Discussion.

The PRESIDENT, in moving a vote of thanks to the Author, observed that the Paper was more than usually interesting and very practical. He thought it would be agreed that it dealt with work of a courageous character, and possessed additional value from the fact that it described the behaviour of the structures for some considerable time after their completion. It was particularly gratifying to get Papers of this kind from Colonial members. Their communications were highly appreciated, as they invariably contained much information and suggested many topics for useful discussion. There had been a good deal of discussion on gravity dams quite recently, and if on this occasion those who were in a position to deal more particularly with the novel and extensive use of the cylinder dam would give their views and experience, a valuable addition to engineering knowledge would be made. Among the many points that suggested useful discussion was one towards the end of the Paper, where it was stated that the policy of providing plant for the use of the contractor—a somewhat novel feature in dealing with large works, whether for governments or for corporations—had proved satisfactory. He had made that experiment himself on a somewhat large scale, with similar results. The Author was at present in Australia, but he was well represented by Mr. Darley. The President.

Mr. CECIL W. DARLEY remarked that he was the originator of that form of construction in New South Wales, where it was necessary to study economy. Small towns could not afford expensive gravity dams, and therefore it was a case of either building a cheap dam or not giving a water-supply. Hence some risk had to be taken. When designing the dams he was of course aware of the existence of the Bear Valley dam in California, built many years ago and still standing. That was still more rash in design than anything attempted in New South Wales, being designed for a pressure of about 40 tons per square foot as against the 20 tons which was the maximum he was prepared to adopt in New South Wales. The adoption of the same stress as in the Bear Valley dam would have halved the thickness of the walls described in the Paper; but he thought it was wiser to be on the safe side and not to exceed 20 tons per square foot in compression for good bluestone, or 10 tons for sandstone concrete. With regard to cracks, no one liked to see a crack in a concrete wall; but extensive experience of concrete Mr. Darley.

Mr. Darley. had taught him that it was very difficult to put up a long wall of concrete without some cracks appearing; and, after all, the curved form was the best where cracks were more or less inevitable. On p. 9 details were given of the condition of five dams in the year 1908, 10 or 12 years after they were erected. Those five dams were constructed under extreme conditions. They all happened to be built during a period of drought, with the temperature at 100° F. and often more. It was of course expected that rain would fall in the following season, immediately after the hot weather, and that the reservoirs would be filled. Unfortunately rain failed that year, and the dams stood empty in the dry and very cold winter that followed, with a good deal of ice about, some of it probably 2 inches thick, on what water there happened to be. In the Tamworth dam there was a crack $\frac{3}{8}$ inch wide, running from the top nearly to the bottom. Some of his officers were alarmed and recommended grouting, but he refused to have grouting done and ordered the crack to be covered so that nothing could get into it, believing that as the water rose the crack would close. When rain came he went to see the full reservoir, and, as he had expected, it was absolutely closed, with no indication of weeping; indeed it was impossible for anybody who had not seen the crack to say what part of the wall it was in. The wall was damp—it was very hard to make a thin concrete wall that would not show a certain amount of moisture—but there was no leakage to speak of: not a gallon per hour passed through the whole wall, so that practically it was watertight. Later on it got still tighter, all the pores becoming closed. To some extent the cracks breathed; if the water was low in cold weather they would open above in the dry portion. The Author properly pointed out that it would be better perhaps to recognize that cracks must come, and to put in radial joints. Probably that would be a wise course, but it was a little difficult to say where the cracks would come; they were most likely to be found where there was a quick change in the height of the wall. The Author's idea was to put radial partings at certain intervals along the wall, keeping the joint vertical. Through such a joint more permanent leakage might be expected than through a crack happening in the natural way. It appeared alarming to read about the cracks in reservoir-walls, but there was nothing to be uneasy about. The work was all perfectly sound.

Colonel Pennycuick. Colonel J. PENNYCUICK was glad the President had suggested that the discussion should be confined as far as possible to the question of curved walls, because a good deal had been heard of late about the gravity section of straight walls, and the question of curved

Colonel Pennycuick.

walls opened up an entirely new line of thought. He remembered expressing the opinion in the Institution about 12 years ago that nothing was gained in the case of a long dam by making it curved; in order to derive any advantage from curvature it was necessary to have a comparatively small radius, and that was impossible in a long dam. He also remembered saying that the Bear Valley dam, which was instanced as showing the advantage of the curved form, merely proved that good masonry would stand much higher pressures than engineers had ventured to subject it to; and he thought the Author's views coincided with his own on that point. The Author deserved credit—and more than credit—for having the courage of his opinions. Many engineers had long been of opinion that pressures of 8 to 10 tons per square foot, which were considered the limiting pressures in high dams, were much less than could be safely used, but he did not know that any engineers had had the courage of their opinions until the New South Wales works were constructed. It was valuable information to know that pressures of 20 to 25 tons per square foot could be borne with perfect safety. The Author mentioned that a curved dam had about the same area and section as a gravity dam when the radius of curvature was practically 25 times the limiting pressure in tons per square foot, that was to say, for a limit of pressure of 10 tons per square foot, at a radius of curvature of 250 feet practically the same section was obtained. There was a very important reservation, because the Author's references were all to dams less than 100 feet high, and in a gravity section the question of pressure did not come into play at all until greater heights than that were reached. In the upper part of the dam the first few feet were fixed by considerations of practical convenience and nothing else; after that the law of the middle third came into play, and in a dam constructed according to that law with a triangular section, having the base equal to about two-thirds of the height, the limiting pressure, whatever it was, did not come into play until a height equal to about half of the radius of curvature the Author had mentioned was reached. Thus a limit of pressure of 10 tons per square foot did not come into play until a height of 120 feet was attained, and it was below that height that the great saving by the use of the curved plan manifested itself. In dams up to about 100 feet in height, the base bore a fixed ratio to the height; as that height was exceeded, the base increased practically as the square root of the cube of the height, in order to keep within a given limit of pressure. The great saving came in the lower part. Unfortunately, very high dams were nearly always of considerable length, and therefore it was not possible to obtain to any large extent the saving that was to be derived from the adoption of the curved form.

