Tunnelling Operations in the Sewering of the City of Melbourne was continued, and its conclusion deferred until the next meeting.

Major J. Monash's paper on "Notes on Modern Building Construction" was, in the absence of the author, read by Professor W. C. Kernot. Owing to the lateness of the hour discussion was postponed.

On the motion of Mr. D. Buchanan, seconded by Major H. V. Champion, a hearty vote of thanks was accorded, by acclamation, to the Author, and it was also agreed to bring the contribution under the notice of the Royal Victorian Institute of Architects.

Mr. A. J. Grant (Secretary of the Association of Municipal Engineers), introduced by Major H. V. Champion, desired to place before the Institute certain matters referring to the insufficient remuneration, etc., of Shire Engineers.

It was decided that Mr. Grant might be heard, but no action could be taken at that meeting, since no notice of this business, which had been introduced only at the termination of the meeting, had been given. It was suggested, as the Premier had consented to receive a deputation on the matter in a few days, that the President might, in the exercise of his discretionary power, call a special meeting of the Council to consider the matter and if necessary take action. This course has since been adopted.

At 10.30 p.m. the proceedings terminated.

---

PAPERS.

THE QUEBEC BRIDGE DISASTER.

By Professor W. C. Kernot.

The Quebec bridge is, or rather was (for it is now an utter wreck, of no use except as a heap of gigantic scrap of minimum money value owing to the difficulty of utilizing it) a cantilever bridge of greater magnitude than any heretofore constructed. To understand the idea or motive of a cantilever bridge let us consider the various possible means of crossing a chasm such as a ravine, river or creek, so that men, animals, and vehicles can pursue their journey without interruption. First and most obvious we have a simple beam supported at the ends—a plank or log. By the expansion and elaboration of this idea we are led up to all the varieties of girder bridge of which many excellent and interesting samples of moderate size are to be seen in
and around Melbourne. This type has been successfully employed up to a span, or distance between supports, of about 500 feet, but not much further, as it then is coming within measurable distance of the limiting span, or that span at which the whole strength of the structure would be needed to bear its own weight, leaving no margin or provision for carrying useful load. Next we have the voussoir or block arch, which has not yet been attempted for more than 300 feet, which is probably about the possible limit with the strongest stone available. In steel we have the continuous arch, of which a magnificent example is situated just below Niagara Falls, and spans a little over 800 feet, which is the present limit of that type of construction. Next comes the suspension bridge, which, by taking advantage of the enormous tensile strength of steel wire has been extended at Brooklyn to the magnificent span of 1595 feet. This type of bridge is, in my opinion, susceptible of considerable further development, and a span of 2600 feet, or say half a mile, should not be difficult of accomplishment. There has, however, been a good deal of prejudice against the suspension bridge owing to the failure of imperfectly designed structures in early days, and to the lack of rigidity under concentrated loads frequently experienced, and hence its application has been rather limited.

Lastly, we have the cantilever system, of which the Forth bridge, near Edinburgh, is the most stupendous existing example and has the distinction of spanning the greatest distance without a support ever accomplished, namely, 1710 feet, or nearly one-third of a mile, or say the distance along Flinders-street from the Cathedral to the Custom House.

To understand the cantilever system suppose you have to bridge a chasm 40 feet wide and you have a number of planks only 20 feet long with which to do it. The simple obvious system of laying timbers across from one support to the other is inapplicable, but by projecting a plank say 10 feet out from either side, securing it by loading down the tail end you reduce the span to 20 feet, which then can be bridged by another plank. Behold then your bridge, consisting of two cantilevers and a central beam or girder. This system has often been used on a small scale. I have seen it long ago made roughly with logs over an Australian creek.

Some thirty years ago the project of bridging the estuary of the Forth near Edinburgh was mooted, and designs for a suspension bridge having two spans of about 1700 feet each were prepared. The necessity of such large spans arose from the fact there was about three quarters of a mile of very deep water, too deep to permit of any supports either temporary or permanent being introduced except just at the centre, where an island rose suddenly out of the water. The execution of this scheme was prevented by the failure of the Tay bridge, a totally different structure, merely a long viaduct of many small spans crossing shallow water. This structure, however, being by the same de-
signer, public confidence was so shaken as to kill the larger scheme.

Before long, however, a proposal by the late Sir John Fowler and the late Sir Benjamin Baker was adopted by the railways interested, and having been endorsed by the experts of the British Board of Trade, the Government controlling body in the interests of public safety, the present bridge was carried out successfully, being opened for traffic nearly 20 years ago. These engineers adopted the cantilever system, which, though well known in a rough elementary form, was new on a large scale and for railway purposes. The great advantages claimed for it over beam or girder bridges are:—

1. That the massive and heavy parts, instead of being near the centre of the span as in a girder bridge, are at or near the supports, and so their weight causes much less stress on the structure.

