The stresses are:

$$\sigma_c = \frac{Px(e + p_t - a)}{(p_t - p_c)\Sigma Av_x} \quad \ldots \ldots \ldots \ldots \quad (4)$$

$$\sigma_t = \frac{p_a - x}{\Sigma a_t(p_a - x)}\left[\left(\frac{\sigma_c}{x}\Sigma Av_x\right) - P\right] \quad \ldots \ldots \quad (5)$$

where P denotes the direct thrust,

e ,, the eccentricity $= \frac{M}{P}$.

As a check, for the position of the neutral axis,

$$x = \frac{p_a}{1 + \frac{\sigma_t}{n\sigma_c}} \quad \ldots \ldots \ldots \ldots \quad (6)$$

First of all, the section subjected to the maximum bending-moment was examined and with the reinforcement of sixty-five rods of $1\frac{1}{2}$-inch diameter, in tension, and twelve rods of $1\frac{1}{4}$-inch diameter, in compression, the maximum stresses were 17,615 lb. per square inch tension in reinforcement and 1,200 lb. per square inch compression in concrete. The concrete used throughout the balcony was $1 : 1\frac{1}{2} : 3$ mix. Table 5 shows the stress analysis of the midspan section.

Other sections of the beam were examined, reinforcing rods were curtailed or bent up to resist the shear forces in groups of four or more, and the moment of resistance of the section at each curtailment or bend-up was calculated in a manner similar to that described previously. Naturally the values of the Table 5 were used again for the partial summations, omitting elements of the section below the now rising neutral axis.

The shear stresses were calculated in the usual manner and the shear-stress diagram was plotted at an angle of 45 degrees to the axis of the beam. The total diagonal shear was illustrated by proportional areas and the bars were bent up in the position of the centroid of the respective stress areas. The balance of the shear stresses is resisted by the system of vertical binders. At the ends of the beam the binders are of $\frac{7}{8}$ inch diameter, in groups of seven (fourteen vertical legs), at 18-inch centres. The 18-inch spacing was adopted from the consideration that a group of seven $\frac{7}{8}$-inch-diameter bars occupies about 7 inches, thus leaving a clear spacing of about 11 inches between the binders, which was considered the minimum to provide access during construction.

The main bars were arranged in four layers and a minimum of 2-inch spacing maintained between the bars in both horizontal and vertical directions, to allow the free flow of the concrete around the bars.

Fig. 36 illustrates the combined bending-moment and shear-stress diagrams with the bar curtailments and bends. The maximum shear stress is 248 lb. per square inch.

Discussion

The Authors introduced the Paper with the aid of a series of lantern slides.

The President, in moving the vote of thanks, said that the Paper was of outstanding interest in many ways. First, it had been presented jointly by an engineer representing the Consultants in collaboration with an engineer representing the Contractors. That was not common in the proceedings of the Institution. Secondly, it contained a description of the most important non-industrial structures erected in Great Britain for many years. Thirdly, the work had been carried out with considerable speed,

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

yet careful attention had been paid to detail, and the most up-to-date knowledge, both theoretical and practical, had been applied to the problems involved. Appendix I might to some extent be considered to meet Professor Pippard's point in his article in *Chartered Civil Engineer* in February 1951.

Fourthly, no effort had been spared to gain the confidence and to maintain the interest and enthusiasm of the workmen. That was surely one of the lessons to be learned from the job.

What exactly did the Authors mean by the statement on p. 251 that:

> " It is considered that the essential requirement is that a sufficient percentage of reinforcement should be provided to ensure plastic behaviour of the concrete near the support." ?

On p. 255 the Authors had stated that:

> " Owing to the nature of reinforced concrete, to much importance was not attached to the calculated stresses. . . ."

Was that statement intended to apply particularly to the problem treated or did it express their general feeling about concrete ?

The reference made to torsion on p. 265 showed that there was a paucity of information as to how structures such as the balcony beam torque-box actually behaved. Could anyone give those details ? It seemed most important that engineers should learn by experiment, and otherwise, more about the torsional strength and the torsional design of such structural components.

