

on the Indian side. It was noticed that Mr. Shadbolt had made Mr. Preston. an estimate for a broad-gauge line—there being no broad-gauge line on the Indian side—while Mr. Lewis had made an estimate for the metre gauge. Was it the intention of the Indian Government to make a broad-gauge connection? Because, if so, it meant at least adding 170 or 180 miles to the length of broad-gauge railway that would have to be laid. The Author might also have given some information as to material. It seemed difficult to form any opinion as to whether the embankment should be made right across, quite apart from the question of currents and the necessity for keeping the waterways open, or whether it would be better to make, as the Author suggested, partly embankment and partly bridges. If it was an embankment, it must depend entirely on material, and the Author had said nothing as to the material that would be available. According to Mr. Lewis, rubble would have to be brought about 120 miles, but the question was whether it was obtainable in any quantity. It was essential in any scheme to know what materials were available.

Mr. R. ST. GEORGE MOORE said the Author proposed openings Mr. Moore. and an embankment. He had produced sections and criticized the embankment proposed by Mr. Shadbolt and the embankment proposed by Mr. Lewis, but he had only said that his own embankment was to have stone ends. Therefore it would be valuable to have the details of the embankment that he proposed.

. The Author's reply to the Discussion is printed at p. 326.

Correspondence.

Mr. ROBERT C. BRISTOW remarked that, having had some years Mr. Bristow. experience in dealing with constructional work in a tideway, and over sandy deposits, he would like, in the first place, to congratulate the Author upon his complete and lucid presentment of the subject. It seemed fairly obvious that the existing sandy deposit which formed the half-submerged "Adam's Bridge," maintained its position as a whole, notwithstanding alternate monsoons from the north-east and south-west, each of which replaced, somewhere on the bank, material which the previous one had displaced. Further, it was clear that openings in the sandbanks had been formed approximately in the naturally suitable positions for the

Mr. Bristow. relief of water ponded up during monsoon periods. These conditions were well known, and the conclusions to be drawn from them were believed to have been ascertained with some degree of certainty by experience, namely:—(a) it was difficult, if not impossible, to predict in what manner a system of tides and currents would be affected if existing channels were closed, or obstructed, in the vicinity; (b) scouring might occur in the most unexpected places and prove very difficult to deal with; (c) as a rule, therefore, works should be designed so as to disturb as little as possible the natural currents arising from existing physical contours above and below water-level. Examples in support of this could easily be given, but it was believed that for the majority of cases the statement would be generally accepted. In the present instance, however, one of the engineers who had studied the question on the site, boldly advocated blocking the water-channels entirely, making a solid barrier from India to Ceylon. This was rather an exceptional case; but here, again, it seemed inevitable that the existing tides and currents would be affected along the coasts, and possibly experience alone would decide whether for good or evil. It might be a serious matter, for instance, if the shutting-off of what was practically an outlet, or overflow, were to result in raising the tide level at neighbouring coastal stations by 2 or 3 feet in stormy weather, which was quite a feasible supposition. Secondly, it was probable that another result would be the eventual silting-up of the bottom on each side of the barrier, as hoped for by the designer; but, before this occurred, considerable scour might go on during certain seasons of the year which would affect the stability of the structure before the following period of accumulation began. Thirdly, there seemed to be no particular advantage in a solid barrier *per se*; and if a means of construction were devised which left the physical features more as they were, such an alternative would presumably be more acceptable, if not too costly. A few notes, therefore, tentative and subject to revision by those better acquainted with local conditions, were submitted as to the construction of the proposed embankment or viaduct. This would have to pass over about 20 miles of land and water, and rock was stated to exist for a good part of the way at 35 feet below average low water, the rise of tide being practically negligible as a rule. Considering first that portion of the structure across the water (about half the total distance) and applying the principles noted above, the supports of the structure would be designed as small as was consistent with safety, in order not to obstruct the waterways; and they would go down to rock wherever possible, to give vertical and

lateral stability in the sandy bottom. The ordinary jetty type of Mr. Bristow. construction seemed suitable in such a case, the piles being driven with the aid of a water-jet if necessary, and all the work executed in reinforced concrete. In deep-water piling—say, over 25 feet—two piles driven raking (or at least one of them raking) and joined into one stem above low water, would be found extremely strong and rigid. Mr. Bristow had used this system with success in difficult cases. As to the type to be adopted over the sandbanks, an embankment, protected from wind and scour, might perhaps be made secure in this position; but, being affected on both sides alternately by monsoons, this long embankment would probably prove to be a continual source of anxiety, and also expensive to maintain. For these reasons it might be better to continue the piled formation right across the sand, neglecting the latter entirely as a means of support. The superstructure throughout would be simple in form, on familiar lines, and, in the absence of much rise and fall of tides, easy to construct. As all the bays would be practically the same, except in the matter of bracing, there would be an enormous amount of repetition work; and, assuming similar physical conditions, such a scheme would probably cost not more than a million pounds if executed in this country in peace time. The design by Mr. Lewis (*Fig. 6*) showed some rather unusual features. The “jetty formation” in this case was closed in by slabs of concrete down to sea-bed. Some excavation and levelling up would certainly be found necessary before fixing the bottom slabs. It appeared, therefore, that it was proposed, not only to close all the water-channels, but also to carry out excavation work in them, and fixing of slabs by divers over a total distance of about 20 miles (counting both sides of the barrier across the water areas). This seemed a rather formidable proposition, and weighty arguments would appear necessary in favour of a scheme which included such a disability. No method of fixing the slabs was proposed, and it was assumed, apparently, that their weight would hold them vertically in position, and hard up against the piles. Some proper fixing would surely be necessary, and this was not so easy to provide when jointing reinforced-concrete members below water. Again, the stud-link chains and iron caps referred to as temporary measures were rather unusual. The chains and caps could not be fixed until the piles had been drawn into position and held fast by other means, and this being done, it seemed that the top bracing might just as well be added at once, and the chains and caps omitted altogether. The chains below low water would necessitate further divers' work in fixing, and this would be a troublesome job if the

Mr. Bristow. chains were stretched really taut, as would be desirable. It would be of interest to know how it was proposed to make the joints of the slabs previously referred to "watertight by cement." Surely this would be a difficult if not impossible task below water. The very heavy cost of divers' work, and the practical difficulties to be overcome, appeared to be serious disadvantages to this scheme, apart from the time it would take to complete, and its subsequent effect on the tides and currents. Perhaps, however, the Author could give other information which would throw a more favourable light on the proposal.

Mr. Brodie. Mr. J. B. BRODIE remarked that the object of the Paper, as the Author admitted, was to elicit discussion on the question whether Adam's Bridge, in view of the currents across it, should or should not be constructed as a solid causeway. An engineer who had not seen the site, or studied the phenomenon of the tidal currents, and who had no experience of a north-eastern or a south-western monsoon, naturally hesitated to advance an opinion, but accepting the information regarding the physical features of Adam's Bridge as related by the Author, it occurred to Mr. Brodie to make the following observations. Out of a total length of 20 miles the Author proposed to close 10 miles with embankments, including the existing sandbanks, and provide 10 miles of openings at all places where the depth of water exceeded 3 feet, believing that to encroach further on the channels would entail serious acceleration of the currents coupled with greater scour, whereas Messrs. Shadbolt, Stracey and Lewis proposed to close the whole length with solid structures, believing that if the channels were closed they would silt up. The Author's proposal would appear to be a half measure towards the solution of the scouring process, whereas the solid construction was a straightforward proposition having for its object the stopping of the scouring action of the currents. Considering the statement in the Paper that all heavy seas broke, owing to the shallowness of the water, at least $\frac{1}{2}$ mile from the crest of the ridge, and bearing in mind the configuration of Palk Strait and the Gulf of Mannar, the direction of the monsoons, and the range between high and low waters, there was every likelihood, if a solid causeway were constructed, that the channels would silt up; whereas if the channel were restricted to half its width only, a greatly-induced scouring effect would occur, and the maintenance charges would be considerably increased. It was quite conceivable that it might have been possible at one time to walk dryshod from India to Ceylon across the bridge, but throughout the ages it had been

