. In any case it was very simple to adopt protective measures, either when such a wharf or jetty was constructed, or at any subsequent time. Sir William Matthews had described one interesting example: Mr. Ellis, in the case of wharves Nos. 2 and 3 at Kowloon, was about to adopt another method of encasing the steel piles, namely, by lowering over them a series of moulds formed of reinforced-concrete slabs dovetailed at the corners, and grouting the space between the moulds and the piles when the former were in place. The lower framework of steel bracing was removed temporarily for this purpose, so as to save diver's work, and the sets of slabs were assembled round the pile above low-water level, and lowered in succession. With reference to the section of pile adopted, he agreed with Mr. Meik that a steel joist was one peculiarly liable to corrosion, and should not be used in such waters as Hong-Kong, but on the other hand it was a particularly handy and useful pattern (for both piles and super-structure) in many situations where the teredo was too prevalent to allow of the use of timber (for which material it made a readily adaptable substitute); and above low-water level it was easily maintained in good order by yearly painting. The chief reason why screw-piles had not been used was that the ground for nearly half the width of the wharf was covered with riprap of granite rubble. By having a diver at work removing the stones on which the piles were actually pitched, they could generally be driven through without much delay; but with screw-piles driving would have been a difficult and often impossible operation. To his mind, again, the proper field for the use of screw-piles was where a solid bottom could not be reached, and in this case the piles were driven hard down on to (very irregular) rock, or into the hard decomposed granite immediately overlying it. Sir William Matthews had raised a very interesting point in comparing the relative durability

of steel and wrought iron. The consensus of opinion seemed to be Mr. Ellis. that wrought iron lasted better than steel, and Mr. Ellis's experience would lead him to agree with that view. At the present time, however, engineers were practically restricted to the use of steel, so that the more important question was, what pattern or section was best adapted to resist corrosion? and here the instructive evidence of Sir William Matthews was that the cylindrical section adopted by his firm for jetties had, except at Colombo, escaped the pitting mentioned in the Paper. Mr. Ellis had not, however, had the opportunity of inspecting the under-water portion of the Blake pier at Hong-Kong; and the Douglas Steamship Company's pier, a few hundred yards away, which he had found to be attacked by the same form of corrosion as was manifested at the Kowloon wharves, was of steel-joist piles, so that a comparison of material only could not be fairly instituted between the two. Mr. Elliott-Cooper and Mr. Wilson had both made the suggestion that the corrosion in this case was caused or intensified by the chemical composition of the steel, and in this connection it might be of interest to quote a sentence from Sir William Matthews's Presidential Address.¹ He said: "I may be permitted to allude here to the increased rapidity with which structures of iron, and more particularly of steel, perish in tropical waters, as compared with the life of such structures at home. It has been my experience that the finer the quality of the material, such as steel or the better classes of iron, the greater the rate of corrosion and deterioration." Mr. Ellis would conclude that in tropical waters it was preferable to confine the use of steel piles to solid or hollow cylindrical sections, in which the surface exposed to corrosion was much less than in a joist section. The difficulty then arose that these sections were, generally speaking, limited to screw-piles; so that for piles to be driven (as was in certain situations very preferable), reinforced concrete had great and obvious advantages. In designing a new wharf for Messrs. Alfred Holt and Co., at Kowloon, he had had recourse to a composite structure, with piles and lower bracing of reinforced concrete, and a superstructure of bare steel members which could be inspected easily and maintained without difficulty or undue cost. The second subject of the Paper was the much more important one of the corrosion of steel under a concrete covering above high water. He could not agree with Mr. Humphreys's entire condemnation of such an expedient in this case, however wasteful the combination of materials would have been

¹ Minutes of Proceedings Inst. C.E., vol. clxxi, p. 5.

Mr. Ellis. as an original design. In a Paper read before The Institution in 1905,¹ Mr. Marriott said that he had found concrete the most effectual protection to iron and steel in positions either difficult of access, or where water was liable to lodge, and he cited a case where he had had concrete cut away after 20 years and found the iron still as good beneath. In the discussion on that Paper, the late Sir Benjamin Baker remarked² that in certain places, such as the Underground Railway (before it was electrified) nothing short of encasing the girders in concrete or cement would answer; and (he went on to say) even that casing would have to be renewed from time to time. The owners of the Kowloon wharves would therefore appear to have been justified in extending Mr. Ellis's recommendation (which was that the piles and lower bracing should be encased) so as to include the entire structure, though the latter operation had proved unsuccessful. The importance of the subject lay in the object-lesson it afforded to those interested in reinforced concrete. The general opinion of those members who had spoken seemed to be that a protected steel structure, such as that described in the Paper, was not comparable with one of reinforced concrete. He would be very glad to think it was not, but he was afraid that one was only an extreme case of the other. Of course, if the adhesion of the concrete to the steel was imperfect, or failed, or if the concrete cracked owing to vibration or other causes, as had been suggested by Mr. Meik and Mr. Wilson, then corrosion would be set up at an earlier stage; but as long as the adhesion was good, and the coating unfractured, it did not matter whether the metal to be protected was a steel rod or a steel channel. The adhesion in that particular case was remarkably good. Corrosion had evidently set in years before any cracks were manifested, and after the cracks occurred, when the concrete was cut into, it needed hard hammer-and-chisel work to get away small portions of the concrete. Even when they did come away, the scale adhered to the concrete, not to the steel, showing that the concrete had been adhering to the steel throughout, except in the places referred to, where bad workmanship was evident. As an example of this it might be mentioned that since the Paper was written a vessel had run, stem first, into No. 1 wharf, cutting through the timber fenders and bending slightly the steel