The Authors, when introducing the Paper, had mentioned the 1851 Exhibition building—the Crystal Palace building as it subsequently became in a modified form. The President thought that it was not generally realized that the Institution had played a considerable part in the construction of that large and important building. It had been a civil engineering structure in the true sense of the word. The Paper [1] which had described it had been presented to the Institution in January 1851—6 months after the first ideas about the scheme had been recorded. By that time the building had been virtually completed.

The then President of the Institution had played a most important part in the building. In the words of Mr (later Sir) Digby Wyatt:

> " . . . the weight of responsibility, the arduous duty of supervision, the honour of acting as the master mind, to weigh the requisites, to determine the design, and to govern the construction of this great apparatus ",

had been reserved for Mr (later Sir William) Cubitt. He had been assisted by Robert Stephenson and I. K. Brunel in that work and Mr

[1] M. Digby Wyatt, " On the construction of the building for the exhibition of the works of industry of all nations in 1851 ". Min. Proc. Instn Civ. Engrs, vol. x (1850–51), p. 127.

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

Charles Manby, then Secretary of the Institution, had been seconded to help full-time with the job.

Mr C. L. Champion observed that the Paper had amply demonstrated the fact that once the basic architectural requirements had been determined, both the design and the construction of a building of the magnitude of the Royal Festival Hall were essentially civil engineering problems.

Perhaps the fairly general failure to appreciate that point among those responsible for building operations in Great Britain might be partly responsible for the frequent complaints which were heard about the very slow general rate of building as compared with that of similar large structures in the United States. In the present case, a very creditable rate of progress has been maintained, considering that the building was one of unusual complication; and, so far as the cost given in the Paper indicated, it had been obtained quite economically.

It would be of interest if the Authors could give more details of the cost of the building—if they could add, for instance, the cost of engineering services and of architectural treatment, so that a picture could be formed of the total cost. Mr Champion appreciated that the Authors were not directly concerned with the engineering services of the building, but those services were nevertheless a feature of very great interest.

He was interested in the decision to adopt gas for heating the boilers, and thought that the very high cost of the fuel intake to such a large boiler house—he believed it was approximately 30,000,000 B.Th.U per hour—would, in general, more than offset the economy to be expected from reduced attendance.

The unusually high floor-level of the auditorium might lead to inconvenience to visitors from the large amount of stair-climbing to be encountered. Had consideration been given to the possible installation of escalators for the building, or at least to the possibility of leaving space where they might be installed in the future?

Could the Authors say a little more about the actual site organization? Did the Engineers, for instance, assume responsibility for all measurements, or was that dealt with by an independent firm of quantity surveyors? What were the Authors' views as to whether the present very complicated system of quantity measurement in use for building work in England was the best that could be devised? Did they think that simplification would be possible in the case of those very large structures?

Mr G. M. J. Williams described the model tests which had been made when designing the dog-legged staircase, illustrated in *Figs 10*.

It would be seen that the only supports of each staircase were at the top and the bottom, and that the half-landing was supported from the two risers, the one going down from the upper support, and the other rising from the lower support, so that there was a total cantilever of about 19 feet. Furthermore, the risers were subjected to torsional forces, because the steps were cantilevered 3 feet 5 inches beyond the edge of the concrete

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

members. The staircase had been designed for a live load of 100 lb. per square foot and, in addition, there was a wall 6 feet high at the outer end of the cantilevered half-landing. The mathematical treatment of the staircase was dealt with in Appendix I, and *Figs 30* illustrated the method adopted.

To have analysed the staircase as it stood would have involved finding six indeterminate forces. There had been insufficient time to set up the six simultaneous equations that would have been involved and to solve them for cases of both overall loading and partial loading. A search had, therefore, been made for simplifications which did not involve great modification. Fortunately, there was one which could be used easily, because, although the staircase was not quite symmetrical, it was nearly so, and it was easy to show that with a symmetrical staircase the redundant forces could be reduced to two, as shown in *Fig. 30* (*c*).

Furthermore, having assumed a symmetrical staircase, it was necessary to integrate the strain energy over only one-half instead of the whole of the staircase. Then it remained to show first to what extent the stresses in that ideal symmetrical staircase departed from the stresses in the staircase that was built; and secondly whether asymmetrical partial loading had a worse effect anywhere than symmetrical loading, because obviously a symmetrical case could be solved only for symmetrical loading. A model of the staircase had been made and analysed after the method described [1] by Professor A. J. S. Pippard and Mr S. R. Sparkes.