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In two or three of his dams the Author had adopted a principle which seemed to be entirely new and to offer a great opportunity for saving, namely, building a short curved portion with straight tangential portions at the ends of it. In order to see how much that saving would be, it was interesting to consider the possible radius. Taking 10 tons per square foot, it was possible to have a radius of, say, 240 feet. The Author also said—and Colonel Pennycuick entirely agreed with him—that the most economical curve was one whose versed sine was about one-third of the radius, that was, an arc of about 100°. The chord of that arc was about one-and-a-half times the radius, so that with a radius of curvature of 240 feet the curve in the middle of the dam could be made about 360 feet long. Whatever the length of the dam might be—one he had in his mind was 1,300 feet—it would be a very substantial gain to save 30 or 40 per cent. out of a quarter of the length of the most expensive part of it. He had made a simple calculation to find the most economical length of radius to use in a case of that sort, where a curved portion was placed in the middle of a straight dam. The shorter the radius, the lighter the section and the greater the economy per foot. On the other hand, the longer the radius, the longer the curved part and consequently the greater the saving. The radius of what might be called maximum economy was found by simple proportion; taking the area of section to a given height, that was, the area of section of the gravity dam, then that multiplied by the limit of pressure in feet of water and divided by the square of the height, would give the radius of maximum economy. He knew of one large dam having a depth of 160 feet and a cross-sectional area of 8,330 square feet. By the formula he had given the most economical radius of curvature for a dam of that height would be about 94 feet. The dam was calculated for a limit of pressure of 8 tons per square foot. Taking that same limit, by adopting the curved form with a radius of 94 feet a section would be obtained of very little over 5,000 square feet, showing a saving of 3,000 square feet on the section. With that radius of curvature of 94 feet, taking the proportion the Author recommended, with which he quite agreed, there was a saving of 3,000 square feet of section on a length of 140 feet, or a little over 400,000 cubic feet. He was sorry the Paper had not been presented 26 years ago, because the Madras Government would have been saved about £40,000 by the adoption of the simple expedient of putting a curved piece in the middle of the straight. It was of great importance that the saving was effected in what was usually the most expensive part of a high dam —the central part, where the excavation was troublesome. He thought the Paper opened up a line of work which might often lead

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to very important savings in large works: he would not have had the slightest hesitation in adopting the principle if he had thought of it, and the Author deserved the greatest credit for his suggestion. But was there not just a possibility that in adopting such slight sections as in some of the works there was a risk from shearing, or some effect of that kind? Taking, for instance, the Medlow dam, 65 feet high and 8·96 feet thick at the bottom, a year ago he had said in the Institution that with an ordinary dam properly designed there was no need to bother about anything except pressure; that the dimensions which were sufficient to meet the crushing stress were sufficient also to meet all danger of shearing or slipping. But he could not help thinking that in such a section as that of the Medlow dam there was a real danger of shearing. He had calculated what the actual resistance to shearing was in the long dam he had spoken of previously. Shearing stress was resisted by two forces—the friction due to the actual weight of the dam itself, and the resistance to shear of the material of which it was composed. Those forces must act on the dam as a whole; it was impossible to conceive of a particular section of a dam being punched out by the water, but it was possible to conceive the whole thing to be moved by shearing along the whole of its length near the base. He doubted whether it was possible to say how far those two resistances, the friction due to the weight and the resistance of the material to shearing, supplemented one another; but in all dams built of gravity section each of those resistances was sufficient in itself. In the case he had in mind the actual weight of the masonry was almost double the pressure of the water on the whole water face The coefficient of friction was amply sufficient, even supposing the material had no power at all of resistance to shearing. Again, omitting the friction, the shearing stress on the material was about 4,200 lbs. per square foot, which he did not think was a stress anybody need consider. In the case of the Medlow dam he could not calculate the figures exactly without a longitudinal section, but the data given in the Paper were sufficient for making an approximation, and he found that the weight of the masonry there was little more than one-third of the weight of the water pressing upon it, which did not give a very high margin of frictional resistance. On the other hand, the shearing stress, taking the whole of the base, was about 5,800 lbs. per square foot. He thought little was known about the shearing-resistance of masonry, because as a general rule masonry was not put in positions where it was subject to any high shearing stress, and when it was, it was of dimensions which practically put such stresses out of court. He hoped that either the

Colonel Pennycuick. Author or Mr. Darley would be able to say whether the matter had been taken into consideration, and whether any calculations had been made on the point: also whether any signs of horizontal cracks had been seen anywhere near the base of the dam. He was of opinion that in dams higher than 120 feet the question of shearing stress would be a very serious one. With regard to the Cataract dam, he was pleased to find that the Author's calculations followed very closely his own. The dam to which he had referred had been calculated for a pressure of 8 tons per square foot, while the Cataract dam was calculated for $8\frac{1}{2}$ tons; and the difference in the sections of the lower part, where it came into play, practically coincided with this difference in pressure. The Author laid stress on a matter which Colonel Pennycuick had found to be important in practice, namely, the question of putting large plums in concrete work. In practice it had been found that those plums were not worth putting in; for the labour of moving them, and the very serious risk of uneven bedding and of incomplete filling underneath, more than counteracted the saving, which in any case was very slight as compared with ordinary concrete. He could not help thinking that the Author's designs in one or two cases were perhaps a little over-bold; but, however that might be, he felt that the man who ventured to go far beyond established custom among the profession deserved the highest credit and praise, and he sincerely hoped and believed that the Author's courage would be found to be justified by events.