¹ W. Marriott: "The Strengthening and Maintenance of Early Iron Bridges," Minutes of Proceedings Inst. C.E., vol. clxii, p. 213.

² *Ibid.*, p. 237.

members of the front of the wharf; yet the concrete was not Mr. Ellis. shattered or flaked off, but merely chipped away at the points of contact. Therefore in this case there was a thickness of $2\frac{1}{2}$ inches of concrete protecting the steel, exactly in the same way as in reinforced concrete, and there were also the wire ties embedded in the concrete, under the same conditions as the ties in reinforced concrete; and yet over this zone, 6 feet or so in height, corrosion of the steel had proceeded apparently almost unchecked. Apart from this wharf, he had recently had the opportunity of inspecting various other marine works in the East which were typical reinforced-concrete structures, and were the only examples he knew of in those waters which were more than 4 years old; and in every one of them corrosion had by now manifested itself in the zone in question. "One-Fathom Bank" lighthouse which Mr. Wilson had mentioned, in the Straits of Malacca, was a skeleton pile structure of reinforced concrete, constructed about 1907-8. It had a framing of horizontal bracing about 5 feet above high-water level, and it was there that corrosion first appeared. Through the courtesy of Mr. W. Eyre Kenny, M. Inst. C.E., the acting Colonial Engineer for the Straits Settlements, he had more recent information on the subject¹ than was contained in the report mentioned by Mr. Wilson: it now appeared that active corrosion, manifested in the form of cracks in the concrete, was evident throughout the whole length of these members, instead of only at one end; also that the superstructure at a higher level showed the same serious defects, so that the lighthouse was now having to be almost entirely reconstructed. That, however, was not a simple instance of the corrosion of steel under concrete, because it appeared that the vibration due to wave-action had hastened, and at the higher levels probably originated, the deterioration of the reinforced-concrete members. The other structures which he had inspected were three small reinforced-concrete jetties in Eastern harbours. Unfortunately, he had not obtained permission to mention the locality of the most striking example, in which the tension-rods of the deck-beams had corroded to such an extent that the concrete had in many cases flaked right away from under them, leaving the steel exposed. The remaining examples were in Penang roadstead—one at Butterworth, on the mainland side, and the other at the quarantine-station, a few miles away—and had been seen through the courtesy of Mr. H. V. Towner, Assoc. M. Inst. C.E., the Executive Engineer at Penang. Both these jetties exhibited

¹ See also *post*, p. 196.—SEC. INST. C.E.

Mr. Ellis. traces of similar corrosion at the same level, namely, from high-water level to 4 or 5 feet above it. That at Butterworth was particularly instructive, as showing the limits of the worst zone. It had landings at two levels, one about 6 feet above high water and the other about 2 feet. The first was absolutely good, without a crack in it anywhere, while the second had cracks in the under side of nearly all the deck-beams, showing that corrosion had taken place to a serious extent. In the quarantine-station jetty there was very little the matter with the deck-beams, so far as could be seen, but most of the vertical posts exhibited cracks, following the lines of the reinforcing rods, in the same zone. All the three jetties mentioned were more than 5 years old, and in each one the concrete was of excellent quality and appeared to be at least as rich as 4-to-1. With these examples in his mind, and with the list of marine structures showing defects which were mentioned in the reports of the Institution Committee on Reinforced Concrete, he would appear to be justified in his conclusion that concrete was not, for structures immediately above salt water, an efficient protective covering to steel. He believed that no corrosion was liable to take place in reinforced-concrete structures below mean-tide level, or above about 10 feet above high-water level, given good design and workmanship; but he believed that in the zone between high-water level and 5 or 6 feet above it, in either tropical or temperate climates, some additional coating should be given to concrete to render it impermeable to the evaporation from salt water. He doubted whether extra richness in cement was enough, and imagined that something external was required to close the pores after the concrete was in position. It would be instructive if the works mentioned by Mr. Grierson could be examined by cutting into the concrete to see whether the steel was still in good condition at the critical levels. If it were, in structures more than 4 years old, very reassuring evidence would be obtained against Mr. Ellis's conclusion, which he would be only too glad to have disproved. Professor Dixon had raised an interesting point in contrasting the behaviour of members concreted on shore and in situ. Mr. Ellis was strongly of the opinion that all possible members of marine structures should be moulded on shore, particularly those placed in positions below high water. In the case in point, however, the lower horizontal bracing could not be completely encased on shore, owing to the design of the steelwork. Bare strips had had to be left at the junctions of bracings and verticals to be concreted in situ, and the workmanship at these points, owing to their low level, had unfortunately been often