Fig. 61 showed a side view of the model, which had been made of brass strip. The two risers and the half-landing could be seen. Briefly, the method which Professor Pippard and Mr Sparkes had described stated that, if unit displacement were applied at one end of the staircase, the resultant vertical displacement at every point down the rest of the staircase were measured, and the values were plotted to form a curve, that curve would represent the influence line for the vertical reaction at the top due to a vertical load applied at various points along the staircase. Similarly, the twist at each point would give an influence line for the vertical reaction at the top due to an applied torsion at various points along the staircase. The special clamp at the top had been designed so that the unit displacement could be applied in any direction or there could be a specific rotation about any axis.

Fig. 62 showed another view of the model, looking from above. Steel knitting-needles had been fixed to the brass strips at various points to indicate displacement. The disturbed condition of the needles in the Figure was due to the fact that the photographs had been taken after the experiments had been completed, and the model had by that time suffered considerable handling. The floor had been used as a datum, and distances had been measured up from the floor to the knitting-needles, so that both

[1] "Simple Experimental Solutions of Certain Structural Design Problems." J. Instn Civ. Engrs, vol. 4, p. 79 (Nov. 1936).

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

Fig. 61

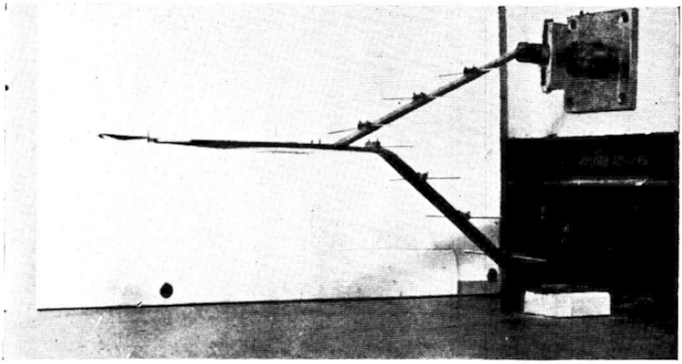
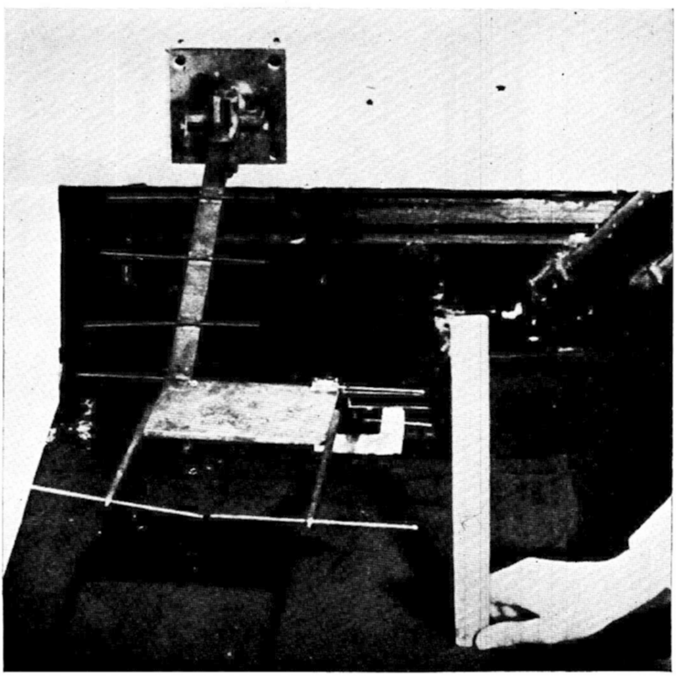


Fig. 62



TWO VIEWS OF THE MODEL STAIRCASE

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

the rotation and the displacement at each of those points could be determined. Influence lines had thus been obtained for the horizontal, vertical, and all the other redundant reactions of the top. The comparison of those lines with the curves calculated on the assumption of symmetry showed a maximum error of about 15 per cent., which was not extremely accurate but, " owing to the nature of reinforced concrete " was sufficiently so for practical engineering purposes.

Mr E. R. Hole felt sure that many would share with him his regret that the late W. L. Scott, M.I.C.E., had not been able to be present that evening.