Mr. Pilkington. Mr. Woodford Pilkington regarded the Paper as one of the most practical communications he had read for some time. The dams he had been accustomed to in Africa had generally been those required by farmers for agricultural purposes—small dams thrown across watercourses. In times of flood the trouble was that the cataract carried away the down-stream ground and the dam was overturned. The thirteen dams shown by the Author had sections like lighthouse walls, and their complete success afforded a valuable lesson. Such a method of construction did away with the great embankments sometimes 20 feet or more wide at the top, with puddled clay in the middle, a 3-to-1 slope on one side, and a 5-to-1 slope on the other. Where there were abutments of rock, as in New South Wales, an arched dam constructed in the manner described by the Author appeared to give excellent results. In speaking of concrete the Author invented an appropriate term—"sloppy"; and his experience with regard to rendering concrete watertight was very valuable. The Author stated that with sloppy concrete a watertight skin of cement was formed at the surface, which, however, cracked in dry weather, and he was of opinion that it was a better thing to put in very dry rammed concrete. The Author spoke—and his remarks agreed with Mr. Pilkington's own experience—of the value of concrete with only sufficient water in it to make it solid. Concrete that contained too much water was just as unreliable as cement tested with too much water, and the less the quantity of water put into concrete the better. With regard to cement this was easily proved by squeezing all the surplus water out of the cement mastic, as glaziers did their putty, and then placing it in the cement briquette-mould. Briquettes made in this way would resist twice as much stress. Mr. Pilkington.

Mr. WALTER HUNTER observed that the boldness of the design of the dams appealed to him, and it appeared to have been fully justified by the results. The Paper was another illustration of the old proverb, "Necessity is the mother of invention." The position in Australia was that there were a number of scattered townships which could ill afford to spend the money necessary for dams built in the usual way, and Mr. Darley had met the need by producing some very successful dams constructed with a minimum of material. In works where cost was the first consideration, and where the work could not be undertaken at all unless the construction was cheap, economy in material was of the utmost importance. In order to obtain that economy true principles of design had to be carefully followed, and therefore great credit was due to Mr. Darley for initiating the type and to the Author for his work as supervising engineer during construction. On the principle *Ce n'est que le premier pas qui coûte*, he thought the main credit belonged to Mr. Darley. Looking at the cross sections, he would feel a little nervous if he had to sleep on the down-stream side of one of the dams: still, they did their work efficiently, though it should not be forgotten that, with the exception of the Parramatta dam, the oldest of the walls had been in existence for only 11 years. It was to be presumed that they were all in open country, where failure would not entail very serious loss; if they were in a valley containing a large city or valuable property the question of durability would come in, and he thought it was necessary to be very careful in designing such works, which were intended to last for many years. In that connection he was reminded of an instruction which he received once from the late Mr. George Burt, then head of the firm of Messrs. John Mowlem & Co. At that time he was designing a crane for Mr. Burt, who, on looking at the drawings, said, "Are you quite certain it is strong enough?" Mr. Hunter replied, "I am quite sure it is; I have been very carefully through every part of Mr. Hunter.

Mr. Hunter. the structure and I have allowed a factor of safety of 6." Mr. Burt said, "You are quite sure for yourself; now put on just a little bit more for me." In a structure such as a dam, which had to last for ages, economy of material should not be considered too closely if it involved the sacrifice of durability, except when that course was absolutely necessary upon financial grounds. The whole surroundings of each scheme had to be carefully considered, and then the dam most suited to the situation had to be built. The Author himself said that the class of dam described in the Paper was suitable only for narrow valleys. With regard to the construction, Mr. Hunter thought the use of plums in dams of such small sections was not desirable, but evidently there had been no lack of safety, though he still believed that concrete throughout would have been better. A part of the Paper that interested him particularly was that dealing with the steps taken to face the dams with neat cement in order to make them watertight. That experience was very valuable. He had been interested also in the cracks, because there had been some fear of the same sort of thing happening in connection with the Staines reservoir-works. There his partner, Mr. Middleton, in lining the reservoir, took the view—in which Mr. Hunter agreed—that as concrete when laid in large masses would crack, it should be cracked to begin with; and accordingly the reservoir-slopes were faced with blocks made in situ, 4 feet square and 5 inches thick, with interstices between them. Hence, no expansion or contraction would crack the concrete more. Those slopes had stood remarkably well and he thought they were a good example of that class of work. In the same way, in designing the aqueduct, expansion-joints were placed at every 30 feet. The structure was of brickwork, with soft asphalt for the joints; it also had stood remarkably well, and no cracks whatever had appeared in the concrete. The construction of the dams in New South Wales seemed to have been based on right principles, namely, the difficult part of the work was done by the officials and the easy part of it was left to the contractor. He had always thought that too heavy a responsibility was often put upon contractors, so that they had to make allowance in their tenders for contingencies which sometimes never happened, and of which they then pocketed the profits. Such contingencies, in his view, ought to be met and paid for as they arose by the people who constructed the works. When too much responsibility was placed upon the contractors the work often proved to be rather more expensive than it otherwise would be. He congratulated Mr. Darley upon the success that had attended his design.

Mr. R. B. Buckley observed that, since listening to Colonel Pennycuick's remarks, he had been thinking what his proposals would lead to. He understood the Author to say that when a segmental dam was built, flanks were sometimes built tangential to the curve. That of course was what would naturally be done. He presumed that Colonel Pennycuick, who proposed to build the central portion of a dam, where it was deepest, in an arched form, would do the same thing. In that case it seemed to him that, in the case of a dam across a broad but comparatively shallow river, the plan of the work would take the form of a series of segmental dams with abutment lengths. These abutment lengths would be tangential to the curved portions and would meet each other at points which would be on the line of the down-stream boundary of the dam. This development was an interesting one: it might be doubtful whether it would be economical. Mr. Buckley.

Mr. F. Hudleston pointed out that in a dam such as had just been described, if there were a series of arches, there would have to be a strong abutment to sustain the thrust of each arch. It would be necessary to provide not only for the gravity-section force, but also for the thrust of the arch, and consequently the abutments would have to be extremely heavy. He believed something of that kind had been done in India. It appeared to him that a good many members had been rather led astray by the extraordinary cross sections and by the fact that there were no plans showing the general shape of the dams. Taking, for instance, the Medlow dam, the Table on p. 5 showed that the thickness of the dam was 8·96 feet and the radius of the curved part only 60 feet; so that the thickness of the dam was very little more than one-sixth of the radius. If that were drawn out on plan, it would be found to convey quite a different impression. For example, the Lithgow No. 2 dam was 24 feet thick at the base and the radius of the curved part was 100 feet only, the radius being thus four times the thickness. Striking two curves with radii in the ratio 3 : 4, it would be found that the dam was nothing like so startling as at first appeared. The other dams were much the same. The Mudgee was 18 feet thick and 253 feet in radius on the curved part, but it was only 50 feet deep, so that the pressures were not very high. The Wellington dam, on the other hand, was 10 feet thick and 150 feet in radius. On plotting the figures it was clear that the designs were not so very extraordinary, and that if the pressure was kept down to 10 or 12 tons per square foot there was nothing startling about the structures. The question of long straight dams, to which previous speakers had referred, was dealt with in the Paper, where the Author said that if Mr. Hudleston.

