ENGINEERING AND ARCHITECTURE
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ENGINEERING AND ARCHITECTURE

A paper by

PROFESSOR ING. RICCARDO MORANDI

read to the Society on Wednesday, 15th November, 1961, with Sir Herbert Manzoni, C.B.E., City Engineer and Surveyor, Birmingham, and President, Institution of Civil Engineers, in the Chair

CHAIRMAN: Professor Riccardo Morandi has travelled from Italy especially to talk to us this evening. You might think that, having regard to the name of your Chairman tonight, there is some matter of collusion. But I assure you that that is not so, for indeed I find it quite impossible to speak to Professor Morandi in his own language—he speaks very well to me in mine. On the other hand, although I am wholly English, my father was Italian, and if in introducing the speaker to you I appear to lean somewhat towards Rome that is understandable.

It is particularly appropriate that a lecture with this title should be given by an Italian, because in Italy there is to-day a very great movement towards what one might call the combination of two aspects of a single subject, which in this country, unfortunately (and I say *very* unfortunately), have become separated far too widely in recent years. That may be because the science and the art, like oil and vinegar, do not mix very well, but in Italy they appear to mix oil and vinegar splendidly in their salads and I am quite sure they can be united to the improvement of both. It is natural, I think, that this movement should have originated in Italy because, of all the people in Europe, the people of that country seem to have an innate sense of design, or harmony of beauty, which is more intense than is usually found in other parts of Europe.

So it is natural that the engineers of that country should think architecturally, and if I know anything at all, it is that Professor Morandi's life and works have indicated that this combination can lead to very beautiful and most interesting structures. Professor Morandi's work is well known in engineering circles. When I asked at the Institution of Civil Engineers for some information about him, it was produced at once, as it would be of several of his eminent colleagues.

The following paper, which was illustrated with lantern slides, was then delivered.

THE PAPER

Before I begin to consider some of the ideas which have influenced my working life, and to explain something of my work, I wish to express my thanks to the Royal Society of Arts for the honour they have conferred on me by their invitation to read this paper.

I who speak to you am an engineer, a structural designer; that is, a man who has been trained by the schools of his day to act as an intermediary between the ideas of the architect and the requirements of the constructor—the man who, in Italy, is still called the *calculator* of a work of engineering.

I began therefore to be a 'calculator' of structures in reinforced concrete, and, at first, my clients required nothing more of me than a structure which adhered exactly to the dictates of the designer (the architect), economical, easily built and statically correct.

Collaboration with the architect has often been pleasant and fruitful, but I remember many bitter moments when the architect and the client could not understand that the 'calculator' might have his own sensitivity, and above all an understanding of the possibilities of the stylistic expression of the materials which he had learned to deal with.

That was at the time when there was still an absolute separation of engineering and architecture.

A remainder of the positivist outlook, a technical literature, especially German, founded on a tabulated casuistry (almost as if a good set of formulas could take the place of an engineer with his sensibility), all of which formed a tendency which exasperated a young engineer with its cold reasoning—such was the preparation of a 'calculator' in those days!

All those cases in which masterpieces of engineering were also, and essentially, masterpieces of architecture—the Forth bridge, Eiffel's viaduct over the Garabit, Maillard's bridges, Freyssinet's hangars at Orly, Hennebique's Risorgimento bridge, Nervi's first works—were not yet being considered by the critics, and 35 years ago men of culture in Italy were still discussing the style of Vignola and its use, even though under the tympanums and classical arches a solid reinforced concrete beam, carefully hidden, happily performed their statical function.

At a certain point in my life I refused to be relegated to the position of a second-rate employer of formulas and, little by little, helped by the evolution of the times and especially by the ever-increasing liberty provided by the new techniques, I learned to express my own personal style.

My generation has thus had to free itself from a training falsified by prejudices and from mistaken distinctions, in order to reach an individual style of its own, relying essentially on intuitive statics, on the sense of structure, and on the possibility of finding in calculation the confirmation of its own invention.

Calculation: let us speak for a moment about this word, so mysterious to the uninitiated and in the name of which so many beautiful projects have been, and continue to be, spoiled. It is well known that the theory of Structures (as we call the study of the stability of bodies which can be altered by the forces acting upon them), after Leonardo da Vinci's first intuition, the investigations of Galileo in the first half of the seventeenth century, and the enunciation of Robert Hooke's famous law *sic tensio ut vis* (1676), developed rapidly during the last century, until it provided the solution of the most complicated problems. The formulation and demonstration of fundamental theorems for the solution of problems of hyper-statics forms one of the most striking pages in the achievements of modern engineering. And at the same time the various technologies were giving the engineer ever better and more constant materials.

At this point I must mention in parenthesis that a new idea, together with a new material or new possibilities, has always found a designer of strong character who has understood and immediately put into practice its first great application. The viaduct of Truyere at Garabit and the Forth bridge were both constructed

(1884) a very few years after industry had put at the disposal of technicians drawn and cast mild steel. The wonderful Risorgimento bridge in Rome was built barely twenty years after the first production of artificial Portland cement.