broken down to the extent of 10 or 12 miles, owing no doubt to Mr. Brodie. the ravages of time and to the scouring action of the tidal currents, which was still going on. If, in the accomplishment of a railway connection between India and Ceylon, a form of construction could be adopted whereby this scouring action could be reduced if not entirely stopped, that form of construction would seem to offer the best solution of the problem, notwithstanding the greater expense that would be involved. The problem might also be looked at from the following point of view:—Was it desirable, in an important work of this kind, to provide a relatively cheap railway connection, with a probable large annual maintenance and renewal charge, or to provide a solid and substantial work with little or no annual charge for upkeep? From this point of view it would seem that the solid causeway, notwithstanding the greater expense and the difficulties of construction, offered the best solution. A modified section on lines similar to that proposed by Mr. Shadbolt appeared best to fulfil the conditions for a stable structure with a low maintenance-cost, although exception had been taken to the use of heavy rubble which could not be obtained within 120 miles of the site; but even at this distance the difficulty did not seem to be insurmountable, considering the importance of the work; and the plan was to be much preferred to the reinforced-concrete pile-and-slab construction proposed by Mr. Lewis. The Author did not indicate the form of construction which he proposed to adopt for the 10 miles of bridging, but the maintenance and renewal charges, through deterioration, on a work of this kind, whether in steel or in reinforced concrete, could not be compared to the rubble-mound form. In this criticism the fact that increased scour would be created in the Pamban Pass, if a solid causeway were constructed across Adam's Bridge, had not been lost sight of; but the advantages to be gained on the one hand appeared to Mr. Brodie to outweigh any disadvantages that might occur through difficulties of navigation.

Mr. A. E. CAREY observed that the Paper raised one of the most Mr. Carey. interesting issues submitted to The Institution for some time. The problem of creating a barrage across the chain of reefs and sandbanks between India and Ceylon opened a fascinating vista of investigation. The basis of proposals for effecting the desired end offered many tempting suggestions to those specially interested in work of this class. Mr. Carey did not know the locality, but the condition of affairs indicated in the surveys in Plate 6 was, broadly speaking, familiar. In the case of Mont St. Michel the French

Mr. Carey, authorities had run a causeway and railway across the sands from the mainland to the island. To those who remembered Mont St. Michel as approached across wide stretches of treacherous sands, this action had turned into commonplace the charm of one of the most romantic spots in Europe. Mont St. Michel being in the Bay of Cancale, the rise of tide there was abnormal, and shifting patches of running sand formerly rendered the passage across them by no means free from danger. Mr. Carey had a vivid recollection of watching thousands of sea-birds floating in with the tide during its extreme September range, thus furnishing a graphic index of its extraordinary velocity when the sea began to overlap the edge of the sands. The origin of the chain of shoals, sandbanks, and channels intervening between Ceylon and the mainland gave, he thought, a clue to the method by which a route of access could possibly be secured. It was the opinion of early observers that Ceylon and India had formerly been united, but this view was now, from the geological side, exploded, as in the existing formations there was no evidence of tectonic movement, and the fauna and flora of India and Ceylon had marked differences. Strong currents traversed their coast-line, and as the south-west monsoon lasted longer than the north-east monsoon, its permanent effects were more in evidence, the spits formed at the mouths of rivers being hooked and sometimes extending parallel to the coast-line for miles in the direction of the dominant currents. It was highly probable that in the course of time, along the line of Adam's Bridge, an uninterrupted barrier would be slowly produced by natural forces, linking up its chain of shoals and banks. What was termed "littoral concretes" were now in process of regular formation.¹ The tessellated platform of coralline sand which stretched across the Strait had been produced by cementation of sands and gravels through the instrumentality of zoophytes, resulting in calcareous sandstone and coral reefs. It appeared to him that the same agency which had thus within a recent period produced conglomeration in the isolated shoals could be utilized to complete the chain of connection and achieve the desired end. The process would, however, be an extremely slow one. By the deposition of rubble, or by means of a piled structure with a core of sand, the end to be attained would be the formation of a barrier across the deeper shoals, which barrier during formation would be kept as nearly as possible at a uniform level. It would not be necessary to follow

¹ J. Lomas, "On the Origin of 'Adam's Bridge.'" Transactions of the British Association, 1903.

any hard and fast line, but to select such routes as would result in Mr. Carey. the greatest economy in material. The object of this submarine barrage would be to stagnate the currents flowing through the deeper channels. The action of the littoral forces would then probably heap up the sand and tend to create a more or less continuous under-water barrier. Of course, if the operation were not carried out uniformly, its effect might be to induce increased scour in certain localities; but the evidence available seemed to point to the conclusion that the calcareous consolidation of the submarine deposits would prevent erosion to any considerable degree. Upon the barrage so formed, when raised to a level which rendered the operation practicable, the reinforced-concrete skeleton of a dam could be reared, its outer walls to consist of reinforced-concrete shields and its hearting of sand. Raising this at a uniform level, the consequent growth of an accreted embankment would be slow and gradual. Step by step the work might be heightened until it reached a few feet above water-line, when the natural accumulation of sand having been fostered to a level which would permit of the growth of marine plants,¹ advantage would be taken of these to consolidate it into a causeway. An *Ipomoea* and the *Spinafex* were probably the most potent vegetal allies, but the South American species of *Spartina* could, perhaps, be brought into service to advantage. The accretion of sand, capped by a crest within the zone of tropical vegetation, and thus rendered incapable of erosion, would by slow degrees convert the structure into a continuous embankment. The operation would be on a gigantic scale, but the movements of littoral deposit would also doubtless be of correspondingly vast proportions.

Mr. W. DYCE CAY considered that the various schemes for con- Mr. Cay. structing a railway across the Straits upon the line of shoal called Adam's Bridge did not sufficiently take into account the physical causes of the shoal, which, roughly viewed, were that the sand stirred up and borne by the south-east monsoon, and carried by the current across the "Bridge," was deposited in the slack water, caused by the breaking of the waves in the shallow water across the line of the shoal. If, however, a solid embankment, such as was shown in *Figs. 3* and *6*, were carried along the "Bridge," the general current across the site would be stopped, and the movement would be confined to several bridges, which on the Author's scheme would occupy 10 miles, or say half the length. These outlets would

¹ Tennent's "Ceylon," pp. 48-50, gives a clear description of the sequence of halophytic vegetation on the Ceylon coast.—A.E.C.

Mr. Cay. carry silt into the Palk Straits, but would not maintain Adam's Bridge. He feared that the parts of the latter which were not bridged, not receiving any depositing current, would be undermined by the waves, and the sand would be drawn down into the deep water of the Gulf of Mannar; and that heavy works would be required to maintain the railway on its south side. He thought the best plan would be to construct over the whole length an open viaduct, similar to an English south-coast pier, supported on concrete or metal piles. This would involve no interference with the action of the monsoon forces, and its accommodation could easily be extended as required.