Mr. Hudleston. the radius was more than 500 feet the necessary thickness that had to be given to meet the thrust of the arch made the dam heavier than a gravity dam; and consequently the application of the arch principle was confined to short dams, where it was possible to use short radii and thus obtain dams that were really only about $1\frac{1}{2}$ radius from abutment to abutment. All the curved dams were built in places where there was solid rock, so that there was no question of settlement. Nothing short of an earthquake could disturb the conditions, the dams being under the most perfect distribution of force possible. There were not the same variations as, for instance, in a brick arch under a railway. In the original dam of this kind, the Bear Valley dam, built 25 years ago, the pressures were more than double those in any of the dams described in the Paper, and the Bear Valley dam stood well. Any information as to how that dam was built would be of great interest, because the accounts extant seemed to vary between granite and concrete in describing the material. He was a little surprised that the Author had not broken the walls when building them, as he suggested in the Paper. The difficulty with a concrete wall was that it cracked not at right angles to its length, but very often diagonally, and if there were two diagonal cracks at any acute angle to the line of the arch the whole structure would be in an exceedingly dangerous condition.

Mr. Burge. Mr. C. O. Burge, referring to the comparison of curved dams and straight dams, observed that he would like to have some information as to the very large dam the Author was building in New South Wales, the Barren Jack dam and reservoir, which would be one of the largest in the world, comparing in storage-capacity with such works as the Assuan dam and the Roosevelt dam in America. When that great dam was before the Committee of Public Works in Sydney it was, according to the description, a curved dam, the length of the crest being about 910 feet and the radius about 940 feet. It was also of gravity section. Quite recently he had seen from the figures issued by the Minister of Public Works in New South Wales that the length of the dam had been reduced from 910 feet to 784 feet, and it would seem as though the Author had adopted a straight wall. It would be very interesting to hear whether that change had been made because the Author considered that the principle of the arch was not applicable to such large works. Of course, the saving on so great a work as that—126 feet of wall 232 feet high—was a very important matter.

Mr. Ward. Mr. H. T. S. Ward remarked that the Author gave no description of the method which he proposed to adopt in dealing with any necessary repairs to the sluices. He mentioned that the pipe had a wooden cover, but at a depth of 150 feet from the surface it might be somewhat difficult to fit on that wooden cover so as to enable the pipe to be emptied in order to deal with any defect in the sluices. Perhaps Mr. Darley could say what arrangements were made to enable that very important matter in connection with the discharge of water to be dealt with. With regard to the concrete, it was rather difficult to realize what the Author meant by dry concrete, but he believed the Author's meaning was to be found on p. 11, where he said: "The wall is then built up in 3-foot courses, fairly dry concrete being placed in 12-inch layers, and rammed until water appears on the surface." His own experience in Ceylon was that if the concrete was made too dry it did not get properly mixed, and that a certain quantity of water was necessary to enable proper mixture to take place. He always added water to such an extent that the concrete when mixed could be handled with a shovel without the water running away with the cement. The consistency of the mixture was a more important matter when dealing with reinforced concrete, because concrete which was too dry did not adhere to the reinforcement. With the proportion of water he had described the concrete was fairly dry, and when it was tapped on the top with a shovel, water rose to the surface. With regard to parting joints, a previous speaker had suggested that they should be filled with some plastic material such as asphalt. That had been done in the case of the Maligakanda service-reservoir in Ceylon, of which a description was contained in the Proceedings.[1] That wall failed about 25 years ago under a head of 40 feet. The joints were cut out, and brickwork was built in, three or four of the joints at the corners being filled with a mixture of bitumen and cement, and the dam still stood, apparently quite safe. He thought that if thin dams were reinforced both vertically and horizontally the cracks would not appear. He had with him some photographs of a very thin wall built in Ceylon, holding up 14 feet of water at one part. The wall was only 4 inches thick at the top in the panels, and 10 inches below, with buttresses about 10 feet apart. It was finished about a year ago, and he examined it after it had 10 feet of water against it, when there were no cracks visible. He did not think the reservoir had ever yet been filled to the top. With regard to reinforced concrete, it was claimed by a number of users that the combination of steel with concrete gave to the concrete a degree of extensibility that it did not otherwise possess—almost elasticity. That had been ably put

Mr. Ward.

[1] Minutes of Proceedings Inst. C.E., vol. cxvi, p. 284.

Mr. Ward. before a meeting of the Ceylon Engineering Association last year in a Paper by Mr. J. A. Balfour [1] on "The Design of Reinforced-Concrete Retaining-Walls"—a communication which would repay perusal. Another point was with regard to high masonry dams out of which water was running all day, probably 600 to 1,000 HP. going to waste when the dam was full. It appeared from the section that there were coal-pits 9 miles away, and he thought it was a pity some use was not made of this water-power. The engineers of the New South Wales Government possessed great capacity for writing practical Papers, as the present Paper showed. It was, however, not the first Paper of that kind, as Mr. Ward had received valuable assistance from one by Mr. E. M. De Burgh [2] on "Pile-Sinking by Hydraulic Jet." Such Papers were of very great value to members of the engineering profession who were away in the jungle and unable to get technical assistance when in difficulties. The thanks of members in such positions were especially due to the Author.