During the running of the job, with which he had had some slight connexion, Mr Hole had, to some extent, envied the engineers their job in their separate capacities. It had always seemed to him to be delightfully simple. Since studying the Paper, he had envied them further for the ability they had shown in describing the building.

He stressed a point already alluded to by the President—namely, the collaboration of the consulting engineer with the contractor in the presentation of the Paper. He himself would have liked to see more emphasis placed upon the linking up of the efforts of the workmen. Everyone was aware that it was necessary to gain the full interest of the men if they were to put their heart into the work. At the present time, when reliance had to be placed upon mechanization and simplification in a number of building processes, in order to reduce the cost, workmen should receive greater attention. They were at the "front-line" end of a tactical plan. The architect produced a drawing to show what he wanted. Then the engineer made a drawing which explained it. The contractor made drawings and sketches to convey to the men what was really wanted ; and at that point the real work began.

The men often had to work under severe weather conditions ; it seldom rained in the drawing office ! It was much easier to get steel bars into position with a set square ! It was often easier to consolidate concrete with a typewriter than with a vibrator ! He would like to see the men brought into the picture to a greater extent by all parties connected with the work, and it was essential that the architect and the contractor should collaborate in that matter. On the Festival Hall, such collaboration from all parties had, fortunately, existed from the beginning ; and the results had shown that it had been worth while.

He felt sure that it would be valued and appreciated if, when similar Papers were to be discussed, the Institution would invit ea few of the real workmen—men of the artisan class—to hear about the building that they had constructed.

Mr W. S. Rundle, on behalf of Mr H. H. Harridge, who had been unavoidably prevented from attending, showed a short film which had been made during the erection of the steel roof trusses. The film illustrated how the girders were at first loaded in two halves on to one lorry. The

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

lorry had been fitted with a special bolster designed to take the unusual loading to which it was subjected. Subsequently deliveries to the site had been made by loading only one half-truss on each lorry. The transport contractors had preferred to send two lorries with one half-girder on each, rather than send the two on one lorry.

The film showed how a half-truss had been hoisted into position, and illustrated the great care that had been taken to lift at the centre of gravity of the truss. That position had been found by experiment in the works.

The pin connecting the top booms of two half-trusses was driven home quite easily with the aid of a hammer, although there was only a very small clearance.

The movement of the bogies carrying the shoe ends was shown to be not altogether smooth but rather a series of little jerks.

In order to prevent racking during the travelling of the girders, the tracking marks had been in foot dimensions. A certain amount of deliberate racking had been done, however, in order to centralize the rocker plate of the truss over the bearing plate.

Mr R. H. Matthew said that, as the Architect of the London County Council, with day to day problems tumbling in over the past 3 years, he had found it difficult to view the operation as a whole. As one phase had succeeded another, the earlier parts of the operation had been apt to become obscure and a little indistinct. It was therefore a great pleasure to be able to sit back and read a very clear statement of what had been done on a very complicated building and structural problem, from the general considerations at the beginning of the Paper which had led to the shaping of the plan right up to the erection of the roof, which had just been shown in so interesting a manner.

The Authors and almost every subsequent speaker had emphasised the requirement of speed. Time had, in truth, been a major factor affecting all members of the building team. From the very start it had been quite evident that, without an unusual degree of co-operation and collaboration between the contractor, the engineer, and the architect, the building could not have been built in time. In June 1948, when the possibility of getting Government authority to go ahead with the building had been first discussed with the Government, Mr Matthew's original time estimate had been 3 years, and he had thought that that was a very short time indeed, consisting of roughly 3 months for preparing preliminary sketches, 9 months for working drawings, and 2 years for building. That time schedule had very soon been cut and the period from September 1948 to May 1949 was then available for preliminary sketches; for all-important decisions to be taken on planning and other services; for estimates to be obtained for the Council procedure; for obtaining tenders; and for selecting the contractor. The contractor had had 20 months to the end of December 1950, leaving about 4 months until the opening date of

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

the Festival for furnishing and for acoustic tuning. The work was now well into the last stage of furnishing and tuning, with about 6 weeks still to go until the opening date; that was a measure of the success of collaboration. It was a considerable tribute to the structural engineers and to the contractors, both of whom had had to fulfil very difficult assignments from the architect.