Returning to the subject of calculation: anyone with even a limited experience in designing statically indeterminate structures knows that, using the same quantities of materials, it is possible to change the dimensions of the structures themselves in many different ways. For example, it is sufficient to vary reciprocally the stiffnesses of the different parts of a framework to obtain, within certain limits, different solutions and therefore different expressions while still using the same total material, with the same safety and at the same cost. Not only so, but the most up-to-date studies of the elasto-plastic behaviour of a structure (especially in concrete) have already led to considerable divergences from the methods of calculation previously used, and which are already being called 'old' and 'traditional'.

In this connection I feel I must clarify certain points. Until now, in compliance with Hooke's Law, the dimensioning of a section has been done according to the so-called 'elastic method'. That is to say, the maximum stresses to which the material is subjected by external forces are determined, and the permissible stresses, assumed to be contained within the limits of linearity, are a suitable proportion of the allowable unit stresses conventionally indicated as ultimate strength.

In the particular case of reinforced concrete—that is to say, in a structure composed of two different materials—it has been assumed that sections remain homogeneous under all conditions of loading. However, this assumption is far from representing the actual state of the internal forces of the structure, either as regards the fictitious significance of the allowable unit stresses or the consequent assumption of two different degrees of safety, one for the reinforcement, and the other for the concrete, not to mention the amount of discussion that there has been, and continues to be, on the interpretation of the idea of the safety of a structure!

The Americans, first in aeronautical and later in civil construction, have already been introducing statistical criteria into the assumption of the factor of safety, with regard to the probability that the heaviest conditions of load assumed in the calculations may be realized, even in different types of constructions.

Moreover, calculation based on the ultimate strength in the plastic phase was proposed several years ago, and has recently been increasingly used. And—still taking the case of statically indeterminate structures—it has been considered besides that in the field of elasto-plastic deformations, the phenomenon of the re-distribution of stresses takes place, with the resulting necessity of examining the degree of safety of the sections which the theory of elasticity does not consider as sections of maximum stress.

Finally, the latest research into the influence of internal forces within the material, which has given rise to a very interesting collaboration between physicists and engineers, affords us a glimpse of a new and more deeply studied approach to structural engineering.

After what I have said, can calculation still be considered an absolute factor in the determination of the shape of a structure? Or rather is it not amply demonstrated that this is based on the knowledge and sensitivity of the designer? As long as forty years ago Robert Maillart, the great creator of structures, said:

> The view that calculations should determine dimensions unequivocally and unanswerably is fairly widespread. But since it is impossible for them to allow for every factor, calculations can only be a starting point for the constructor, who must then proceed to take precisely these factors into consideration. Then, accordingly to circumstances, the design will either follow the original calculations, or it will undergo a change. And if the work is being done not by a calculator but by a true constructor, this will often happen.

And Luigi Piccinato says:

> The designer must be capable of experiment in human terms, surpassing, in this means of expression, those technical aids which Science puts at his disposal but which can only be one of many tools.

Finally, Pier Luigi Nervi, on the other hand, emphasizes the danger of a false structuralism—in other words, the excess of liberty which, 'instead of being the natural outcome of structural requirements originates in a formal presumption'.

Now for more than twenty-five years—that is, since I came to a full realization of both my capabilities and my limitations—I have devoted myself to problems in which the structural aspect largely determines the architectural aspect of the work, and in almost every case I have adopted the solution of one person being responsible for the whole project—that is to say, the functional design, the static design, and also the method of construction. For example, my prestressed concrete structures are all carried out with a prestressing system expressly designed to permit the realization of my structures according to my own ideas.

I should now like to show you some works which will explain my meaning better than I can in words. And I shall try at the same time to indicate the successive steps which have been necessary to reach results which give me satisfaction.

Parish Church at Colleferro, Rome (1934)

This church (Figure 1) built for an industrial centre near Rome echoes, in terms of its own day, a characteristic feature of the neighbourhood—the ruins of a medieval castle of which three very tall arches remain standing. The forecourt and the bell-tower, the latter 115 ft. high, are built of reinforced concrete 6 ins. thick.

The external surface of the concrete is bush-hammered; its typical appearance is due to the crushed stone aggregate exposed by the bush-hammering, which is white (limestone) and black (basalt).

I think this is one of the first uses of reinforced concrete left uncovered and bush-hammered.

Giulio Cesare Cinema in Rome (1934)

This cinema, with a seating capacity of about 2,000, is the first step in a long journey carried on through many later works: the problem of basing the