Mr. Cooper. Mr. A. G. COOPER stated that, in connection with certain proposals of the Ceylon Government, soundings had been taken at intervals of 6 months at both the Talai Mannar piers since January, 1916. The sections plotted from these soundings showed that the sea-bed varied slightly in level along the line of and near the foreshore at both piers during the different monsoons, due probably to sand-drift. These soundings had not been taken over a sufficiently long period to determine whether the deposit of sand was causing any permanent growth of the foreshore at the piers. Observations taken over a prolonged period might show that the deposit was only a temporary one. Should it prove to be of a permanent character or to last over any considerable period, it might be necessary to lengthen the north pier, which at present was used in both monsoons. The direction of the sand-drift along these coasts probably coincided with the prevailing monsoon, and the position, size, and height of the sandbanks would be affected to some extent by the strength and duration of the wind in each monsoon. Should the project outlined in the Author's scheme be carried out, the sand drift would be held up permanently along the portion formed in embankment, and it was probable that in time long stretches of sand would form with well-defined channels towards the openings provided through the causeway. Careful consideration should be given to the possible effects of scour, and in building the bridges the foundations should be taken down deep enough to ensure the safety of the work. In determining the height of formation-level and the height of the top of the pitching on the embankments above high-water level, it was presumed that the Author had taken into account the possibility of storms, in either the Indian Ocean or the Bay of Bengal, driving in the sea towards Adam's Bridge and temporarily raising the level of the water. At the end of 1908 a typhoon broke over the latter sea, with the result that the water was driven into the lagoon lying

between the mainland of Ceylon and the Jaffna Peninsula shown Mr. Cooper. on the map (Fig. 1, Plate 6) at the extreme north of Ceylon. The railway here crossed the lagoon on an embankment, which was pitched with rubble up to formation-level. Formation-level was approximately 9 feet above the lagoon level at its deepest portion and 3 feet above high-water level. The incoming water broke over the embankment, causing considerable damage and stopping traffic for several days while repairs were carried out. Had it not been for a new 120-foot span bridge built in the causeway the previous year, the damage would have been more extensive. In the design of the bridges and viaducts concrete or reinforced concrete would be preferable to steelwork, on account of the high cost of maintenance of the latter material in proximity to the sea.

Mr. J. L. HOLMES remarked that, considered only as the struc- Mr. Holmes. ture to carry the railway, the Author's proposal to alternate embankments with viaducts was, in his opinion, much to be preferred to schemes for solid causeways or embankments throughout. Constructionally the section proposed by Mr. Lewis was particularly open to criticism, owing not only to the absence of ties and bracings to stiffen the structure as designed, but also to the impossibility of adding to them; it was also difficult to see how the reinforced-concrete slabs behind the piles could be accurately placed below low-water level. Mr. Shadbolt's proposal was more practicable, but it was doubtful whether the sand core and also the sand foundation would not be washed out by the stroke of the waves or the scour of the current. All these embankment schemes had one outstanding defect, which had been pointed out by the Author, and which to Mr. Holmes seemed insuperable: no consideration appeared to have been given to the issues involved by their construction. Practically they would result in converting Palk Strait into a land-locked bay. A study of the chart showed that Adam's Bridge, the Strait 21 miles wide between the islands of Rameswaram and Mannar, was kept open owing to its exposure to the direct onslaught of the breakers of the south-west monsoon. Before entering the Gulf of Mannar and up its centre the general direction of the rollers was probably north-east; along the coasts of India and Ceylon, however, they were inclined towards the land, and eventually they broke almost parallel with the shore, but sufficiently inclined to it to cause the travel of sand northward. Doubtless the islands of Rameswaram and Mannar owed their protection to the accumulation of sand caused by this inclined strike of the breakers. Opposite Adam's Bridge the direction of the rollers was still normal, and eventually they broke in full force against the

Mr. Holmes. weakest part of the connecting ridge. The tendency of the south-west monsoon was to heap up the sand at the north end of the Gulf of Mannar, and if this were the only factor the ultimate result would be the formation of a solid natural causeway across the Strait. This tendency was counteracted by the combined effect of the waves and currents of the north-east monsoon, assisted by the raising of the water-level on the north side and the draw-off in the Gulf of Mannar referred to in the Paper. The first result of the closing of the Strait between the islands by an artificial embankment would be that in both monsoons, and especially in the north-east monsoon, the water would be piled up by the force of the wind at the inner end of the Strait or Gulf, as the case might be; to what height he was unable to say, but it was safe to predict that it would be reckoned in feet, not in inches. The consequence would be an increase in the tidal velocity through the Pamban gap to such an extent as to prohibit navigation for the greater part of the year. Another result to be expected from the piling up of the waters would be the inundation of low-lying lands, especially those at the south-west corner of Palk Strait and the northern shores of Rameswaram. It did not seem probable that much of the sand and mud now brought into the Palk Strait during the north-east monsoon escaped again by the northern outlet; if the southern outlet was closed, the gradual silting up of the strait would follow—a slow but certain process. The foregoing objections seemed to be sufficient to put the embankment scheme out of court, and they also pointed to the necessity for avoiding any scheme which might introduce more obstruction to the tidal flow than there was under existing conditions. A systematic series of surveys for several years near the close of each monsoon would show what was to be expected in the way of the travel of the sandbanks; probably it would be found that while the ridge itself remained within certain limits the banks composing it were unstable, and that even those now above high-water level were liable to erosion. A facing of stone to the existing banks might be sufficient protection against erosion due to currents but would be practically useless as a protection against wave-action, however slight. It was impossible to predict how far erosion might extend either vertically or horizontally, and it appeared that the only satisfactory course would be to construct a viaduct for the whole length of the bridge, taking every pier down to rock level. In order to reduce to a minimum the obstruction to the free run of the tide, the spans would have to be made as long as was practicable. A point to be observed in the design was that all steelwork should be kept well above the reach of heavy spray.

Mr. JOHN D. ISAACS, of New York, observed that the problem Mr. Isaacs. of building a railway connecting India with Ceylon was similar in many respects to that of the Galveston Causeway, connecting Galveston Island, Texas, with the mainland. The water to be crossed was shallow, and in normal times there were moderate currents, set up by winds and tides. The first "permanent" causeway at Galveston consisted of 8,150 feet of sand filling, retained by reinforced-concrete protection, and 2,500 feet of reinforced-concrete arch bridges. In August, 1915, a storm of unusual violence destroyed nearly all of the protected filling, but left the arched bridging unscathed. During the storm the water-level of Galveston Bay was raised by atmospheric pressure, wind, and waves; the currents were accelerated and probably confused into eddies by the restricted waterway; and the usually harmless and shallow waters of Galveston Bay attacked the reinforced-concrete protection, undermining it at first in spots, and finally causing its total failure. In the light of the foregoing brief description of the destruction of protected filling construction, he believed the types of structure shown in *Figs. 3 and 6* to be hazardous for the exposed position under consideration. There was no assurance that a tropical storm of unusual violence would not some day approach the proposed structure from the Gulf of Mannar and produce similar effects to those which recently occurred at Galveston. The concrete walls shown in *Fig. 3* were not massive enough to resist attacks of heavy seas, and would probably be quickly undermined and destroyed in a storm like the Galveston hurricane. To be effective under such conditions they would have to be much larger. Instead of trying to resist wave-action and change existing current-conditions, it might be safer and better to so construct the bridge that waves and currents could go underneath with practically no change from present natural conditions. He believed that such bridging could be constructed for the entire distance from the Island of Rameswaram to the Island of Mannar without using very much more reinforced-concrete than was required for the type of causeway shown in *Fig. 6*. Reinforced-concrete girders on concrete piers, with concrete piles where necessary, would leave the original waterway practically unrestricted, and would guard against the dangers here described. From a strictly economical point of view, laying aside æsthetic considerations, and provided the proper material were available, it was likely that a creosoted-pile trestle viaduct could be constructed and maintained more cheaply than a substantial causeway.