The nature of the site and the external-noise problem had immediately suggested the raising of the auditorium, and so at once there had arisen new and exciting possibilities for the architectural handling of the foyers, the staircases, and the ancillary accommodation grouped as an envelope round the main auditorium.

The architects had simultaneously posed two separate sets of problems to the engineers. First, there had been the problems of mass and weight for the main auditorium, which was to be raised so many feet from the ground; secondly, the problems of lightness and economy of dimension in the surrounding envelope. It would be noticed throughout the Paper that the latter theme occurred very frequently, limiting the depth of slabs, the width of columns, and so on, and thus creating severe structural problems for the engineer.

The treatment of the auditorium for the purpose of excluding external noise had now been successfully achieved. The first full-scale acoustic test in the hall with a full audience and an orchestra, had been held and external noise had, in fact, been eliminated.

As for the second group of problems, it could be stated that the architectural conditions had been well met, and that the flying staircases flowed with all the grace of well-concealed strength with, so far as he was aware, no undue deflexion.

Apart from those general problems arising out of the nature of the building, many others had been posed and had had to be solved at very short notice. On the choice of structural method, attention had been drawn in the Paper to the advantages of steel for speed; and that, of course, was quite true. All the contractors, in the preliminary discussions before the contract had been made, had laid stress on that point. Mr Matthew was quite certain, however, looking back and taking into consideration the acoustic requirements, particularly in relation to external noise, that reinforced concrete had been the right choice. On the other hand, as the Authors had pointed out, reinforced-concrete construction, particularly for the main balcony, had added considerably to the difficulty of taking such a great unsupported load.

The Authors had mentioned the planning of the preliminary work, and that, he imagined, had been a fascinating study in itself. When the competing contractors had been asked to submit not only their price but also their scheme of organization, it had been realized that it was important to build up a continuous programme of work from beginning to end. In fact, constant planning and replanning of progress schedules had been a vital

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

factor in enabling the job to be completed. There had been comparatively little time for prolonged study.

A mere architect could not be expected to follow the engineers through their very learned Paper. He, himself, had read it with an architectural eye. That was to say, he had understood the diagrams, more or less; he had enjoyed the photographs; and he had skipped the difficult bits! It would be understood, perhaps, that sentences commencing with the words, "Stress trajectories were calculated from the Cauchy-Riemann equations for the condition of a deep continuous beam over an infinite number of supports" did not make for easy reading on the part of an architect. On the other hand, the Authors' observation that: "Owing to the nature of reinforced concrete, too much importance was not attached to the calculated stresses" had led him to reflect that perhaps, after all, in spite of appearances, the structural engineer was in some measure a creature of instinct and not wholly at the mercy of inexorable mathematics.

Mr T. A. Nanson confined his remarks to the dewatering of the site. The well-point system of dewatering had made a very notable contribution to the necessary rapid start that had had to be made on the job. It had been very impressive when, in July, after the bulk excavation had been completed and the ballast uncovered, several hundred men had been at work at the bottom of that hole, without rubber boots, working at a much higher speed than they would have done had they been under wet conditions of open pumping. He thought that that well justified the use of the method.

The Authors had stated that the water had been lowered after 36 hours of pumping. That was true, but Mr Nanson recalled that those responsible for the dewatering had originally asked for 4 days' pumping before excavations started. In fact, the pumps had been started up at 10.30 a.m. and the excavators had begun to work below the ground-water-level at 3 p.m. on the same day; but they had never encountered the water again. The water-level had been maintained at approximately 4 feet below the sub-grade throughout the period of the job, or throughout the 8-month period when the dewatering plant was in operation.

Mention had been made in the Paper of the anticipated danger of damage to Charing Cross Bridge. Subsequent events had proved the fears to be unfounded. There was, indeed, significant proof of that in that no further damage had been recorded to the bridge, nor had there been any movement of the Shot Tower after a prolonged period of time.

Referring to the stratification in the ballast adjoining the river, there was clearly some evidence of direct contact with the river on the river side of the Waterloo Bridge corner of the site. Indeed, there had been three well-points used as observation wells on each of the four sides, and regular observations had been taken over a period of one month. It had been discovered that the water had, in fact, risen about 12–18 inches, 2 hours after high tide on the Shot Tower corner of the site and 3–6 inches elsewhere. There had been a time-lag of approximately 2 hours after high tide.