Mr. Hudleston. Mr. F. HUDLESTON thought that the answer to Mr. Burge's question was to be found in the Paper. The Cataract dam was 811 feet from end to end and the radius of a curved dam would have been about 500 feet. The pressure was 3 to $3\frac{1}{2}$ tons per square foot. That gave at least 1,500 tons pressure as an arch, and it would be found that a thickness of 125 feet would be required at the base. On p. 6 the Author said, "The cross section of a curved wall 500 feet in radius and calculated to resist a stress of 20 tons per square foot, or of a curved wall of 270 feet radius to resist a stress of 10 tons per square foot, closely approximates to the cross section of a gravity wall designed to retain a similar depth of water"; and Mr. Hudleston thought that statement really supplied the answer to the question why the Barren Jack dam was being made straight.

Mr. Kilburn Scott. Mr. E. KILBURN SCOTT stated that he had recently returned from New South Wales where he had had the pleasure of seeing some of the dams described in the Paper, including the Cataract dam. He saw this in the early stages, when it was being done by day labour, and he thought the engineers were to be congratulated upon a fine piece of work. He only wished that Mr. Darley and the Author had been private engineers getting a remuneration of 5 per cent. on the cost of the work, instead of salaried Government officials; because he himself had suffered in that respect at the hands of the Public Works Department. Indeed, the country was not a happy one for a professional engineer to live in. The day labour would

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[1] Transactions of the Association, 1908, p. 17.
[2] Minutes of Proceedings Inst. C.E., vol. cl, p. 340.

Mr. Kilburn Scott.

have continued on the Cataract dam, but fortunately in Australia there were some sensible people and a sensible Press, and a stir was made about it, with the result that the day labour was stopped and the work was completed by contract. The tendency in Australia was to have day labour. Australia was an extraordinary country in respect to its suitability for the conservation of water. He had never seen anything like it in the United States, in Canada, or in Europe. There were huge valleys, several miles wide, sometimes 20 miles long, with small gorges only $\frac{1}{4}$ mile to 1 mile across, where water could be conserved with the greatest ease. He thought the people who had governed the country so far had been at fault in not seeing how easily water could be stored; but they were now waking up. If the policy of the country had been to encourage private enterprise, the matter would probably have been taken in hand 30 years ago. He had been particularly interested in the Cataract dam because a good deal of the work was done by electric power. He did not think it could have been done in the time, or done as well, without a large power-station working the cableways, crushing-machinery, mixers, etc. All the plant had been shifted to the Barren Jack dam, which was also being built with the aid of electrical power. He himself was interested as joint engineer with Messrs. T. M. and H. E. Coane, of Melbourne, in first proposing the Trawool scheme. Trawool was about 60 miles north-east of Melbourne, on the Goulburn River. It was found that with a dam about 160 feet high and 1,900 feet along the top, V-shaped in plan, twice as much water could be dammed as was held by the Assuan dam—due, of course, to the configuration of the country. That possibility had been staring the inhabitants in the face for years, and yet they had allowed a railway to be constructed up the centre of the valley which it would cost £300,000 to shift to a higher position! Farther down the river there was a place known as the Warranga Basin with a large dam. The proposition at Trawool was to generate electrical energy and to run the water, when it was not wanted for irrigation, into the lower dam. When the water was used for town supply or for irrigation as well as for power, as the water of Trawool and Barren Jack could be used, a catchment- or balancing-reservoir lower down was necessary, and dams should be schemed out with the utilization of water-power in view, the power-station being built as a part of the main dam, at the foot on the down-stream side, and the turbines being in the sluice-channels. At Trawool for 6 months in the year, during the drought, 10,000 HP. would be developed, and during the other 6 months 20,000 HP. His figures had been revised by Mr. Elwood

Mr. Kilburn Scott.

Mead, M. Inst. C.E., an authority on irrigation in the United States, who was Chairman of the Water-Supply and Rivers Commission in Victoria, and they were if anything a conservative estimate of the power available. That power would be developed by reason of the Warranga Basin dam lower down. It would not do to run the water away, as it would then be lost for irrigation; it would be caught lower down and distributed to the irrigators. By generating electrical power the cost of the water to the irrigators or to people using it for other purposes would be reduced, and that was one of the strong points put forward in connection with the Trawool dam. Directly the development of power was suggested the irrigators objected, but it was pointed out to them that no water would be lost owing to the dam lower down, and also that they would be able to buy their water much more cheaply, as 10,000 HP. would be generated, selling at £3 per horse-power-year, and producing £30,000 per annum. In New South Wales and Victoria there were places with water-bearing gravels 40 feet to 60 feet beneath the soil, and he believed that a large quantity of water ran away to the sea through those underground rivers. At any rate, very careful measurements showed a vast discrepancy between the rainfall and the discharge of the various rivers. There were places remote from the mountainous districts where water-bearing gravels were found similar to those of the fruit-growing districts of California. It would be possible, with electrical power, to raise the water out of the gravel by means of pumps, as was done in California, and in that way the irrigation-area would be extended very considerably. He had been in close touch with the "native-born" students at the University of Sydney and had found them capable of being trained into good engineers. The fault about the country was that there was so little chance for private enterprise in engineering. The Public Works Departments pottered along at ideas originally suggested by private engineers, who got nothing for their work and suggestions. Some of the young men trained had found it advantageous to come to Great Britain or go to America. His own experience was that at the present time there was not a fair living to be made by a private professional engineer in New South Wales.

Major Copeland.

Major H. P. Ramsay Copeland observed that it was not quite clear to him where the action of the arch came in. The Author had dealt with the arched dams as sections of rigid cylinders, and in his opinion they were such, as they were tied in at the bottom and at the haunches. It was known that in striking the centering of a vertical arch compression took place, which meant movement. Unless there was a certain sliding action on the base of the dam, it seemed to

Major Copeland.