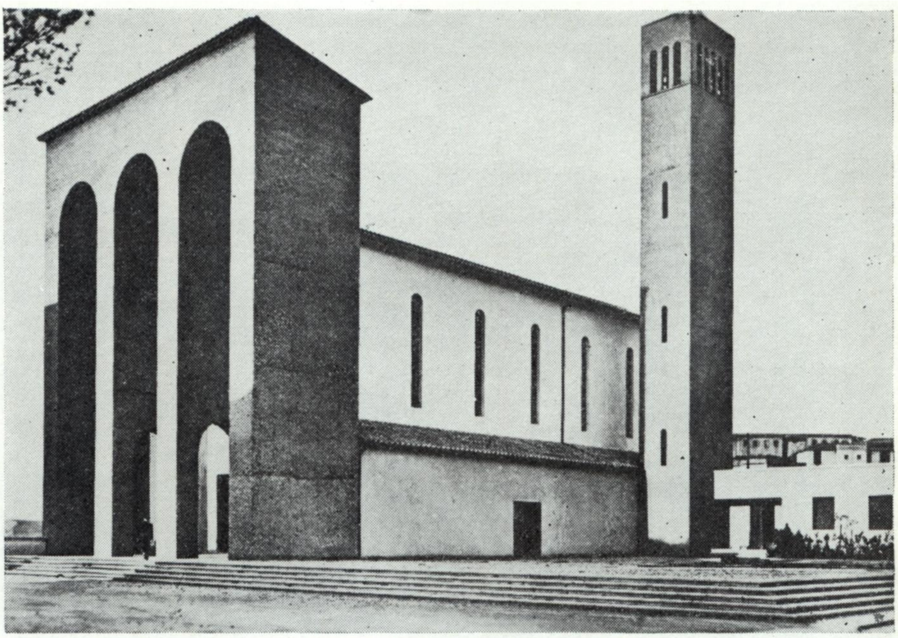

FIGURE 1. *Church at Colleferro*

architectural character of the interior of the hall exclusively on the structure, making this visible as far as possible.

It must be remembered that, until a few years before, the cinema was developed only as an adaptation of the theatre. The invention of the wide balcony in place of walls pierced by boxes, developed to give all the spectators a view as little distorted as possible, has created considerable structural problems. This hall, whose characteristic is a very light balcony, makes use of the theory of balanced torsion. This means that the torsion transmitted to the principal bearing beams by the extreme cantilever end is compensated by the opposite torsion originating, on the same beams, from their curvature on the horizontal plane, which follows the line of the rows of seats.

Alcyone Cinema in Rome (1948)

This is one of the stages of the journey begun fourteen years earlier in the Giulio Cesare cinema, and continued in other examples which I must omit for the sake of brevity.

The Alcyone cinema, with a seating capacity of 1,500, has two balconies in which the whole framework is visible.

Deep research into the question of perfect visibility, and of the lightening of the structures, has enabled the double balcony to be used without increasing the height of the building excessively. The access stairs determine the fundamental element of expression of the halls.

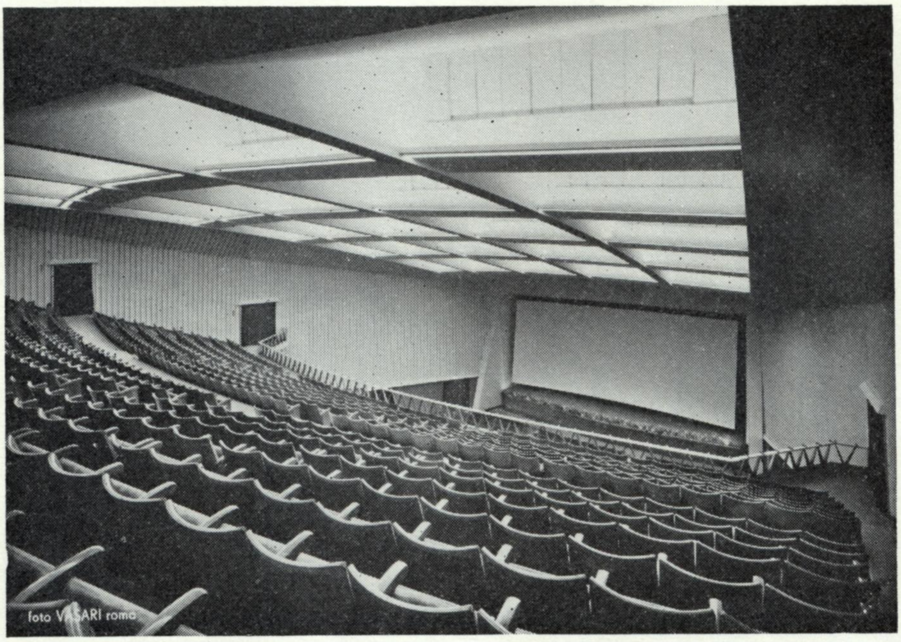

FIGURE 2. *Maestoso cinema, Rome*

Maestoso Cinema in Rome (1957)

This large cinema (Figure 2) represents the last stage (at least for the moment) in that journey begun more than twenty years before with the Giulio Cesare cinema.

The requirements here were rather exacting: in the basement a warehouse with an area of about 16,140 sq. ft.; above, a cinema with about 3,000 seats; above this again a block of flats of 100 rooms.

The co-existence of the various functions of the building introduced a difficult static problem. The whole complex is supported by a series of statically indeterminate portal frames with a span of 131 ft., each one of which supports a system of concentrated loads of several hundred tons.

The balcony, completely cantilevered, is tied to the principal structure by means of a rather complex static system.