Mr. Moore. Mr. GODFREY W. MOORE observed that the subject of the Paper was of great interest, not only on account of engineering considerations, but in view of the importance of connecting India with her wealthy neighbour, the Crown Colony of Ceylon, and of the benefits to be derived therefrom. He differed from the Author in regard to the necessity for openings. The only reason for providing openings appeared to be that the velocity of the current through the Pamban Pass would be increased, so endangering navigation through it, if, by the construction of a solid causeway, the difference in the level of the water on either side of the chain of islands and sandbanks of Adam's Bridge, separating Palk Bay from the Gulf of Mannar, were increased. While admitting that the effect of blocking up Adam's Bridge would be to increase the existing differences in the level of the water on either side of it, he contended that the increases in head would be inappreciable, and further that the effect of the increase in head would not extend to the Pamban Pass: he would also point out that, if the effect would be to increase the velocity of the current through the Pamban Pass, that disability could be overcome, at probably considerably less cost than providing openings at Adam's Bridge, by the provision of a lock at the Pamban Pass; or possibly it would not be a serious matter to close the Pamban Pass for navigation. The provision of openings for the railway across Adam's Bridge would add enormously to the cost of the undertaking, because, owing to the excessive scour that would certainly take place in the sandy bottom at and in the vicinity of the openings, it would be necessary, in order to ensure the safety of these structures, to found their abutments and piers on the rock about 29 to 42 feet or more below sea-level, as well as to construct either training-bunds to restrict the area of the scour, or other protective works—costly in maintenance as well as first cost—at each opening. Whether provision for such works had been made in the Author's estimate of Rs.25,500,000 or £1,700,000 was not known, but the financial practicability of the undertaking, even at this figure, seemed very doubtful. The existing difference in the level of the water on either side of the chain of islands and sandbanks of Adam's Bridge was caused mainly by the north-east and south-west monsoon winds, and varied according to their force and prevalence in one or the other direction. The effect of the wind was to head up the water on the windward shore and lower it on the leeward shore. In support of the contention that a causeway without openings would not appreciably increase the head of water, it was urged, in that the closing of the gaps in Adam's Bridge, which aggregated about

11½ miles in length, would add comparatively little to the existing Mr. Moore. obstructions in the channel between India and Ceylon, that the effect of doing so would not be great; and further, from another point of view, since there seemed to be no reason why the tide levels should be affected, except in so far as they were influenced by the wind, it was suggested that the wind blowing the water up against a causeway across Adam's Bridge, instead of over its shoals and sandbanks, would increase the existing difference between the water-levels on either side comparatively little, and would only have effect locally. As to the silting-up across Adam's Bridge hoped for as the result of the construction of the causeway, there seemed little doubt that silting would take place in the shallow-sea or north side, but on the deep-sea or south side there was not such certainty. It was difficult, if not impossible, to foretell what would be the effect, either locally or on the adjacent coasts, of stopping the cross currents through Adam's Bridge, but if the existing sandbanks and islands were washed away and sand did not accumulate alongside the causeway as anticipated, then artificial means for causing accretion, such as stone groynes, must be employed, or possibly protection by heavy boulders would be necessary, or even wave-breakers, as proposed by Mr. Stracey, might be required. Mr. Moore's late colleague, Mr. J. T. Lewis, possessed probably a more intimate knowledge of the tides, currents, and coasts of the seas in the neighbourhood of Adam's Bridge than any one else; Mr. Lewis had resided in and had been in close touch with the engineering work of the locality for about 20 years, first, while on the construction of the Madura-Pamban Railway, again when in charge of the investigation of the canal project through the Island of Rameswarum, and subsequently in connection with the construction of the Pamban Reef, for the successful completion of which, as chief engineer, he was responsible. It might, therefore, be stated that the scheme submitted by him was based on wide experience of the local conditions.

Mr. NEVILLE PRIESTLEY remarked that, not being an engineer, Mr. Priestley. he could not offer expert criticism either on the late Mr. Lewis's proposals or on the Author's objections to them, which seemed to fall chiefly under the following heads:—

- (a) That closing some of the openings or channels in Adam's Bridge would lead to an increase in the velocity of the current, accompanied by greater scour due to increased head, which would result in corresponding greater difficulty and cost in closing the remaining channels.

- Mr. Priestley. (b) That the complete closing of Adam's Bridge would result in increased velocity of current, possibly to a very serious extent, through the Pamban Pass.
- (c) That if the silting-up upon which Mr. Lewis relied should be unequal, his causeway would be subjected to lateral stresses which presumably it would be unable to stand.

Taking these objections in reverse order, the experience of the South Indian Railway Company in the neighbourhood, which now was considerable, did not suggest the probability of unequal silting; but if this should happen, the question was whether the silt pressure on one side would not be balanced by the water-pressure which would be exerted all the time on the other. Assuming that the Author's fears as to increase of velocity were realized, the Pamban Pass was 22 miles in a straight line from Dhanushkodi point, and the configuration of the island of Rameswaram did not suggest the probability of sea-water, which found itself checked at Adam's Bridge, working its way round to the Pamban Pass. Lastly, experience at Pamban did not lend support to the Author's fears. The objections raised by him had also been raised in regard to the crossing of the Pamban Channel. Expert opinion had been very divided as to the probability or otherwise of a causeway leading to an increase in the velocity of the current through the Pamban Pass. To avoid any risk of this happening a viaduct had been provided; but in building this viaduct and the Scherzer rolling bridge over the Pass, the channel had been obstructed to no small extent, and no increase in the velocity of the current through the Pass had been noticed.

Mr. Rothera. Mr. PERCY ROTHERA was of opinion that the general line of Adam's Bridge as a whole was permanent, as stated by both the Author and Mr. Lewis, but that the edges of the various sand islands were constantly changing during the different monsoons, due to the influence of winds and currents, the change naturally being greatest in the vicinity of the different openings. It was evident that sand was eroded from one side of the islands and deposited on the other side during one monsoon, and that the same process went on in the opposite direction during the other monsoon. This being so, Mr. Lewis's proposal to close all openings by solid causeways would appear to be somewhat dangerous. With all openings closed, and all current thereby stopped, no transfer of sand would occur from the windward to the leeward side of the islands during alternate monsoons, as was the case at present. Wave-action, however, would continue, and it was possible that instead of silting occurring, as Mr. Lewis surmised, a lateral travel

of sand along the shore might be set up, which would gradually Mr. Rothera. erode the islands between the causeways. This would be most likely to occur on the south side of the reef, where the south-west monsoon struck it diagonally. Unless this sand were replaced by shore travel from elsewhere, it was conceivable that eventually it would be necessary to protect the whole of the shore so affected, either by concrete causeways or by heavy wave-breakers and pitching carried down below the level of the wave-action, thus materially increasing the total cost of the scheme as proposed by Mr. Lewis. It was probable also that the closing of Adam's Bridge might increase the current through the Pamban Pass, which naturally would be detrimental to navigation; this point should by no means be lost sight of. On the other hand, any openings left in an embankment across Adam's Bridge, as proposed by the Author, would require very careful treatment to avoid scour. The Author proposed to provide openings at all places where the depth of the water exceeded 3 feet, but at each of these places heavy foundations would be necessary to protect these openings from future possible scour. It was suggested that it might be possible and advantageous to group openings so that while the same total waterway was provided as existed at present, the expense of abutments and possible training-works and liability to scouring at them could thereby be reduced. Mr. Lewis's criticism that the Author's scheme would involve "enormous expense both in construction and maintenance" appeared therefore to be warranted, for although the Author did not state the nature of the bridging which he intended to use, and on which his estimate was based, presumably his spans would be fairly large, in order to reduce the cost of the heavy foundations for piers and abutments which would be necessary to guard against scour. The maintenance of upwards of 10 miles of steel girder-work in such an atmosphere as existed at Adam's Bridge would certainly form a very considerable item of recurring expenditure. Mr. Lewis's proposal, on the other hand, would require little or no additional maintenance, and the question therefore arose whether that scheme, in spite of the danger of sand-travel pointed out above, might not in the end be the more economical. A very large amount of additional protective works, to counteract the sand-travel if it should occur, could be carried out before the capital cost of Mr. Lewis's scheme would equal that of the Author's. The commercial aspect of the advisability of the construction of a railway link between Ceylon and India at a capital cost of approximately Rs. 8,50,000 per mile, taking the average of the two estimates, had yet to be considered.