him that the principle of the arch did not come in, and he thought the question of the behaviour of a curved dam under pressure might well form the subject of a special Paper. In the discussion of a Paper on the Sweetwater dam by the American Society of Civil Engineers, the Author, Mr. J. D. Schuyler, expressed the opinion that gravity and arch action must go hand in hand. He pointed out that the gravity of the mass in an arched dam was always resisting an overturning force to the extent of its ability, and he could not conceive by what reasoning it would occur to anyone that in order to permit a dam to act as an arch it was necessary to increase the profile. If the profile were designed of such dimensions that it would resist by gravity the quiet pressure of water, the arch was not called into action until the pressure was increased by some extraordinary event such as wave-action, ice-thrust, or earthquakes.[1] Major Copeland considered that the dams acted as rigid cylinders rather than as arches, and he would like to hear Mr. Darley's opinion on that point. With regard to the consistency of concrete, the Author mentioned "dry concrete," "sloppy concrete," and "very sloppy concrete," and recent writers on concrete[2] spoke of "dry," "medium or quaking," and "very wet or mushy" mixtures. There seemed to be no finality with regard to those terms, and he thought the time had arrived when precise terms should be adopted, for the purpose of drawing up specifications for mixing concrete. There was no doubt that there was a definite and proper quantity of water for concrete, anything more or less than that quantity being injurious. Mr. J. Watt Sandeman had urged[3] the vital importance of uniform consistency of concrete, and had expressed the opinion that the proper quantity of water to ensure thorough hydration, without washing the cement out of the concrete or causing the aggregates to settle down in contact with each other, could be determined only by an engineer experienced in the manufacture of concrete. Major Copeland thought sufficient experience had now been gained to enable the exact amount of water required for mixing concrete to be specified. It was known that certain materials used for aggregates took up more moisture than others, and it was an easy matter to determine by test the proper quantity of water for any given aggregate, which should be strictly adhered to throughout the work. While the Author advocated very dry concrete, Messrs. Taylor and Thompson stated that one of the best examples of rubble concrete

[1] Transactions Am. Soc. C.E., vol. xix, p. 229.

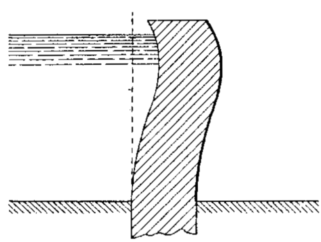
[2] F. W. Taylor and S. E. Thompson, "A Treatise on Concrete, Plain and Reinforced," etc. New York, 1905.

[3] Minutes of Proceedings Inst. C.E., vol. cxxi, p. 222.

Major Copeland. which had come under their observation was the dam of the Jersey City Water-Supply Company at Boonton, N.J., built in 1902–7. The concrete was mixed extremely wet—in fact, like pea soup—so that when dumped it spread out, forming a level bed for the stone. As soon as a bucket of concrete was dumped, a large stone was dropped—not lowered—into the wet mass, usually with its smoothest face downwards. It bedded itself in the concrete, and labourers joggled it with crowbars to bring it to a firm bearing and drive out all air-bubbles. As a Colonial engineer and one who had had the privilege of serving under Mr. Darley, he wished to express his gratification at the cordial reception given to the Paper by the members, and also at the graceful compliment paid by the President's observation that something could be learned from Colonial engineers. He was sure the words of the President would have a far-reaching effect; they would be read by all young engineers in Australia, who, he was quite satisfied, would be stimulated to emulate the success which the Author had achieved. He believed the number of Papers coming from New South Wales would increase, and the result would be to draw closer the bonds of unity existing between The Institution and the Colonies, and probably lead to some action on the lines of the Imperial General Staff. The engineer had duties in war as well as in peace, and hearty co-operation and good organization in times of peace would ensure a better shouldering of responsibility in times of national emergency.

Mr. Martin. Mr. H. M. MARTIN observed that the Author described some very interesting and important work in connection with curved dams, and gave a formula for fixing the wall-thickness, based on the theory that the dam resisted by arch action, or rather by ring thrust, since the fact that the dam abutted at its ends on the sides of the valley was neglected. In order, however, that this ring thrust should be developed, it was necessary that the structure should be free to yield radially. At the top it could do so fairly well, but at the bottom it could not move at all, and therefore in whatever manner it did resist here, it was certainly not by arch action or ring thrust. A good many years ago, when he had a greater belief than now in the general applicability of the mathematical theory of elasticity, he worked out the stresses in a ring dam fixed at the bottom and it turned out that under the water-pressure it deflected in a very curious way. In *Fig. 17* the original water-face was shown by a dotted line, and the water-pressure distorted the face into a curve of double curvature as shown to an exaggerated scale in the diagram, so that at the base there was very severe bending action. The maximum deflection was, it would be seen, not at the top of the dam but a little way below it. This occurred because the water-pressure being small at the top, the layers there could help those below. A rectangular section would not be used in practice for a large dam, but it was much easier to calculate than the types represented in the Author's Paper. He thought, nevertheless, that in all probability the dams shown by the Author would also have their maximum deflection at a point below the surface. So far as he knew, the only dam of that type which had been analysed at all thoroughly was the Bear Valley dam. That was 48 feet high, 3·17 feet wide at the top, 8·42 feet at the bottom, with a radius of 335 feet.[1] About 20 years ago a careful analysis was made of the stresses in this dam, assuming it to act as an elastic structure. The analysis was made by Messrs. Vischer and Wagoner,[2] and although they made some slight slips in deducing their formulas, their general result was apparently accurate. They found that, assuming the dam to act as an elastic structure, the bending stress at the bottom was 80 per cent. of what it would have been had the structure been a straight dam—though, of course, a straight dam could not have carried the load for an instant. This result merely showed that in such cases the mathematical theory of elasticity did not always give correct results. In fact, he had long felt that when a structure could resist in two ways, as for instance by arch action and by bending action, the theory often gave results which were falsified in actual practice. Suppose, for example, that the bending stresses were excessive at the bottom of such dams as those described by the Author and the joint there opened: what would happen? The dam could not go down-stream because it could not get away as long as the arch held. There might be leakage, but the dam could not collapse. Mr. Martin.

Fig. 17.



Mr. Edward Sandeman was glad the Author had given some particulars of the cracks which had occurred in five out of the thirteen dams described. The question of contraction in dams was a very interesting one. It seemed at first sight very difficult to account for the variable behaviour of large masses of masonry under changes of temperature. It was an undoubted fact that most Mr. Sandeman.

[1] These are the dimensions stated in Wegmann's "Design and Construction of Dams." See, however, Transactions of the American Society of Civil Engineers, vol. xix, p. 221.—Sec. Inst. C.E.