The construction of this framework was made possible only by the full use of prestressing in an application which is perhaps one of the most exacting ever attempted until now. Furthermore, we wanted to base the architectural modulation of the entire work on the static principle, which therefore is presented, inside and outside, with extreme frankness.

The critics called this work 'a daring and controversial building'.

Water Tower at Leghorn (1953)

This water tower designed for the city of Leghorn is 204 ft. high and has a capacity of 450,000 gallons. The framework is composed of a number of sloping members arranged along the lines of a hyperboloid in order to increase the rigidity of the structure. The design was not accepted by a Government Commission which judged it 'anti-aesthetic', compared with normal types

Water Tower in Rome (1960)

This design, 197 ft. high and of a capacity of 650,000 gallons, represents, like the preceding one, an effort to break away from already exploited ideas, for works of importance in the landscape.

Fuel Reservoir in Venezuela (1956)

The unusual shape of this underground reservoir, of a capacity of 3,500,000 gallons, arose in order to take advantage of the strength of doubly curved surfaces. The interaction of the central dome and the surrounding vault has, in particular, been exploited with very economical results.

The resulting form is, in my opinion, interesting.

Textile Factory at Castellaccio (1955)

The large upper hall for the working of wool fibres at Castellaccio (68,800 sq. ft.) shows both internally and externally its structure of prestressed concrete and statically indeterminate portal frames, each with a total length of about 260 ft.

Another hall, for synthetic fibres, has a series of beams of 131 ft. span, with a special section within which air at a constant temperature and humidity circulates for the air-conditioning of the hall.

Santa Barbara Thermo-Electric Power Station (1958)

This thermo-electric power station in the Arno valley has a power production of 300,000 kilowatts. The prestressed concrete frame contains halls of notable dimensions. For example the machinery hall is 78 ft. 9 in. wide and 394 ft. long.

This was an example of close collaboration between the technological designers and the designer of the structure. The latter had to make a careful study of the requirements of the various parts of the complex to make them into a harmonious whole.

Garage and Market in Rome (1958)

The complex consists of a covered market and a big garage, and is composed of three halls, one underground, one at ground level and the third above that. The two entities, interpenetrating but functionally independent, made it necessary to provide a uniting element between the various parts of the garage outside the building, and from this an effective result has been obtained. The uniting element is the double helicoidal ramp, which is calculated as a double spatial system of great lightness.

Electro-Nuclear Power Station of the Garigliano (1960)

A big electro-nuclear plant is being built in the South of Italy, whose structural design entails the study of a new and exacting problem.

The whole large building for the production of electrical power is completely

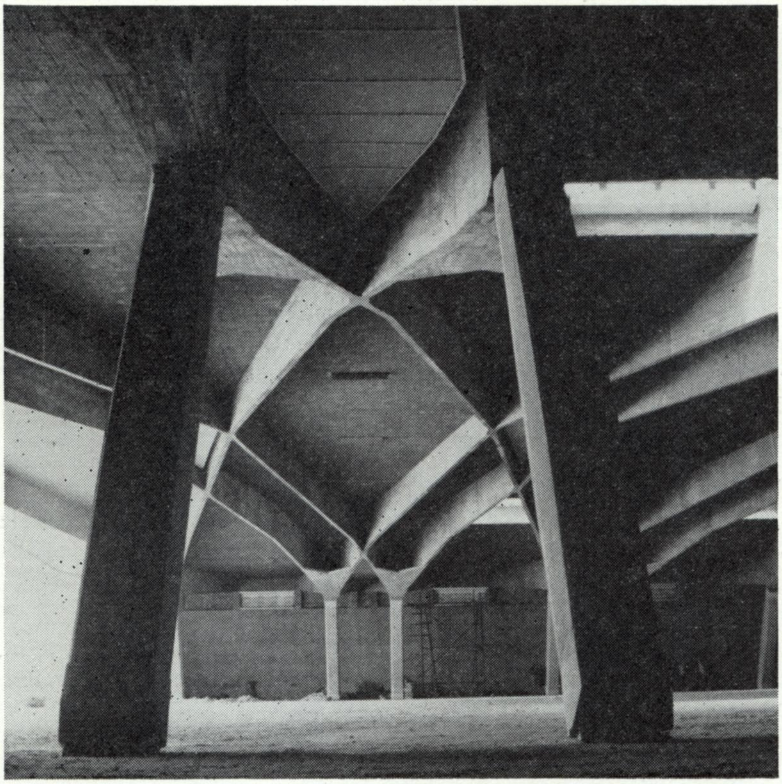

FIGURE 3. *Motor show in Turin—detail*

enclosed by walls of concrete without any opening. I am trying to leave this visible, without any attempt at covering. I seem to be going back twenty-five years, when, for the first time, I faced the same problem in the Church of Colleferro. In this instance, however, with very different dimensions.

Motor Show in Turin (1959)

The new underground hall for the Motor Show in Turin may be cited as an example of how the various difficulties involved in the subject may produce different solutions, all leading towards an architectural result. Here, these were: the great span, free so as not to create obstacles to the exhibition of large vehicles; the very heavy load on the roof caused by covering it with earth, to be cultivated as a garden; the pressure of earth on the sides; the necessity of limiting the height in order to facilitate access from the upper road surface.