2. That it can be built out piece by piece from each side without any staging, or falsework as the Americans call it, for temporary support.

The Forth bridge as completed consists of two main spans of 1710 feet each. They each consist of two cantilever arms connected by a comparatively small girder span of ordinary type. There are also two spans of about 600 feet each under the tails or anchor arms of the cantilevers, and several spans of ordinary type in the approach viaducts. The cantilevers are huge diamond shaped frames, the compression elements of which are tubes as in an ordinary bicycle frame, while the tension parts are lattice girders.

The Forth bridge has been perfectly successful, having for twenty years carried railway traffic and endured without injury the gales of wind, one of which destroyed the Tay bridge within two years of its completion. At the same time it proved a very costly work, and the interest and maintenance charges must constitute an exceedingly heavy tax upon the comparatively moderate traffic that passes over it.

The American bridge engineers, while admitting the boldness and practical success of the Forth bridge, have always criticised it as clumsy and needlessly expensive, and when the decision was arrived at to bridge the St. Lawrence near Quebec, hailed it as an opportunity to show how the Forth bridge ought to have been built.

The Quebec bridge is in general rough outline a replica of one half of the Forth bridge, but with entirely different details. The main span is 1800 feet as against 1710 at the Forth, and the central girder is longer and the cantilever portion shorter in proportion than the other. This, no doubt, improves the bridge both in appearance and economy of material, but tends somewhat to increase the risk and difficulty of erection. It had nothing, however, to do with the present disaster.

The notable difference between the bridges is in their details.
In the Forth bridge the tension parts are lattice girders, at Quebec they are chains of eye-bars united by pins, a theoretically much more efficient disposition of material. At the Forth the compression parts are circular tubes—the most scientific and efficient arrangement possible, while at Quebec they are of a peculiar and it seems to me fatally defective form, the only argument in favour of which was ease of construction and erection. Had I the task of designing a large cantilever bridge I should like to combine the tension members of Quebec with the compression members of the Forth.

There seems no possible escape from the conclusion in view of the available evidence, that the appalling failure at Quebec, involving the loss of 75 lives and the utter destruction of about half a million pounds worth of magnificent structure work, was due to a defective compression element in the lower part, or chord as it is called, of the anchor arm of the great cantilever on the south side of the river, which was approaching completion and was loaded with its own weight, that of part of the central girder attached temporarily to its extremity, and that of certain travellers or cranes used in erection, the total load amounting to not more than three-fourths of the maximum under the most unfavourable conditions possible as to load and wind pressure. This particular compression piece, which for convenience of identification was known as AgL (in accordance with the usual system of lettering and numbering the parts of a complex structure) had a past; that is to say, was not of unblemished reputation. First, a slight defect was discovered before it left the Phoenix works near Philadelphia, where it was manufactured. Second, it was damaged somewhat severely by being let fall through the failure of hoisting tackle. These defects were, it is stated, thoroughly repaired before it was placed in the structure. However, three days before the disaster it was observed to be out of line, bending sideways, a most alarming symptom. Mr. Theodore Cooper, the eminent consulting bridge engineer, who had guaranteed the soundness of the design, was communicated with, and he ordered the contractors to put on no more weight until the matter was investigated. Unfortunately, however, owing to various accidental delays, three precious days were wasted, and before Mr. Cooper’s instructions could be complied with the structure fell. There is little doubt the bridge might have been saved, and that at an insignificant cost. Within thirty feet of the slowly-bending piece was an intersection, or point of strength in the horizontal wind bracing. Had a piece of timber, say 12 inches square and about 30 feet long, been inserted between this point and the slowly-yielding compression piece it would almost certainly have checked further yielding until the matter could be investigated and permanent strengthening effected.

The question of the resistance of comparatively long com-
pression members is a somewhat intricate one, and has engaged the attention of mathematicians from the times of the Euler downward. Hodgkinson, Lewis Gordon, Rankine, and others have made experiments and mathematical investigations, and proposed rules that are used as guides in practice. The general conclusion is that a good long column must be an effective beam in every direction. For this purpose the material should be kept as far as possible from the centre of gravity of the cross section. Now, a hollow cylinder complies with this requirement better than any other form, hence the effectiveness of the Forth bridge construction. But the hollow cylinder is rather an inconvenient form, requiring much costly local modification at the points of junction with other parts. Hence its comparatively small use in bridge work. A much more convenient and not much less efficient form is a square or rectangular tube, and this is sometimes made with solid plate on all four sides, but more frequently for ease of inspection, cleaning, and painting, of continuous plate on two, or perhaps three sides and open lattice work on the others.