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

While the dewatering had been in progress those responsible for the acoustics had had to carry out acoustic tests in a small building on the site, and it had been necessary for the well-point pumps and all mechanical equipment to be stopped for a period during one evening while those tests were made. It had been anticipated that the tests would take about an hour. While the pumps had been stopped for that purpose, close observations had been maintained on the observation wells. The water had risen 2 feet 9 inches in the centre of the job during a period of 1½ hour. But, since the ground-water level had, in general, been maintained 4 feet below the subgrade, there had remained a safety margin of 15 inches at the end of that 1½-hour period.

A variety of difficulties, which could be classified in two ways, had been encountered during the installaton of the well-points. In one section of the job, soft estuarine deposits had restricted the entry of the well-point into the ballast below. The silt had closed in on the well point and there had been no orifice big enough to wash out the heavy ballast encountered below. That difficulty had been overcome by chain jetting to maintain a wider-diameter hole. At another point, particularly in the central zone, along the river front, where it had become known later that the ballast had direct contact with the river, there had been a tougher estuarine deposit but, as soon as the well-points had hit the ballast below, the jetting energy had been dissipated, particularly at low tide, through the river ballast, and, it was believed, to the river. That had raised another problem. Points had had to be installed at high speed and great pressure. At any stoppage of work the points had closed up. In spite of the difficulties, it had been possible to deal with 1,040 feet with a total of 341 well points in a period of about 3 weeks under the most arduous conditions. Apart from that, no anxiety had been encountered.

Mr M. M. Khan referred to the design of the spiral staircase as shown in Appendix I, and in particular to equation (11) which gave the strain energy in half of the helix. After differentiating that strain energy with respect to the two unknowns, the equations had been solved and the whole bending moment and torsion had been calculated. The moment of inertia was I_1 in the first case and I_2 in the second. Did the assumed values of the inertia refer to the whole section of the concrete only, or had any allowance been made for the presence of steel ?

The expression $\frac{(Mt)^2}{2c}$ in that equation was rather complicated in so far as the torsion of reinforced concrete was concerned. Mr Khan had tried very hard to find data or to calculate the value of C, the modulus of rigidity for concrete. Could the Authors give a figure or some method of calculation ? There was, of course, the well-known expression :

$$C = \frac{E}{2(1 + \mu)}$$

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

If that expression were used for calculating the value of C, what value of μ had been assumed ?

Then came the problem of J, the polar moment of inertia. It seemed straightforward if the section were circular, but difficulties arose if it were rectangular. He presumed that some coefficient had been used to modify the value of J as calculated in the form of polar moment of inertia, in which case, for a rectangular or any other section, J would be the sum of the two moments of inertia in the two expressions, namely, $J = I_1 + I_2$. Would the Authors give some hint of the figure they actually used ?

Would the Authors say what value they would assume for J if the section were a long narrow rectangle with a width of, say, ten times the depth ? Six-inch slabs, 5 feet wide, often occurred.

The last item in the equation, $r.d\psi$, appeared to be all right, but he wondered whether something should not be added to it, especially in the case in question. It represented the increment of $r\psi$ as viewed in plan ; but the actual length would be longer, having regard to the fact that there was a rise in the spiral. The difference was not negligible but, in fact, was of the order of 30 per cent. Should it not be $r.d\psi \sec \phi$, where ϕ denoted the slope of the spiral ? In the present case $r \sec \phi$ would cancel out, but there were cases where ϕ changed. Mr Khan had in mind an instance where part of the flight was horizontal.

Mr E. W. Cuthbert observed that in many buildings in London it was possible to hear the sound of tube trains and to feel their vibrations. Before the site of the Festival Hall had been chosen, had any test been made to see whether such effects would be experienced ? Could any such effects be felt in the auditorium, or any other part of the structure, from the Northern Line Tube underneath ?

Lattice bracing had been used in the design of the top chord of the truss, but later, on the site, 12- or 16-gauge steel plate had been added to form a shutter to carry the inner roof slab over the chord. Had any consideration been given to designing the top chord with a structural plate instead of lattice bracing ?