These were the reasons for using the sloping columns which determine in the roof structure components of pressure capable of reducing the bending moments which result from dead and live load. And they were also the reason for using the crossed beams, which tie the roof in all directions. (Figure 3.)

FIGURE 4. *Leonardo da Vinci airport, Rome*

When I read journals from all over the world, praising the architectural qualities of this project, I recall its very laborious planning, full of static and economical difficulties, and I remember the words that Freyssinet wrote about the famous Orly Hangars (1921): 'After long research and hesitations I managed to combine certain forms which could be realized with economy. I was not looking for more, and not for one moment did I think of the possible artistic effect.' He had obviously worked with his true engineer's heart—which nearly always does think 'of the possible artistic effects'.

Project for an Exhibition Hall for the 'Italia '62' Exhibition in Turin (1959)

This project presents on a larger scale the solution already adopted in the previously mentioned hall. In this case also there are prestressed concrete frames (with a span of 492 ft.) linked by a special system of prestressed ties. The elaboration of the form is strictly bound to the necessity of the subject, since the building was first to be used as an exhibition hall and later as an industrial establishment, the halls of which were to have a direct lighting system.

This design was not accepted—Pier Luigi Nervi's alternative solution being chosen.

Leonardo da Vinci Airport in Rome (1956)

This (Figure 4) is an example of fruitful collaboration between myself and a group of architects (A. Luccichenti, V. Monaco and A. Zavitteri). The big passenger building, the flight services building, and the control tower are so many elaborations of basic structural ideas, all of them with a constant module, clearly defined.

The A.B.C.D. Polyethylene Factory in Ragusa (Sicily)

This factory, consisting of a large number of buildings, aims at expressing a composite unity, even though it is based on buildings with very different requirements.

I now propose to show some examples of the solution of a problem that I find particularly congenial.

I have designed many bridges and I have always sought to give them a feeling in harmony with the surrounding landscape, and a form and expression ever more clearly allied to the static requirements of the particular problem.

S. Niccolo Bridge in Florence (1946)

This bridge is of approximately the same dimensions as Hennebique's admirable Risorgimento bridge, that of the Foro Italico, and the 'Africa' bridge, all three in Rome. It differs from them, however, in that it has, with remarkable economy, abandoned the idea of the bearing tympanum, and forms a true arch, relatively thin, of which the elements that support the deck do not form part.

In this work the structure is not yet fully expressed. The static idea is still hidden by the closed and useless tympanums, which give it a heavy appearance. A step forward will be made in a later work.

Viaduct of the New Republic in Caracas (1954)

This viaduct, the arch of which is unusually low (296 ft. span and only 21.4 ft. rise) represents the stage reached in the logical process started in the S. Niccolo bridge in Florence. The entire structure is visible and clearly shows the chosen static principle. The side spans, necessary to pass over two lower roads, are made continuous with the central span as regards both statics and form.

The abutments of the arch are designed to counterbalance the considerable bending moments due to the flatness of the arch. This method of design, which necessitated the solution of some delicate problems of calculation, made possible an architectural expression of remarkable lightness.

The Footbridge at Vagli di Sotto, Florence (1953)

The footbridge at Vagli di Sotto spans one of the branches of an artificial lake belonging to a hydro-electric plant in the Alta Garfagnana (Lucca). It is a three-hinged arch with a 230-ft. span which supports a slab consisting of two elements, each formed by a frame with an intermediate column and two continuous spans of 76 ft.

We have been now for some years in the domain of prestressed concrete. In fact the whole deck is in prestressed concrete, and the prestressing is also used as an auxiliary means in the erection of the two half arches built into the sides of the mountain.

Bridge over the Storms River, South Africa (1955)

This bridge (Figure 5), over a ravine of a depth of not less than 500 ft., using a method similar to that of the footbridge at Vagli di Sotto, has an arch of 360-ft. span, the slab of which is supported by sloping pillars. This arrangement automatically corrects the line of thrust during the passage of loads, especially for sections near the crown. In fact, the horizontal components of the forces of the columns on the vault reduce the eccentricity of the thrust with respect to the plane of the centre of gravity in the crown section.

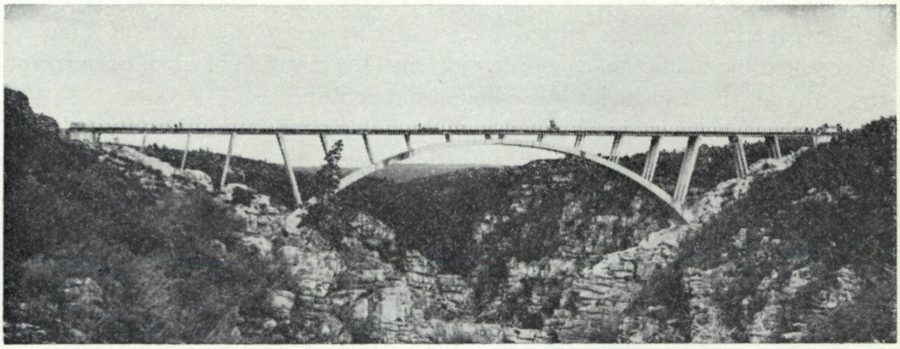

FIGURE 5. *Bridge over the Storms river, South Africa*

Viaduct over the Fiumarella at Catanzaro (1960)

Principles similar to those followed for the bridge over the Storms river guided me in the design of this project, which I consider, at least for the moment, to be our best solution of the problem of big arches. (Figure 6.)