AgL was an example of this last system. It was nearly 60 feet long and about 4 feet 6 inches square. It was placed at an angle of about 30 degrees to the horizontal. Its two vertical sides consisted of three plates of steel rivetted together, forming a mass or slab of metal about 4 feet 6 inches wide in a vertical plane and approximately 4 inches thick. These slabs would, of course, be very strong and stiff as beams in the vertical or 4ft. 6in. direction, but very weak and flexible horizontally or in the 4 inch direction. In addition to these are two other similar slabs in an intermediate position between the outer slabs. Thus there are four of these slabs, all very strong and stiff vertically, and very weak and flabby horizontally. To prevent them bending horizontally there is at top and bottom a lattice work of light angle iron, which, in my opinion, was the fatally defective part.

Somewhat similar constructions exist in innumerable bridges, many of them in Melbourne. We continually see two slabs or members latticed across to prevent bending, and the question that has not yet been properly worked out is what percentage of the total material should be put in the lattice work and what percentage in the longitudinal directly resisting parts. Practice varies greatly, and to arrive at a satisfactory theory is difficult. Were the material perfectly uniform and the workmanship mathematically accurate there should be no tendency to bend, and this bracing or latticing should have nothing to do. But if conditions are not ideal, there will be a tendency to bend sideways, and the latticing is needed. Many years ago I made a number of experiments on small models and obtained my best results with at least 25 per cent. of the material in the latticing and not more than 75 per cent. in the longitudinal parts. Taking actual bridges, I find proportions giving from 12 to 23 per cent., and I find in a pamphlet by Mr. Theodore Cooper himself, pub-
lished about twenty years ago, a construction showing 27 per cent. of the total metal in the latticing recommended. Will it be believed, in view of all this, that at Quebec barely 2 per cent of the material is in the latticing and 98 per cent. in the longitudinal slabs. But such is the case, as shown by fully dimensioned details published in "Engineering." How this amazing departure from previous practice came about, and on what grounds it was thought to be justified we know not. It is hardly conceivable that it was pure inadvertence or neglect, and yet, had the contractors made an experiment on a quarter, or even a twelfth full size model, surely they would have discovered the weakness. If they did not their experience would have been strangely different to mine in my models of twenty years ago. There was no excuse for omitting such an experiment. There were over one hundred compression elements of the same type and approximately the same size as A9L, and the Phoenix Company possess a testing machine of 1000 tons power, of which they years ago supplied me with photographs and particulars.

Again, as a further precaution, an organised system of extensometry should have been carried out. By extensometry is meant the accurate measurement of small changes of length, and this art has now been developed considerably, and many simple and effective devices are available for the purpose. On every important or typical part of the Quebec bridge I would have had points finely engraved, say 3 feet apart, and measure their distances to the ten thousandth part of an inch from time to time during construction. In this way a strict watch could be kept on the actual stress. This has been done over and over again by our railway engineers in Victoria, and I have repeatedly done it myself with the simplest and cheapest apparatus.

The moral of the awful Quebec disaster to me is this: Have plenty of experiments on models, and a liberal amount of extensometry. Thus, and thus only, can the bridge engineer pursue his course with safety and confidence, and I trust that this will be done in building the new Quebec bridge that will doubtless replace that so lamentably wrecked.

NOTES ON MODERN BUILDING CONSTRUCTION.

By Major J. Monash.

For some time past the question of a revision of the Building Regulations of this metropolis has received attention, and municipal bodies have displayed activities in this direction. The excellent paper on "Building Regulations" presented recently to this Institute by Mr. Anketell Henderson has directed attention to many anomalies and incongruities in existing methods, and has made out a strong case for a thorough revision of our building laws. Such a revision, however, if confined merely to the correction of anomalies, would proceed but a very little way upon
Mr. Jas. Alex. Smith said that one point in the author's parenthetical remarks which appealed strongly to him was the reference to the necessity for completeness in physical testing as a complement to purely mathematical deduction. Upon the evidence before them, it would seem that had tests to destruction of large scale models of the chief typical components been made, the disaster might have been averted. The cost would have been fully justified.

The illustrations which had been exhibited showed the designs for the completed bridge, and the wreck. A copy of "Engineering" that had reached him that afternoon reproduced a photograph of the bridge as it was fifteen days prior to the failure. There had not been time to prepare a lantern slide, but he had, as would be seen, sketched the illustration on the blackboard. It would be noted that a traveller, weighing 1000 tons, near the end of the cantilever, had been partly removed, hence the dead load at the time of the wreck was somewhat less than it had been at a previous period.

BUILDING REGULATIONS.

The discussion on Mr. A. Henderson's paper was resumed. Major H. V. Champion asked if the thickness of walls was affected by the materials of construction. He understood the scheme applied to any class of brick work. Was any difference made in the case of cement as against lime mortar work?