Could the Authors give any estimate of the increased consumption of steel through the enforced use of section-depths and column-diameters less than the economical ? Mr Cuthbert believed that reinforced concrete had been selected in order to save steel, but it seemed that it had been necessary to use many sections of reinforced concrete containing more steel than was necessary.

In view of the large air space between the fibrous plaster ceiling and the inner roof slab, did the Authors think that the outer slab could have been dispensed with ? He felt sure it was an acoustics problem, but it seemed that there was an air space which would have some cushioning effect. Perhaps the fibrous plaster ceiling could have been thickened up or made to serve the purpose ?

He was sorry to see a spiral staircase in a new building. In railway

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

practice the product of tread and riser was very severely regulated, and he did not know how that rule would apply in designing public buildings.

What arrangements had been made to deal with any seepage that found its way into the basement ? Having seen a little of waterproofing, he did not think any could be permanently regarded as 100 per cent. successful with basements as low as —9·00 in close proximity to the river.

Mr E. F. Humphries asked whether the Author's remarks on latitude of stress in reinforced concrete also applied to the foundation pressures. He appreciated that in a job of that nature the time factor was such that drawings went straight from the engineers to the contractors and the work was put in hand. When the foundations had been in the design stage, had full information of the possible weight of the building, with all the appurtenances, been available ? What latitude had the designers allowed to cover possible additions which might be required later on ?

The Authors, in reply, said that they were interested in the information given by the President about the assistance given by the Institution to the Great Exhibition of 1851.

One of the President's questions had related to the statement on p. 251 that " It is considered that the essential requirement is that a sufficient percentage of reinforcement should be provided to ensure plastic behaviour of the concrete near the support." Those words had been written at about the time when Professor A. L. L. Baker had presented his Paper [1] on recent research in reinforced concrete and that Paper seemed to support the belief on which the reduction of support moment had been based. Professor Baker had referred to further experiments to determine the reinforcement necessary to ensure plastic behaviour of the concrete. In the meantime, the Authors would hesitate to say what was the critical percentage of reinforcement.

The President and Mr Matthew had made reference to the statement in the Paper that: " Owing to the nature of reinforced concrete, too much importance was not attached to the calculated stresses. . . ." That had not been intended to be in any way derogatory to reinforced concrete calculations. It merely referred to calculation of the stresses in very deep beams, assuming the material to be isotropic. Clearly, near the bottom of the walls there would be considerable re-distribution of the stresses owing to plastic behaviour.

The Authors agreed with the President's remark that previous research had not been very helpful to them in their effort to analyse the stresses in the torque box. The final result of the calculations had been that the designers had looked upon the various parts of the box as taking shear in a similar manner to the web of a beam, and they had considered that they could exceed the percentage of reinforcement indicated by the various tests outlined by Turner and Davies,[1] which were really applicable only to solid

[1] " Recent Research in Reinforced Concrete and its Application to Design." J. Instn Civ. Engrs, vol 35, p. 262 (Feb. 1951).

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

sections. At any rate, there did not seem so far to have been any untoward results in the torque box in question.

The Authors could not yet give the information which Mr Champion had asked for, regarding engineering services or the use of gas for heating boilers.

Quantity surveyors had indeed been engaged on measurement and, whilst the Authors were glad that that was so, it was Mr Measor's opinion that the quantity surveyors' system of measurement was somewhat elaborate, whereas engineers tried to use simpler methods. Therefore he entirely favoured the engineers.

Mr Khan had raised some interesting points in the design of the spiral staircase. The effects on steel reinforcement on the moments of inertia had not been allowed for either in direction of bending or in the torsional rigidity. It had been considered that the values of I_1, I_2, and J would be increased to approximately the same degree by that effect and the important point was the relationship between them. J was not, of course, the geometrical polar moment of inertia but was its equivalent, calculated for the rectangular shape, for instance, by means of Prandtl's analogy. Numerical constants for calculation had been given by Dean Peabody.[2]

Tests which gave some idea of the effect of reinforcement on torsional rigidity had been described by Mr Henry M. Cowan, M.Sc.[3]

With regard to the value to be ascribed to G, Peabody had given a figure of $G = \frac{3}{7}E$, and that was the figure which had been assumed in the Authors' calculations.