I have already explained the reasons that led me to incline the columns that support the deck on the arch. Also, where the deck is supported directly on the sides of the valley, the inclination of the columns has made for economy, given the great height of the columns themselves.

The bridge is 1,640 ft. in length, with an arch of 758 ft. span and 197 ft. rise, and with 394 ft. maximum height. This last dimension made it necessary to build centering which is among the highest in the world.

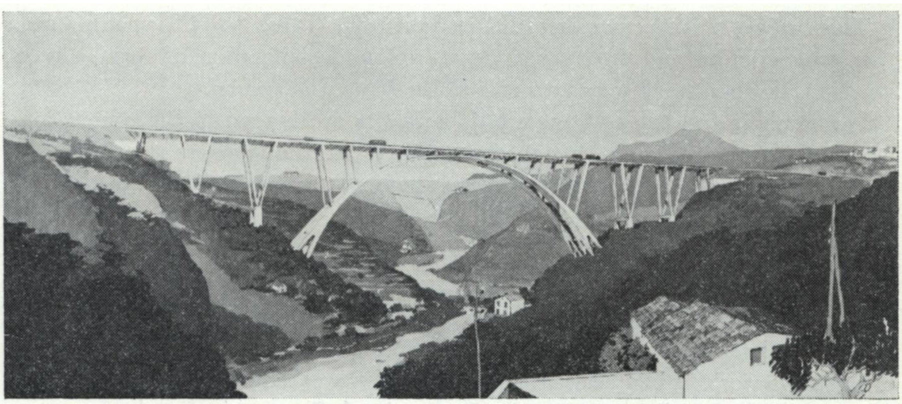

FIGURE 6. *Artist's perspective of the viaduct over the Fiumarella at Catanzaro*

Amerigo Vespucci Bridge in Florence (1956)

The Amerigo Vespucci bridge, built in the centre of the town of Florence, represented the solution of a delicate problem—the insertion of a modern structure in surroundings of great historical and aesthetic value.

The length of the bridge is made up of three straight prestressed concrete beams, supported on piers which were faced with the same stone as that with which the whole town is built. The central beams are of 187 ft. span, and the two side ones of 174 ft. span; they are of extreme lightness and of a line determined strictly by static laws. This bridge is only a few hundred yards from the famous 'Santa Trinita' bridge by Ammannati, which is considered the most beautiful of the Renaissance bridges. The Florentines, faithful custodians of the beauties of their city, and inherently severe critics, were very satisfied with the result. This repaid me and my collaborators for the considerable effort needed to overcome some difficult technical problems—in particular to obtain the desired slenderness of the beams. The three beams, which are independent of one another, are each tied to the piers by prestressed bars, which reduce the mid-span moments under live load.

Overbridge on the Corso Francia, Rome (1960)

This overbridge, with a span of 131 ft. was built in great haste for the Olympic Games in Rome. It makes use of an interesting type of design, already employed by myself and by others, known as the tied bridge: that is to say, a bridge in which the bending moment due to the passage of loads is regulated by the reaction of two prestressed elastic ties attached to the cantilever ends of the beams.

I had already used this solution in the Amerigo Vespucci bridge in Florence, although it did not appear externally. In this overbridge the static principle has been made evident, in order to create a clear, expressive form.

A Bridge at Sulmona (1960)

This bridge, much bigger than the preceding one (it has a 295 ft. span), repeats the same solution and attempts a more profound elaboration of form, always, however, through small improvements in the structural system.

For example the bases of the trestle supports are hinged to the foundations, whereas, in the preceding case, they were fixed. Furthermore, in this bridge the extremities of the beams continue beyond the top attachment of the ties.

Bridge over the Maracaibo Lake, Venezuela (1957)

Here in London on 19th March, 1957, at the conference of the Joint Committee on Structural Concrete held at the Royal Empire Society, I had the pleasure of presenting, by special invitation, my project for the competition for the construction of this large work. It had been designed only a few weeks previously.

In the meantime I have won the International Competition, and after many vicissitudes I have now the pleasure of showing, for the first time, the work nearly completed. (Figure 7.)

FIGURE 7. *Bridge over the Maracaibo lake, Venezuela*

Before giving a brief description of the bridge, I should like to express my thanks to my fellow workers, to the Ministry of Public Works in Venezuela, to the Commission for the Control of Calculations of the Polytechnic of Zurich, to the Consultants responsible for the difficult foundation problems, and lastly, to the Venezuelan and German contractors, who helped me to carry out such a complex enterprise, and who scrupulously respected my wishes concerning the plan of work.