Mr. Sandeman. Mr. J. WATT SANDEMAN observed that the proposed construction of a railway on the site of the shoal called "Adam's Bridge," between India and Ceylon, afforded an engineering problem of great interest. The formation of this shoal was the result of a very long period of sand-drift under the combined action of waves and currents, this being confirmed by the occurrence of similar shoals between other islands and mainlands under somewhat similar conditions. Sand from the coasts of India and Ceylon was driven by the waves and currents of the north-east monsoon into Palk Strait, and by those of the south-west monsoon into the Mannar Gulf, Adam's Bridge being the resultant effect of the monsoons, as modified by the configuration of the coast-lines. The maximum speed of the currents during the prevalence of the monsoons was stated by the Author to be 6 miles per hour. If a viaduct were adopted for the proposed railway the temporary nature of the shoals on the line of Adam's Bridge would render it inadvisable to bank more than 3 miles in length of the higher banks. Embankments on short temporary shoals would necessitate the protection of their ends by means of close sheet piling and training-bunds, which might render their cost per lineal yard as much as that of a viaduct. The obstruction caused by the piers of a viaduct would increase the velocity of the currents between them to an extent which would necessitate abnormally deep and costly cylinder foundations, and it appeared questionable if it would be possible to sink these accurately in the desired positions during the prevalence of such currents. The solution of the problem appeared to him to be one which comprised the construction of an embankment over the whole length of Adam's Bridge. Such an embankment would, however, intensify the velocity of the currents at the Pamban Pass and Mannar Channel to an extent which might endanger the viaducts and embankments at these passages and render it necessary to close them by protective embankments. The closing of the whole channel between India and Ceylon would have the effect of raising the water-level in Palk Strait and Mannar Gulf alternately during the prevalence of the monsoons to such an extent as would render it necessary to provide a lock for the passage of ships in lieu of the Pamban Pass. In order to prevent interruption of traffic it would be necessary to provide such a lock before closing the present passage, and as it would be advisable that it should be in duplicate, a swing-bridge for the railway, spanning two locks, could be conveniently carried on a pier between them. Such locks would require double gates at each end, to enable ships to be locked

either up or down into Palk Strait or Mannar Gulf. The lock- Mr. Sandeman.
entrances on the Mannar Gulf side would require protective breakwaters, and these might be economically constructed in open pile work of reinforced concrete enclosing a hearting of rubble. On a sea-bed of sand such breakwaters possessed the advantage that in the event of scour taking place the rubble would settle down below the level of the sea-bed and could be readily replenished from above. Jetties for shipping could be constructed inside the breakwaters, which might provide valuable trade feeders for the railway. The great depth of the Mannar Gulf allowed the propagation of heavy ocean waves which at present broke within $\frac{1}{2}$ mile of the crest of Adam's Bridge, but the raising of the water-level by an embankment and the gorging and focusing of waves by the absence of an outlet for their run, would probably bring them up to the embankment, and would necessitate heavy protective works on the gulf side, particularly over the submerged portion. Judging from the cost of single-line viaducts over Indian rivers, the cost of 18 miles of viaduct and 3 miles of embanking over the length of Adam's Bridge would, in Mr. Sandeman's opinion probably be nearer £6,000,000 than £1,700,000, taking into account the difficulties of the situation, the present enhanced cost of labour and materials, and the necessity of providing 18 miles of temporary railway on piling to carry materials and workmen over the length of the viaduct. Such a railway alone would cost about £1,000,000. The cost of an embankment over the whole width of the channel between India and Ceylon, including that of two locks, would probably amount to nearly £3,000,000; but its construction would involve a problem of considerable difficulty in order to carry out the work in such a manner as to minimize the cost of destructive scour which would occur during the closing of the water-channels. One great advantage to be derived from an embankment as compared with a viaduct (even assuming that the latter were practicable) would be the provision of two spacious harbours of refuge, one in the Mannar Gulf during the period of the north-east monsoon and another in Palk Strait during that of the south-west monsoon. The suggested method of closing the water-channel by means of piling and concrete slabs would, in Mr. Sandeman's opinion, be quite impracticable, first because it did not appear to be possible to place slabs in position without the employment of divers, who could not work in currents of such velocity, and secondly because, if slabs could by any means be placed, the current would immediately undermine and dislodge them. It would also be impossible to seal the joints of slabs under water with cement, and piles could not

Mr. Sandeman. be driven accurately enough to enable efficient joints to be made between them and the slabs, so that the sand filling would be washed out. With reference to the proposal to construct a solid causeway between side walls founded on rubble mounds, he considered that it would be more economical to dispense with side walls and embank with rubble to formation-level, as the rubble would be liable to settlement for a time due to scour in front by waves. The raising of the water-level by closing the channels would enable waves to reach the walls enclosing the causeway, and the rebound from these would cut down the rubble, so that continual maintenance would be required, unless it were protected by heavy covering blocks. Before arriving at any decision in regard to the construction of a railway on the site of Adam's Bridge the following points would require careful consideration: (1) As to the effects which would result from the construction of either a viaduct or embankment. (2) Assuming that it were possible to construct a viaduct (which was very doubtful), the increased velocity of currents which would result, would deepen the channel to such an extent as to cause the passage of waves through the viaduct, and probably the formation of a shoal across Palk Straits north of the viaduct. (3) On the other hand, the construction of an embankment would cause shoaling on its south side in the Mannar Gulf, and shoaling at the northern entrance to Palk Straits.

Sir Francis Spring.

Sir FRANCIS SPRING, K.C.I.E., remarked that he felt a particular interest in the Paper because in July, 1908, he was asked to advise the South Indian Railway Company—who did not accept his advice—in regard to the western terminal arrangements on Rameswaram Island for the ferry then proposed, and since established, between Dhanushkodi and Mannar. His advice was that a basin should be made in the sand-spit forming the end of the island, with exits to the north and to the south between suitable pairs of walls running out into soundings deep enough for the ferry-steamers. The basin was to have been constructed on the same principles as had been adopted at Springhaven basin in Madras Harbour.¹ His idea was that, according to the state of the weather, the ferry-steamer could decide from hour to hour whether to run out to the south or to the north of Adam's Bridge for her voyage to Mannar. His advice as to the basin with a double entrance not having been accepted, the steamer was now obliged to do a voyage of 40 or 50 miles, round by Pamban, if ever she found it necessary, because of a change in the weather, to run

¹ Minutes of Proceedings Inst. C.E., vol. cxc, p. 119 and B, Fig. 1, Plate 4.

on the south of Adam's Bridge instead of on the north. As mentioned by the Author, however, the ferry-steamer nowadays habitually used the northern passage; chiefly, Sir Francis Spring understood, because she could not ordinarily lie quietly at the south pier because of waves. Had the basin idea been adopted there would have been no such trouble.