[2] Transactions of the Technical Society of the Pacific Coast, 1889.

Mr. Sandeman. masonry dams had cracked, and the reason why a few had not cracked seemed obscure. Fortunately some light had been thrown upon the question recently in a Paper read by Mr. Charles S. Gowen before the American Society of Civil Engineers. The Paper described the effects produced by changes of temperature in the masonry of the New Croton dam for New York. In the interesting discussion which followed, other engineers gave their experiences, and the gist of the whole matter seemed to be the following. Contraction occurred mostly in large masses of masonry which were built in the summer months, and occurred least in masonry built in winter. Most masonry work being built in summer-time, the result, according to Mr. Gowen, was contraction when winter arrived, and usually cracks as a result. Mr. Gowen's theory for the prevention of cracking was interesting. He suggested that a large mass of masonry built in the summer-time should be covered with another mass built in the colder months, say, October, November, or December, before the frost came; and that plan seemed to prevent contraction to a large extent. His own observations somewhat bore out Mr. Gowen's theory, and he hoped at a future time to be able to give more particulars. He would be glad if the Author could throw any light upon the question by reference to the dates at which the different portions of his dams were constructed.

Mr. Jones. Mr. C. E. Jones remarked that when he heard the Paper read his fears were aroused and he thought a dangerous point had been reached in the construction of dams for impounding water. Having had some dams under his responsible charge for more than a quarter of a century, he felt very much concerned about the engineers who had charge of the dams described in the Paper, and he thought that the responsible engineers in Australia might at times pass sleepless nights. The method described by the Author appeared to him to be a daring innovation in the construction of dams, and although the dam seemed to have been successful and efficient, he doubted very much whether they would be applicable at home. The mode of construction appeared to be more suitable for a climate like Australia, the variation in atmospheric conditions being there less severe than in England, where the temperature would vary in a year through a range of more than 100° F. Most engineers had been taught that dams should be constructed of a homogeneous material, and an honoured Past-President of The Institution, the late Mr. Thomas Hawksley, in describing how to make a dam, said it should be made of material resembling lead as closely as possible. Mr. Jones had not the slightest doubt that that was true; and when he saw a dam constructed with modern concrete and lumps of stone thrown here and there, he could see in it no resemblance to a pig of lead and doubted whether the dam was improved by putting blocks of stone in the concrete, probably leaving air-spaces beneath them. Perhaps the Author would say why the stones had been put sometimes in mortar and sometimes in concrete, because mortar and concrete could not be of the same tensile strength and therefore there was a source of weakness in that respect. The oldest of the dams had been standing for 12 years, a very short experience. He wondered what the people of Sheffield would say to a wall such as that depicted in Fig. 7, Plate 1. Many years ago the Dale Dyke embankment at Sheffield burst, causing considerable loss of life and great destruction of property; but that dam, to all appearances, was five or six times as strong as any of the Australian dams. If a dam like these Australian dams had been built at Sheffield it would have been in the Don long ago. With regard to coal beneath the reservoir, wherever coal was got there was always subsidence of the ground. He had in his charge a dam built on a site from beneath which coal had been removed many years before by the owners of a neighbouring pit. That dam had been leaking for 25 years to his knowledge, and was leaking to-day. In the same neighbourhood there was another dam that was always leaking, and a local geologist advised that the rocks should be blasted. The engineer shook the rocks with dynamite until he got an ample supply of water, but the dam was unable to retain it. Mr. Jones.

Sir ALEXANDER BINNIE, Past-President, remarked that the chief characteristic of the Paper was that it was a practical one, in no sense theoretical, and was modest in the opinions expressed. Anyone reading the Paper and looking at the wonderful cross sections must, as Mr. Hudleston had remarked, be somewhat at sea. He thought the Author of the Paper had done himself considerable injustice in the way in which he had presented it to The Institution. To look at the cross sections produced a blood-curdling sensation, because it was not evident, without going carefully into the matter, that the walls were not straight, but curved. In that respect he thought the Paper was somewhat deficient, and he hoped that Mr. Darley would kindly communicate to the Author an intimation that the Paper would be much enhanced in value if a plan of each dam could be added to the illustrations, as that would render an obscure point perfectly simple.[1] The lesson taught by the Paper was one which Sir Alexander Binnie.

[1] Plans of five of the dams have since been furnished by the Author, and have been reproduced in Plate 2.—SEC. INST. C.E.

Sir Alexander Binnie. engineers were always learning—the need for adapting works to the circumstances under which they had to be constructed. It was not a matter of cavilling at theory or formulas; the dams had been built and were standing. The problem that now arose was for mathematicians to show how the strains were accommodated in such apparently narrow walls. That they were accommodated was a fact, and the members were indebted to the Author for bringing before them something which undoubtedly tended under certain circumstances, and proper circumstances only, to very economical construction of dams for the retention of water. He desired to look at some of the sections in the light of the materials of which they were constructed. The Paper was not only a practical paper in the way in which the works were designed, but very practical in the sense of the remarks made with regard to concrete. Every engineer had had much to do with concrete, and one of the things that struck him was the great care that had been exercised in varying the actual proportions of the concrete according to the aggregate that was being used. One speaker had remarked on the indefiniteness of the terms "wet" and "dry" concrete, and such terms were indefinite unless the material to be dealt with could be stated accurately. A concrete composed of granite mixed with a proper proportion of sand and a certain quantity of water might be an exceedingly wet concrete; but supposing the aggregate was a somewhat absorbent stone, with the same quantity of water it might be a very dry concrete. It was not in that sense, however, that the Paper impressed him, but in the sense that in building such large masses of concrete it was of the greatest possible advantage to use dry concrete; because if the concrete was allowed to remain in the condition of a wet mixture, as it dried the water disappeared, and consequently there was a more or less porous mass left ultimately to deal with. The horizontal cracks noticed in concrete which was mixed wet were caused by the exudation of the water used in excess of the necessary quantity. A properly dry concrete was a solid mass which would shiver like a jelly, indicating that there was no fluid water other than what appeared upon the surface. The component masses were in contact, and just enough lubricating water was left to cause them to move on each other. Further, concrete used in that way had all the air worked out of it. The working out of the superfluous water and of the small particles of air was really the art of making concrete. Engineers were only beginning to understand how important these matters were. The most valuable part of the Paper related to the cracks which had appeared in some of the dams. No doubt they were due to a certain extent to the very thin sections that had been adopted, although it was somewhat difficult to say that, when it was known that even in the most massive gravity dams cracks had occurred. In masses of concrete or masonry there must be expansion and contraction with changes of temperature, and in dams which were exposed not only to changes of temperature but also to severe varying compressive stresses as well, the importance of the question was emphasized. The problem of the cracks that had occurred in some of the dams resolved itself, as suggested in the Paper, into the question how to build so that the cracks which must inevitably occur should occur in directions less harmful to the structure itself. There were many lessons for all engineers in the Paper, and he thought The Institution was greatly indebted to Mr. Darley and to the Author for bringing forward matters which were exceedingly interesting, especially when considered in conjunction with the discussion on gravity dams in The Institution a year ago.[1] Sir Alexander Binnie.