In its final form the bridge, which is about 5½ miles long, is composed of many spans: one span of 87 ft.; twenty-nine spans of 153 ft.; two spans of 216 ft.; twenty-six spans of 297 ft.; two spans of 525 ft.; five spans of 771 ft.; twenty spans of 120 ft.

The bridge, which is built entirely of prestressed concrete, permits the passage of large ocean ships bound for the oil centre, and provides the link between the town of Maracaibo (about 600,000 inhabitants) and the rest of Venezuela.

Where the navigable canal occurs it rises 164 ft. above the level of the lagoon, and its five major spans were dictated by the requirements of navigation.

I hope that the illustrations that I am showing to you to-day will give an idea of the scope of the work and of the difficulties of form and statics that had to be overcome.

Overbridge on the Polcevera in Genoa (1961)

Construction of this great viaduct, of about 4,900 ft. in length, which passes

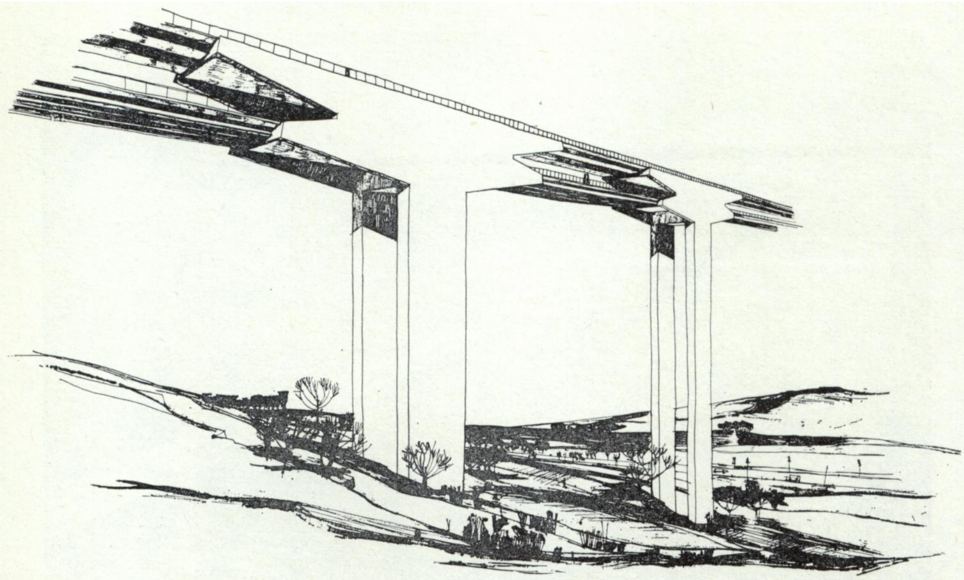

FIGURE 8. *Project for a two-level bridge for the Cisa highway*

over a district of Genoa, the river Polcevera, and two big railway yards, has now begun.

It is composed of one span of 141 ft.; five spans of 235 ft.; one span of 248 ft.; one span of 468 ft.; one span of 682 ft.; one span of 664 ft., and other small assembling spans.

The large spans repeat the static scheme adopted for Maracaibo bridge, with refinements in static form which interest me greatly.

In conclusion I wish to say that over the last months I have devoted study to the economical solution of the problem of bridges with two roads at different levels (Figure 8), to the solution of the problem of big hangars for the Rome Airport of Fiumicino and, lately, to enthusiastic collaboration in the project of raising the temples at Abu Simbel in Egypt. This last is a scheme of the greatest interest.

And while I thank my listeners for the attention they have given me, I should like to express the plea that all my works may be judged as deriving from a singleness of thought which has guided me all my life.

DISCUSSION

CHAIRMAN: By way of starting the discussion, there is one point that occurred to me as I looked at that screen. There is no doubt that Professor Morandi's theme is that the structures must be functional, but I have seen structures which were purely functional and terribly ugly. Now I should like to ask him if it is correct to say that to a purely functional solution one must also add something of aesthetic design.

In other words, that it is not quite sufficient that a structure is functional, because it will not inevitably be beautiful.

THE LECTURER: I do not think that a functional structure is necessarily also beautiful. I think—and it is the main point of my theme—that it is possible. Generally, the functional structure is correct, but it is not always beautiful, because it is necessary to choose the best among the several possible solutions—according to our feelings, of course, and so it is that the design of a structure is essentially an artistic job.

MR. HUGH CLAUSEN, O.B.E., I.S.O., B.SC.(ENG.): The Chairman, in his introductory remarks, said something about the wide and possibly increasing divergence in engineering between the science and the art, and pointed out that this was a dangerous tendency, presumably in civil engineering work. Equally it seems to be a dangerous tendency in other kinds of engineering work as well. I should like to ask Professor Morandi if he could express any ideas on the proper training of engineers so that the art and the science could be suitably combined.

THE LECTURER: First, there is a difference between the man who wishes to devote himself to design and the man who wishes to devote himself to research and to science. I think that the young man with the scientific mentality is becoming one of our best assets, because we need to have the scientist near us. But in the case of those who wish only to concentrate on the design, it is necessary to teach them the scientific and architectural points of view. Otherwise we shall have in our offices two types of student: the intelligent and decisive young engineer who knows and enters into the mentality of the scientist, and on the other hand the young people with only the mentality of 'expression' without having in their hands the tools to achieve it: they cannot understand the calculations—they lack the tools.