He was acquainted with Mr. Shadbolt's proposals, and had had occasion, officially, to criticize them favourably. The proposals of Mr. J. T. Lewis, M. Inst. C.E.—unhappily killed in Gallipoli as a Major in the Lincolnshire Regiment—were based on certain work done at Madras, as described in Sir Francis Spring's Paper.¹ The work in question, of which about 4,700 lineal feet had been done in Madras Harbour, consisted of reinforced-concrete piles tied back to anchors in the rear, backed by reinforced-concrete slabs, the lowest of which was chisel-edged. All piles and slabs in Madras have been sunk by water-jetting. About 3,240 lineal feet of it was still standing up to its work admirably, the remaining 1,460 feet having been dismantled because of a new quay for full-draught ships having replaced the lighter wharfing. He considered that two rows of the design in question—especially with toes of rubble on the sea-bed outside of them—if braced together and filled with sand between, would serve admirably for the crossing of Adam's Bridge. He did not believe that the complete closure of Adam's Bridge from side to side, with, in addition, the closure of the greater part of the west Rameswaram Channel, the Pamban Pass with its Scherzer bridge being alone left open, would result in any greater heading up of the water than now resulted from the monsoon winds, or that the Pamban Pass would thereby be rendered more difficult for navigation. For the ocean surface, somewhat raised by a south or by a north wind, had the whole of the Indian Ocean, across to Malaya, up to Calcutta and down to the South Pole, wherein to find its own level, without being compelled to acquire an inconvenient "head" through Pamban Pass for that purpose. He understood that Sir John Benton, K.C.I.E., M. Inst. C.E., when Inspector-General of Irrigation in India, advised that the closing of the greater part of the channels west of Rameswaram Island would have the effect of causing an increase of head, and consequently stronger currents during certain hours of the day, in the Pamban Pass. But Sir Francis Spring dissociated himself wholly from any such theory, and believed that the Adam's Bridge passage as well as the Pamban passage might be hermetically

¹ Minutes of Proceedings Inst. C.E., vol. clxxvi, p. 427.

Sir Francis sealed—all except the actual Pamban Pass beneath the Scherzer lift bridge, which might be left open—without anybody being a penny the worse.

In a former Paper he had drawn attention to the rapid corrosion of steel deck-girders over tropical salt waters.¹ Since then he had dismantled the screw piers therein referred to—all but the ship wharf, G, in which jarrah beams were used instead of steel—disclosing extraordinarily rapid corrosion, especially at the shore ends where the girders were constantly exposed to small surf-splashing. He was very strongly of opinion that it would be wise to give up the use of steel beams for the decking of such piers in tropical waters. Usually plenty of Australian hardwoods would be available for the beams as well as for the decking. One great trouble was that usually it would be entirely useless to paint girders in such a position.

Mr. Stracey. Mr. H. J. STRACEY remarked that the Author's view that continual changes, within certain limits, took place in the sandbanks and channels constituting Adam's Bridge, was no doubt correct. At the same time, any comparison of surveys made at different dates and by different engineers was rendered difficult (1) by the very irregular tides; (2) by the flat slopes of the sandbanks, as a difference of a few inches in water-level would cover, or uncover, considerable areas. In the opinion of the native fishermen, the only dwellers in this solitude of sand and sea, the sandbanks were increasing in size, and it was said that within living memory the open channels extended to the temple of Rameswaram. This temple was now 5 or 6 miles from the extremity of the island, which consisted of loose sand of recent formation. The reasons for the increase in size of the sandbanks and islands forming the bridge were not easily arrived at. Possibly the sand deposited by the currents in one monsoon might be greater than that removed when the monsoon changed; possibly the whole ridge might be undergoing slow upheaval. While the work as a whole did not present any engineering difficulties which would render the construction of a line between India and Ceylon impossible, the lack of material, other than sand, in the vicinity of the line was undoubtedly a factor which would affect both the cost and the time taken in construction. This was referred to by Mr. Lewis in his report dealing with the conditions of construction from the Indian standpoint—conditions which might be said to apply with equal force to supplies obtainable from Ceylon. The Author considered that difficulty might be expe-

¹ Minutes of Proceedings Inst. C.E., vol. cxc, p. 107.

rienced in closing the channels as the area of waterway was reduced. Mr. Stracey. Mr. Stracey had had the opportunity of experimenting on a small scale with a similar problem, where the present railway crossed the channels separating the Island of Mannar from the mainland of Ceylon. The conditions were in every way like those affecting Adam's Bridge, the line crossing two islands, and three channels through which a strong current flowed during the monsoons. The channels were crossed by embankments of earth, with the slopes protected above and below water by stone pitching, and openings spanned by bridges were provided. During construction his attention was drawn to the natural causes which brought about the flow in these channels, and the conclusion was arrived at that no harm would be done by closing any which were not required for navigation. The Consulting Engineers concurring, one channel was blocked without trouble, and no appreciable increase in the velocity of the current in the remaining two was observed. It should be noted that the currents through Adam's Bridge were not caused by a volume of water falling from one level to another, but were almost entirely due to the surface action of the wind. In the above-mentioned case the water stood about 2 feet higher on the windward side of the embankment than on the leeward, and in Mr. Stracey's opinion this might be taken as roughly indicating the head due to wind-pressure, which would not be affected by the length of the embankment, or the number of openings provided.

Mr. H. J. THOMPSON had read the Paper with much interest, Mr. Thompson. as the plans for the extension of the South Indian Railway to Dhanushkodi on the island of Rameswaram had been prepared by the late Mr. Lewis in 1909-10 under his direction as Agent of the Railway at that time. The further extension of the railway over Adam's Bridge to Talai Mannar was then the subject of consideration and discussion by Mr. Lewis and himself, and perusal of the present Paper confirmed the opinion Mr. Thompson then formed—that the information available was insufficient to enable a decision to be arrived at as to whether a causeway could be constructed across Adam's Bridge which would be secure against destruction by the sea unless protective works of such magnitude and cost were provided as would render the project impracticable. On this point he would remark that during the heavy weather of the monsoons the sea attacked the sandbanks on the windward side of Adam's Bridge, carried the eroded sand across the bank, and deposited it on the leeward side; in the following monsoon from the opposite direction the reverse process took place, and the

Mr. Thompson ultimate result depended chiefly on the relative strength of the two monsoons. If there were a succession of weak monsoons in one direction alternating with strong monsoons in the other direction, the movement of the sandbanks in the direction of the weaker monsoons would be considerable, and it was possible that none of the sandbanks on the Adam's Bridge were sufficiently permanent for the construction of a railway across them at moderate cost. This lateral movement of the sandbanks might account for the differences in bearing and length referred to on p. 294, and it might also explain the irregular alignment of Mr. Lewis's survey of 1913 as compared with the line laid down by the Author in 1895, since, owing to erosion, the latter line might in 1913 have been in deep water. It appeared to him, therefore, that to enable a decision to be arrived at as to whether a safe alignment for the railway could be obtained at reasonable cost, a detailed survey of the sandbanks was necessary, and that when this survey was made a number of permanent points should be established on the banks, in order that after the heavy weather of each monsoon for several years important alterations in banks and channels might be surveyed and recorded on the original plan. The question whether bridges were necessary to accommodate the spill-water had been very carefully considered in connection with the crossing of the Pamban Reef, and although to meet the wishes of the Madras Government a viaduct had been substituted for the rubble bank originally proposed, Mr. Thompson fully concurred in Mr. Lewis's opinion that if the channel had been blocked by a bank, the level of the sea in the Gulf of Mannar would not have been appreciably affected. Assuming that a causeway could be safely carried over Adam's Bridge, he was of opinion that openings in the causeway would introduce unnecessary elements of danger, as apart from the risk of underscour to the structures themselves, the openings would tend to assist the scour of the sandbanks and provide a means for the sea to transfer eroded sand from one side of Adam's Bridge to the other. With a continuous causeway such movement could not take place, and eroded sand would ultimately settle down on the same side of the bank as it was removed from. With the information at present available it was premature to discuss the detailed design of the causeway, but he would remark that for banks in the estuaries of tidal rivers on the west coast of Madras rubble bases and protection similar to that suggested by Mr. Shadbolt had been successful, and where there was risk of considerable scour, that form of construction was more suitable than the rigid structure proposed by Mr. Lewis,

which Mr. Thompson was sure would be troublesome to erect in deep water and to replace in the event of breach. Whatever type, however, of causeway was adopted, he regarded it as essential that, in such an exposed position, where trains would be subject to the full violence of squalls in the monsoon, efficient protection to prevent the wind from getting under the carriages and overturning them should form part of the design. Mr. Thompson.