Mr. CHARLES HAWKSLEY, Past-President, was glad to see that it was not intended to pursue the system of building dams with a battered face on the water side, which appeared to him to be open to the grave defect that, in case of any uplift, the dam was more easily overturned than it otherwise would be, because of the leverage afforded by the battered face being next to the water. With regard to concrete, he thought the terms "dry" and "wet" were liable to a good deal of misunderstanding. He was not himself in favour of very dry concrete, believing that it ought to be sufficiently wet to enable it to find its way completely among all stones with which it was mixed. It ought always to be so wet that when it was turned moisture would rise to the surface. Mr. Hawksley.

Mr. CECIL W. DARLEY observed that there had been a little misconception, no doubt due to the absence of plans, in connection with the gravity-section tangents to the curved dams. These tangents were adopted only in cases where one or both slopes of the valley in cross section fell back suddenly near the upper portion of the dam. For instance, in the case of the Tamworth dam the slope rose abruptly on one side to full height, while on the opposite bank it rose steeply for the greater part of the height and then fell away. It was on this shallow, flat portion that the gravity section was introduced, in preference to extending the curve over an unsuitable site. The Barren Jack dam had not been authorized when he left the Colony, but he had had preliminary plans prepared. He investigated the question of making a curved dam, but abandoned it Mr. Darley.

[1] Minutes of Proceedings Inst. C.E., vol. clxxii, p. 89 *et seq.*

Mr. Darley. very early, and he did not know until the fact was just now mentioned by Mr. Burge that the Author had since proposed to the Public Works Committee that it should be a curved dam. It was so long that there would be no economy in using a curve. All the curved dams had been constructed by day work, as he would not run the risk of allowing a contractor to do the work. When the construction of concrete dams was first commenced in New South Wales some years ago he had three gravity-section dams under construction, at Armidale, Junee, and Goulburn, and a contract was first let for the Armidale dam. There was not much choice of contractors, and the Government obliged the lowest tender to be accepted; some small man took the contract on, but not having sufficient capital, he failed. The work was let to another contractor, who also failed. Mr. Darley then recommended to the Minister the construction of the dam by day work, and two dams were thus built and finished within the original contract-price. With careful officers and adequate supervision the work would be done just as cheaply in that way, because proper plant could be provided, which could be moved from one dam to another. In the case of the Cataract dam it was decided to commence by day work and, after the work was fairly started, to let it to a contractor. He was commissioned to visit America and inspect a number of dams in course of construction there. He saw a number of Lidgerwood cableways being used, and on a dam near Boston he saw compressed air used for driving the machinery; in every other case steam was used. After consideration he decided on electrical driving for the whole of the machinery, and spent about £30,000 on plant. That plant had paid for itself. It had constructed the Cataract dam and was now being moved on for constructing the Barren Jack dam. The plant belonged to the Government, and with proper supervision it would last a considerable time. Stones weighing up to 4 tons were used in the Cataract dam, and in the Barren Jack dam the stones used would weigh up to 6 tons. With cableways travelling at 1,200 feet per minute in and out, and at 400 feet per minute for lifting, these stones could be moved very quickly. With regard to the question of the life of dams, concrete was a durable material, and there was every reason to believe that, if properly made and put in, it would improve by hardening in course of time. Some of the Australian dams had been standing 12 years, and he did not see why they should not be in even better condition a century hence. With regard to the shearing stress, looking at the Medlow dam to which Colonel Pennycuick had called attention, it might at first sight appear as if a section of the dam could be pushed out under shear:

the dam must, however, be looked upon as a portion of a cylinder; and with a cylinder of equal thickness surrounded by water it was hard to see how any shearing stress could come in, the dam being in compression all round. With regard to the use of plums, they saved a large quantity of concrete, and good stone had a higher crushing resistance than concrete. Where cement was costly, as in New South Wales, and cartage into places difficult of access had to be considered, it was important to save as much cement as possible, and therefore stone had to be used very largely in the walls. Mr. Darley.

*** The Author's reply will be found at the end of the Correspondence.

Correspondence.

Mr. H. BELLET, of Lyons, remarked that the formula $T = \frac{R\,P}{S}$, given by the Author for calculating the thickness of an arched dam, was the standard formula; it had the advantage of being extremely simple, but, on the other hand, it could only give the magnitude of the normal compression-stresses to which a curved wall was subject, and even that only away from the immediate neighbourhood of the base. First, this formula supposed that the deformed wall maintained a circular curvature, or that in the same horizontal plane the various elements of the arch underwent the same radial displacement, like a cylinder which contracted uniformly. It supposed also that the compression to which the arch was subjected was distributed uniformly. But this was not exactly true, for the ends could not slide on the abutments, and therefore after deformation the wall took up a form approaching to an ellipse. The result was a bending-moment which introduced bending and shearing stresses, varying at different points in the length and thickness of the arch, and of these the standard formula took no account. However, these stresses were small, so long as T was small compared with R. Again, the formula supposed that the wall was very thin, which was only approximately correct just at the top of the dam. The deeper the sections taken, the less exact did this formula become. The pressure was always greater on the down-stream face Mr. Bellet.