Mr. A. Henderson, in replying, said Major Champion's question could be speedily answered. The diagram showed a standard wall which he had designed for the suburban conference, and consisted of three stories of brick work of each thickness, the bottom story of each thickness strengthened by piers. If built in cement it would be allowed two more stories. Where a wall was built in cement, or had acquired elastic resistance through being old, it should be allowed to have a thinner top story. His suggestion was to have two grades lower, but the conference adopted one.

He thoroughly agreed with Mr. Little that it was useless to attempt to reform the building regulations, and in his scheme he had adopted what his judgment accepted after fair and if anything conservative treatment. Mr. J. A. Smith had referred to the question of frosts in Toronto.
DISCUSSIONS.

THE QUEBEC BRIDGE DISASTER.

The President said, that in reconstructing the Quebec Bridge he would suggest that the following course be adopted:

1. That the general design be reconsidered and that careful calculations of secondary stress be made. The question appeared to have been ignored in the original design in which very scalene triangles involving serious secondary stress were found. A method of effecting this computation would be found in his (the speaker’s) work, "Common Errors in Iron Bridge Design," p. 40. These very ill-conditioned triangles should be replaced by more nearly equilateral ones, somewhat as in the Forth Bridge.

2. That the large, imperfectly braced openings through which the trains passed be reduced in height and more completely triangulated. Apparently for architectural effect these openings have been made 40 or 50 feet high, whereas 15 feet would suffice for the locomotive funnel to pass. If diagonals were inserted coming down to within 15 feet of the rail level, at each side, the lateral strength and rigidity would be improved to a large extent.

3. That a model of not less than one-twentieth full size of one cantilever and anchor arm be made, one side of which should be carried out in full detail. The other side, while preserving the same outline, might be simplified, single bars of metal of equivalent sectional area being used. This model would be about 60 feet long and 15 feet high at the highest point, and could easily be made for a few hundred pounds. It should be loaded with loads representing the actual dead, live, and wind loads. Extensometers, reading to the one-twenty thousandth part of an inch, and embracing lengths of say 6 inches, should be applied to all the parts of the frame, and thus the computed stresses would be experimentally verified within a very small margin of possible error.

4. Tests to destruction of at least one-quarter full size models of typical elements and junctions in the bridge by the aid of a sufficiently large testing machine. Such a machine already exists in Philadelphia. Any weakness such as that of AgL would be infallibly detected in this way.

5. During erection, the actual stresses on, at any rate, the more important and typical elements of the structure should be determined by extensometry, and compared with the calculation. These precautions could, I estimate, be carried out at a cost of not more than one per cent. of the money loss that has been involved in the recent disaster.

Mr. Jas. Alex Smith said several members had asked him whether there was not an error in stating in the previous "Proceedings" that the weight of the great traveller upon the bridge
was as much as 1000 tons. The figure was quite correct, as the quotations [read] from various published data would show.

In regard to Professor Kernot's remarks on extensometer method, it was quite possible to measure to much less than the twenty thousandth of an inch at any individual observation, but he would like to know whether Professor Kernot had found it possible to remove the instrument and verify measurements at different portions of a structure and after periods of one or two months.

Professor Kernot said he proposed to apply the refined measures to the one-twentieth scale model. The corresponding figure on the actual work would be one thousandth of an inch. By having two fine lines engraved about 5 feet apart, they could measure to that degree of accuracy by means of a fine scale and a magnifying glass without any lever arrangement at all.

BUILDING CONSTRUCTION.

The President said they now had before them the paper by Major Monash on "Building Construction." It was a question of immediate and local importance, some of the points of which were very forcefully illustrated by the great fire in the city during the previous week. While he was watching that fire, Major Monash's remarks as to the importance of having horizontal rather than vertical firebreaks struck him as being illustrated. The walls of that building formed a great chimney out of which enormous masses of flames were belching, and a "snow storm" of fiery flakes was falling right up to the Trades Hall.

Mr. J. T. Noble Anderson said he had not read Major Monash's paper very carefully, but he had noticed in glancing through the discussion on Mr. Henderson's paper at a previous meeting, that the remark was made that architects had a tendency to make walls more fire-proof than floors. In recent buildings which he had seen, however, the floors were much more carefully fire-proofed than the walls. The type of building most used in large public stores was of strongly reinforced columns carrying extremely heavy reinforced floors and roofs, which were very elaborately made. The walls were mere curtain walls resting on reinforced concrete girders. That seemed to be a very favourite type at present in Great Britain. It pointed to the fact that builders were not so careful about the walls as of the floors and roofs.

Mr. Jas. Alex. Smith said in the light of the recent fire he would like some information. The paper stated there might be considerable spans of horizontal fire-break. In a case such as that, probably the floor span would be heated to a considerable extent, with consequent expansion. He would like to know