Mr. GEORGE WADDELL remarked that he had been in charge of the Public Works Department in the Northern Province of Ceylon for nearly 6 years, and for the past 3 years had paid frequent visits to Mannar and South India in connection with the large quarantine camp being built at Mandapam by the Ceylon Government for the use of estate labour and other passengers entering Ceylon by rail and ferry-boat connection. The effect of the strong prevailing monsoon winds in forming currents and raising water-levels in these shallow seas must be seen to be properly appreciated. On one occasion in the Straits between Mannar Island and Ceylon, after a strong north-east gale had been blowing for some time, he noted a banking-up in the sea-level of nearly 5 feet against the causeway which carried the road across the Straits. Current-velocities of 4 or 5 miles per hour caused entirely by these winds were frequently seen when conditions favoured their creation. In determining the form of construction of the connection which would carry the railway line between India and Ceylon, the consideration of these monsoon conditions was of great importance, the rise and fall of the tide on the other hand being so small, and having so little practical effect, that it might be neglected. Undoubtedly the most economical and strongest form of construction would be a solid causeway, and as stone was only procurable at a considerable distance, some form of reinforced-concrete pile and panel construction on the lines suggested by Mr. Lewis would be the cheapest form it could take; but before deciding to close the waterways which intersected Adam's Bridge, the effect on the navigation of the Pamban Pass should receive careful consideration. At times currents of probably 4 miles per hour ran through the pass; the complete closing of the Adam's Bridge waterways would tend during the prevalence of strong south-east winds to bank up water south of the causeway, with the probable effect of accelerating the current through the pass. The amount of such acceleration, and the question whether it would be sufficient to render navigation of the pass dangerous, or impossible without some locking arrangement, required careful investigation. Were the closing of the channels through Adam's Bridge carried Mr. Waddell.

Mr. Waddell. out during that part of the year when strong monsoon winds did not prevail, the difficulty anticipated by the Author in closing the last of the channels would not, Mr. Waddell thought, be great. Lateral stresses in the causeway owing to differences in water-level on each side would certainly occur, and should be provided for. In the north of Ceylon there were other waterways in some degree similar to Adam's Bridge, connecting sea with sea, the partial or complete blocking of which by embankments in the construction of roads or railways had occurred. The Elephant Pass Lagoon, which divided the Jaffna peninsula from the mainland, was about 1 mile in width. The public road was originally carried over it on an embankment with 1,000 feet of bridging. On the construction of the Northern Railway line adjoining, it was decided that the waterway should be reduced to 100 feet in width, and, although irrigation questions complicated the question, 10 years' experience of the reduced waterway had not disclosed any serious trouble through flooding or other causes. Another case where a wide lagoon had been closed by a solid embankment without any ill-effect was at Chempian Pattu in the Jaffna peninsula.

The Author. The AUTHOR, in reply to the Discussion and Correspondence, remarked that Messrs. Shelford, Moore and Rothera had raised questions as to the commercial results which might be expected to follow upon the construction of a railway across Adam's Bridge. From Fig. 1, Plate 6, it would be seen that that part of India south of a line drawn due east of Cochin which would pass a little to the north of the town of Madura and a few miles to the south of Point Calimere, was, in a direct line, nearer to Colombo than it was to Madras. The area of this portion of India was about 17,000 square miles, or two-thirds of that of Ceylon; it comprised the native state of Travancore, the collectorates of Tinnevely and Ramnad, and part of that of Madura, and contained a population, by the census of 1911, of upwards of 8,000,000. It included not only the coconut, tea, and rubber estates of the west coast, but also the fertile irrigated rice-fields of the collectorates mentioned, the traffic to and from which should gravitate to the excellent harbour of Colombo—which in normal pre-war times was called at by many lines of steamers conveying passengers and cargo without transshipment not only to the principal European ports but also to those of Burma, the Malay peninsula, China, Japan and Australia, as well as New York and South African ports—rather than to Madras, where the harbour was much inferior to that at Colombo, and was without the other advantages just indicated, provided, of course, that reasonable through rates for this traffic were arranged. The

passenger-traffic should also, quite apart from tourists, be considerable, as Tamil labour from Southern India was very largely employed in Ceylon on the tea and rubber estates, and there was a large and constant flow of these coolies either coming to the colony or returning to their homes in India. Unfortunately, however, the fact that the South Indian Railway and the Ceylon Government Railway were of different gauges affected somewhat disadvantageously the full realization of this anticipation, but the late Mr. Lewis, who had been in the service of the South Indian Railway Company, and whose opinions might therefore be considered free from all suspicion of bias in favour of the 5-foot 6-inch gauge, had written the following in his report on the Adam's Bridge project :—

"Gauge.—The scheme, as submitted, provides for a metre gauge track ; hence, since Colombo is the objective, it would be necessary hereafter to consider whether it would be more beneficial to lay a third rail on the existing track of the Ceylon Railway, or to construct a new metre gauge line down the east [? west] coast to Colombo. The other solution, namely, to provide for the broad gauge, raises important issues both of policy and finance. It has been urged from time to time that considerations of Imperial defence may render it necessary to establish through communication between Northern India and Ceylon. Setting aside, however, the strategical aspect, the problem becomes simplified and localized by the enquiry as to whether a single line metre gauge railway can in the near future adequately fulfil its mission. Having regard to the wonderful prosperity during the last decade of years and without being unduly optimistic with reference to the future, it must be admitted that some alleviation will soon be necessary. As regards the South Indian Railway Company, the situation has altered considerably with the acquisition of the south-west line of the late Madras Railway Company. Prior to that time there was little inducement to violate the integrity of their system by permitting a foreign gauge and possibly a foreign railway to invade their territory. Under the present conditions these considerations of vested interest do not hold good to the same extent, and it would appear that the bold policy of constructing a broad-gauge line from Madras through Conjeeveram to Trichinopoly, and hence via Pudukotta to Ramnad, is worthy of serious consideration. For the present the connection could easily be made by re-converting the Trichinopoly-Erode line back to broad gauge and constructing the Trichinopoly-Ramnad (via Pudukotta) to the same standard. It would be necessary to re-girder the Pamban Viaduct, but since the metre-gauge girders are designed under 1908 Rules, there should be little difficulty in disposing of them when released. The superstructure of the Scherzer bridge would also have either to be replaced or strengthened."

The Author had intended at one time to include in his Paper these remarks, which he thought answered fully the questions asked by Mr. Sidney Preston ; but on consideration he had not done so, as he had feared it might have the effect of diverting the discussion from the main question to that of the gauge, and this he had been anxious to avoid. He did not think Mr. Lewis's proposals in

The Author. regard to the lines in Ceylon would commend themselves to the Government of that Colony, and he was certain that they would not do so to their professional advisers. He had been rather surprised that Mr. Shelford should not only have raised this point but gone farther and implied that there was a doubt in his mind as to the need for a connection. This appeared to Mr. Waring to be, if he might use the term, somewhat unfilial, inasmuch as the late Sir William Shelford had been associated with the late Sir George Bruce, Past-President, in suggesting the construction of a railway across Adam's Bridge. The Author had in his office a printed paper bearing the names of these gentlemen, and dated June, 1893, in which they advocated the construction of a line of railway across Adam's Bridge as adding to the prosperity of the adjoining railways: "(a) By converting them into main lines for the conveyance of through traffic, between Southern India and Colombo, where steamer connections are formed with Europe, Australia and the East; (b) by carrying the coolie, rice and other traffic which is already great between India and Ceylon; and (c) by largely increasing the interchange of European traffic in passengers and goods between the two countries." He thought it impossible to conceive that two engineers of such professional standing would promote a scheme of this kind unless they believed it was needed and likely to be a commercially practicable one; and if their views were sound at the time they were written, they were naturally stronger now, for in the interval that had elapsed the population both of Southern India and Ceylon had materially increased; the planting of tea, rubber, and coconuts both in Southern India and Ceylon had greatly extended, and the tourist traffic up to the outbreak of the War in 1914 was much heavier than it was in 1893. Messrs. Bruce and Shelford's scheme was undoubtedly premature at the time it was put forward, as the connecting railways in India were then distant $122\frac{1}{2}$ miles from Dhanushkodi, while in Ceylon they were $163\frac{1}{2}$ miles distant from Talai Mannar. The fact that these connecting lines had now been completed afforded ample proof, if indeed anything further were needed, as to the views the South Indian Railway Company and the Ceylon Government held as to the importance of completing the connection by the construction of a line of railway across Adam's Bridge, if it could be carried out at a reasonable cost.