They did not feel that it was practicable at the present time to make any more accurate assumptions than those described above. It was hoped that, some time in the future, exact data would be available. In the meantime, the Authors would continue to design and build reinforced-concrete structures, subject to torsion, which would meet the loading conditions imposed.

It was agreed that sec ϕ ought strictly to appear in equation (11); but since it was outside the bracket the results were unaffected by its omission.

The question of vibration caused by tube trains had been considered in the early stages of the work. The acoustic specialists had replied to the Authors' inquiries by stating that the tube trains would produce no vibrations of any significance. That seemed to be borne out by the results, because apparently no rumblings of consequence had been heard.

The latticing of the top chords of the roof girders had been designed before the contractor's scheme for shuttering had been known. Furthermore, the Authors did not think that the structural plating of the top chord

---

[1] See footnote, p. 265.

[2] "The Design of Reinforced Concrete Structures" 2nd Ed. pp. 175–6. Chapman & Hall, London, 1946.

[3] "Tests of the Torsional Strength and Deformation of Rectangular Reinforced Concrete Beams." *Conc. & Constr. Engng*, vol. xlvi, p. 51 (Feb. 1951).

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

would have fitted in very well with the design, because, as described in the Paper, those chords were relatively light.

There had been a significant increase of steel owing to the shallowness of concrete sections. The Authors had no idea what the increase amounted to, but as Mr Matthew had pointed out, it was the price of getting as architectural effect. Reinforced concrete had been used to give economy of steel and, though steel-consumption had been more than it would have been if the sections had been larger, it was less than if structural steel had been used.

Fig. 60 showed that the ceiling was not a continuous layer but a series of independent leaves, and it was, therefore, no bar to sound. The two slabs of the roof were necessary to keep out external sound.

Mr Cuthbert had said that he was sorry to see a spiral staircase being used. It was true that there was a certain difficulty in a spiral staircase because of the varying widths of tread. However, it was certainly interesting to look at.

There had been no seepage into the basement up to the present, and it was hoped that that state of affairs would continue. Should a seepage occur, however, there were two large sumps with pumps which would no doubt be able to deal with any water that found its way into the basement. The sumps had really been intended for waste water from boilers and other sources, but they were also a last line of defence in case of leakage.

Mr Humphries had asked about latitude in the design of the foundations. He seemed, at the same time, to have gained the impression that reinforced-concrete stresses had been treated in a rather free and easy manner. That was not so. The design had been made as close as was normal. The foundations also had been calculated as nearly as was possible according to the information available at the time. Although the design had been developed as the building progressed, the general plan had been formulated at the beginning. It had been possible to make a reasonably good estimate of the weight on the foundations, but allowance had been made in excess of what would have been the case if the design had been complete when work started. Some margin was desirable in a public building of that nature to permit alteration in the arrangement of floors if found necessary later.

The President and Mr Hole had again stressed the importance of bringing home to the men the exact part they were playing in the overall plan and of illustrating to them the position regarding targets and actual progress for the various operations.

If quality and production on large civil engineering and building works were to be improved, it was essential that a new interest should be aroused in the men. It was no use allowing them to drift along, seeing no further than their particular trade and their wage packet at the end of the week. The more the workmen's interest in the complete structure and its progress could be aroused, the more satisfactory would be the execution of major schemes.

21

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest

Mr Champion had referred to the site organization. The contractors' senior representative on the site was the Contract Manager, who had all the facilities of Head Office close at hand. His main assistants were the contract labour officer, the contractors' senior quantity surveyor, the Agent in charge of building and general trades, and the Senior Engineer in charge of concrete work.

The reinforced concrete work above ground-level had been divided into three sections, namely the auditorium and the areas on either side, each of which was in charge of a supervisor responsible to the Senior Engineer.

The London County Council employed a Resident Engineer and Assistant Resident Engineer, assisted by a Chief Clerk of Works and four other Clerks of Works and Inspectors, and by an engineer responsible for concrete control, who worked in conjunction with the contractors' control engineer.

The Consulting Engineers had an Engineer resident on the site, thus enabling prompt decisions to be given on any matters connected with structural design and reinforcement.

The Quantity Surveyor had his staff on the site, in charge of the Resident Surveyor.

Downloaded from http://ftp.nowpublishers.com/jince/article-pdf/36/7/305/2581503/ijoti_1951_12735.pdf by guest