faulty, cement having been washed out of the concrete by the Mr. Ellis. quickly-rising tide and leaving it porous. Nevertheless, the steel showed no sign of corrosion, even at the faulty places at this level. It was one of the most disquieting features of the failure that in the zone of corrosion steel deteriorated much more—even when coated with perfectly good, sound concrete—than it did lower down (but still above low-water level) under an evidently permeable coating. With regard to deck-beams, which were always above high water, there was no reason why the workmanship in these should not be equally good, whether they were moulded in situ or on land. The remaining point brought forward in the discussion was the composition of the concrete. He agreed that for the work in question it would have been advisable to use one richer in cement, and that for all situations where concrete had to be laid by tidal work a strength of 4-to-1 was desirable. He would point out, however, that it was not 6-to-1 concrete which was used at Kowloon, but concrete gauged with 1 part of cement, 2 of sand, and 4 of broken stone. Mr. Meik had said that he regarded the two descriptions as the same; but, as a matter of fact, concrete as Mr. Ellis was accustomed to specify it—namely, 376 lbs. of cement by weight, 7·6 cubic feet of sand, and 15·2 cubic feet of screened stone or gravel—worked out at almost exactly 5-to-1. He had used this mixture for the wharves at Shanghai, where, as mentioned in the Paper, no corrosion whatever could be detected, and he was not prepared to admit that any richer concrete was necessary for reinforced-concrete work, either land or marine, so long as it could be moulded entirely above high-water level. It might be interesting in this connection to quote from the “American Civil Engineer’s Pocket Book”¹ which, being compiled by the leaders of the profession in the United States, might be taken to represent the consensus of opinion in that country. Under the heading of “Impervious Concrete” (p. 445) it said:

“The concrete itself can be made of such density as to be practically impervious under moderate pressures. For this purpose a rich mixture should be used of such proportion of sand and stone as to produce the maximum density. . . . Proportions of 1 : 2 : 4 will generally give an impervious mixture, and with well-graded aggregates a somewhat leaner concrete can be used.”

In his opinion a dense, homogeneous concrete could be better obtained by using a well-graded sand, with ample working into place, than by supplying an excess of cement over that required to fill the interstices in the aggregate.

¹ New York, 1911.

Mr. Ham-
mersley-
Heenan.

Mr. HAMMERSLEY-HEENAN, in reply, thanked the members for the kind way in which they had received his Paper. He realized that the subject was one of more interest to engineers who had to carry out concrete work in cold climates, but he hoped it would also prove useful to others who only occasionally had frost to contend with. He quite agreed with the speakers who preferred to stop all concreting during frosty weather. That, of course, was wise, but only possible in countries where the cold spells were few and of short duration. Mr. Maurice Wilson had pointed out that the Paper referred more particularly to light structural concrete. He had chosen to deal with that form of construction in the Paper, because it was the class of work in which he had had most experience in cold climates, and also because, in his opinion, it required greater care than heavy concrete work to protect it from frost. Large bodies of concrete in mass required the same precautions to be taken during the process of mixing and placing; but, when once the concrete was placed, it was only necessary to protect the surfaces, as the heat of the mass would be sufficient to keep it warm during setting. He was glad to be able to say that he had not had an opportunity of examining any serious failure due to frost in the work under his personal supervision, but he had had a little trouble with odd members of structures, which fortunately were detected in time, cut out, and replaced with new concrete. Of the few serious failures that had been reported in Canada, it was difficult to learn much; but he believed that in most cases they could be attributed to carelessness on the part of the workmen or to inexperience on the part of the constructors. The danger lay in removing the supports before the concrete was free of frost.' In examining failures it was sometimes difficult to decide whether frost was the cause; for example, one failure reported to be due to frost he found on examination to be due to faulty sand that had been used inadvertently. He quite agreed with Mr. Shelford's objection to the use of manure and salt in connection with concrete. Mr. Shelford's assertion that properly-made concrete allowed to set in the usual way would never suffer from frost was probably correct if it referred to concrete exposed to air only, but quite a number of cases had been reported, from the North Atlantic coast of Canada and the United States, of concrete piles and bridge-piers, exposed alternately to wetting and freezing, that had shown defects after only 3 years. Therefore it seemed reasonable to expect that concrete exposed to moisture and frost would also suffer, though to a much less degree, in time.