He regretted that he was also unable to agree with Mr. Shelford in ascribing the currents across Adam's Bridge mainly to the non-synchronism of the tides on the north and south sides of it, for if this were so the current would naturally alternate several times

daily, which was not the case, and all the evidence showed that the currents as well as the difference in the water-level were influenced mainly by the monsoon winds which blew for months together in the same direction, and Mr. C. R. White's experience in the construction of the Pamban Viaduct¹ confirmed this. If Mr. Shelford's views as to the cause of the currents were erroneous it followed that his opinion as to what would occur if they were interfered with could not carry much weight.

In reply to those speakers and correspondents who desired further information regarding the Author's proposals and the material available, he would state that the embankment he proposed over the sandbanks was to have a formation width of 18 feet; the side slopes for a distance of 4 feet below formation were to be $1\frac{1}{2}$ to 1, below that depth 3 to 1. The core of the embankment—the formation breadth of which would be widened to about 45 feet at intervals of 3 miles to enable room to be provided for the erection of platelayers' quarters and at a central spot to allow for a siding to be put in to enable trains to pass—was to be of sand, obtained from the sandbanks themselves, covered with clay, 9 inches in thickness, to be brought from the mainland, in order to prevent the sand from being blown away. The 3-to-1 slopes were to be further protected with a pitching of stone or of massive coral, the latter being brought in boats from the Jaffna peninsula, where it was found in abundance. There was, he believed, no rock or stone suitable for building available within about 100 miles of Adam's Bridge, either in Ceylon or in India; at that distance, however, in Ceylon a plentiful supply could be obtained. At the time his estimate was made his calculations showed that girder spans of 100 feet carried on cast-iron cylinders sunk to an average depth of 50 feet below sea-level, the cylinders, when sunk, being filled with cement concrete, would be the most economical form of construction to adopt for crossing the water-channels. At that time reinforced concrete was practically unknown, and it was perhaps now a question, having regard particularly to the corrosion of iron and steel in a situation so especially exposed to sea air, whether it might not be advisable to modify those proposals materially by adopting smaller openings and using spans of reinforced concrete, carried on reinforced-concrete piles sunk to the required depth by means of water-jets.

Several speakers and correspondents had referred to the question of scour, but he thought that if sufficient waterway were provided

¹ Minutes of Proceedings Inst. C.E., vol. xcix, p. 377.

The Author. to prevent any undue acceleration of the current, this should not happen to any serious extent; or, if it did occur, it could be remedied by depositing stone around the piers. It was manifest that in every bridge across a river, especially where the bed was of sand or silt, scour was always likely to occur; but where sufficient waterway had been provided in the first instance, and the foundations were good and carried to an adequate depth, the danger from this cause might be easily exaggerated; while if any scour did occur the remedial measures to be taken were well known and simple.

Mr. de Broë advocated the construction of the causeway on a line sinuous in plan, in order to avoid the deep channels between the sandbanks which Mr. Lewis had described as "pot-holes." One objection to such a course would be the extra length of causeway necessary, while a second, and perhaps more serious, objection lay in the fact that the adoption of such a sinuous course would render the causeway at the apices of the curves liable to the destructive action of heavy seas, from which a line following the course of the crest of the ridge throughout would be exempt; for, as pointed out in the Paper, the shoaling of the water caused the heavy seas in both monsoons to break at a considerable distance from the alignment proposed both by Mr. Lewis and the Author.

If he properly understood Mr. Carey's remarks, that gentleman considered that, with some assistance, Nature might be expected to close the channels in Adam's Bridge. Such an operation, even under the most favourable conditions, would, no doubt, occupy many years, and possibly even centuries. The Author quite recognized the value of the *Ipomœa* and *Spinifex*, both indigenous plants growing freely on the coasts of Ceylon, as important aids in consolidating sandbanks and preventing their erosion by wind or sea; and one of the photographs which he had shown after the Paper was read indicated that already practical use had been made of the former.

He thought the remarks of Mr. Isaacs as to the experience gathered at the Galveston Causeway were very valuable in supporting his view as to the undesirability of a continuous solid causeway for crossing Adam's Bridge.

In reference to Sir Francis Spring's remarks, Mr. Lewis, in his report, admitted that the form of construction he proposed was novel when applied to a causeway, but mentioned that it had been successfully used by Sir Francis Spring as a cheap form of dock-wharf walling for barges in Madras Harbour. The water there was shallow and free from currents and wave-action, and the conditions therefore were quite different from those existing at Adam's

Bridge; and while Sir Francis Spring did not anticipate, if Adam's The Author. Bridge were closed by a solid causeway, any inconvenient rise in the head of water during the monsoons, he nevertheless admitted that Sir John Benton, an equally eminent engineer, who had been consulted in regard to the crossing of the Pamban Channel, held the contrary view.

The breadth of the single channel in the Mannar Strait closed by Mr. Stracey was insignificant in comparison with the total width of the Mannar Strait, and still more so in comparison with the aggregate breadth of the channels in Adam's Bridge, and in the Paper the Author had specially remarked that he did not anticipate, if Mr. Lewis's proposals were adopted, that any difficulty would occur in closing the first few channels dealt with at the estimated cost, but that as the work proceeded the difficulties might be expected to increase. Mr. Waddell, who suggested that, if Mr. Lewis's scheme were adopted and operations were confined to that part of the year when strong monsoon winds did not prevail, the difficulty in closing the channels would not be great, apparently lost sight of the facts that this work could be then only carried on for about four, or at the outside five, months in the year, so that much time would be occupied in its execution, and that if, owing to the gradual contraction of the waterway by the construction of a solid causeway without openings, any scour did occur, it would take place before operations were begun at the last of the channels to be dealt with.

The Author could not agree with Mr. Ward that the channels in Adam's Bridge could be closed by embankments formed of sand only, for it appeared to him that in a current where the velocity was for much of the year about 6 miles per hour the sand would be washed away as fast as it was deposited.

Summarizing the opinions of those who had expressed definite views, a majority considered a solid causeway preferable to one in which openings were left for the water-channels, though a large majority were unfavourable to the form of construction proposed by Mr. Lewis, while a majority also anticipated that the construction of a solid causeway would result in increasing the difference in the levels during the monsoons of the water on the two sides of it. In conclusion, notwithstanding the views to the contrary held by several of the speakers and correspondents, to which he had given full weight, the Author was still of opinion that the safest plan for crossing Adam's Bridge was to interfere as little as possible with the existing waterways, a course that had been adopted with success in the case of the Pamban Channel, and he

The Author. was, he thought, supported in this view by the very varying opinions held as to what might be expected to follow the construction of a solid causeway. The question was admittedly a very complex one, but the practical experience gained by Mr. Cooper at the lagoon dividing the Jaffna peninsula from Ceylon, and by Mr. Waddell at the Mannar Channel, as to the height to which the water in the neighbourhood, when driven by strong winds, was banked up or raised above its normal level by an obstruction to its free passage, was of special value as confirming his opinion as to the danger attendant upon the construction of a solid causeway for a work of such magnitude as a railway across Adam's Bridge.