For this reason we in Italy are trying to transform the architectural schools so as to develop both aspects. For instance, Pier Luigi Nervi and I are both professors and teachers in architectural schools; I in Florence and he in Rome.

MR. E. MAXWELL FRY, C.B.E., B.Arch., F.R.I.B.A. (a Member of Council of the Society): Speaking as an architect for architects, I wish to salute these great works of structure and of architecture which Professor Morandi has shown us. He has answered things which, when the Society invited him to come here, I hoped most he would be able to prove—that was, that civil and structural engineering are as much an art as architecture. In the practice of both these arts one cannot avoid the use of the intuitive approach to the problems, however practical and economical they are.

It has been to my mind a terrible thing that these two disciplines of engineering and architecture have been at war for so many years, and it is my dearest wish (and I am sure this is shared by all young architects) that the two should be brought together. I should like to see in our new universities a Faculty of the Constructional Arts in which Civil and Structural Engineering is joined with Architecture. I am delighted to hear that you, Sir, are already bringing this about in your Italian schools. The moment has gone when we should work apart, and I think that if this were to come about it is we architects who would, as we have seen from your work this evening, chiefly benefit, and it would help us all.

MR. CLIVE PASCALL: Professor Morandi, as an architect I was delighted to hear your references to co-operation with your profession and physicists, which is something—in our small world—we are beginning to need very badly.

Co-operation, not just consultation, between our two professions, is an essential, and I was delighted to hear your sincere comment that certain members of your profession have (you used the word) 'sensibility', and that you were not all just 'calculators'. Such real co-operation does exist in this country, and, albeit in a limited way, I have had the honour and pleasure of collaborating with some very brilliant engineers.

I am now going to ask what may be an impertinent question and one that you may not be in a position to answer. There is apparently a contradiction in the designs and form of the roof of Fiumicino Airport Passenger Handling Building, in that it appears to be designed in a form for reinforced concrete, but I understand it is constructed in steel—why?

THE LECTURER: This roof was designed for prestressed concrete, but for reasons into which I cannot enter now, it was eventually built in steel.

I think that all materials have their own expression. Do you remember in an early development of reinforced concrete we had some important girders made like steel? It was wrong, not solely from the aesthetic point of view, but because we had a lot of cracks. It is the same with all new materials. They are first used with timidity and not always well used, but with contemporary practical use the typical form arises. We have seen already that the aesthetic and wise expression of prestressed concrete is different from reinforced concrete. We have now some real prestressed concrete forms, and one can say: 'this is the expression of steel, this is the expression of stone, this is the expression of wood, this is the expression of the reinforced, and at last of prestressed, concrete'.

MR. I. D. B. PILKINGTON: Mr. Chairman, having heard such a past master as the Professor refer to himself as a structural calculator, I feel it rather pretentious to call myself a consulting engineer. Nevertheless, I should be very interested to know from the Professor how long it takes him to evolve some of these splendid designs. Are these efforts the result of a great deal of groping, of trial and error, of building up slowly and laboriously, or is he in the happy position of being able to get his idea in the first instance and work throughout on that to his final scheme? I am interested to know what approximate time it has taken the Professor to design, let us say, the underground reservoir which was shown.

THE LECTURER: I suppose I have passed the whole of my life among concrete, and for this reason I have of course a great deal of practice. But my method of work is this. I have a theme, of course. I try to solve the main point of the theme—with a pencil. I put the idea in one rough drawing with all dimensions, not with only a line like an architect's [*laughter*], and in the case of a very complicated system, with a very rough calculation made by myself. When I am convinced in my mind that I have completely clarified the problem, then partly by myself, because I like to make calculations—in smaller part, because I have not time; the major part is done with my young collaborators—we begin to develop all the calculations. And I am very proud when they say to me 'O.K.—this dimension is O.K.'

MR. R. F. MARSH: As a young engineer I find this process of design rather difficult. In English universities, in particular, the thought process required for design is just not taught. I was interested to know that both the lecturer and Professor Nervi teach in the principal Italian schools of architecture. What, in the Italian schools of engineering, is being taught of design? Is design as a thought process being taught to engineering students at all? We seem to be lacking in it very badly in this country.

THE LECTURER: Yes, in Italy too. But, as I have said, we are trying now to improve the situation, and I belong to a movement which is trying to do so, but there are other teachers who do not agree. It is a rather difficult question, and for this reason we have in our offices a lot of young people who wish to work on these lines. Also English, American and from all over the world, they wish to come to work in our offices especially to make this particular synthesis.

MR. E. GIFFORD: It would seem impertinent of me to congratulate Professor Morandi on his work, but as one who has struggled a little with long span bridges I should think it a pity if this evening went by without somebody saying what I feel—that is that the Maracaibo concept is one of the biggest jumps forward in structural engineering in the century, particularly the way in which the use of prestressed concrete follows a different form from the manner in which this material has previously been used.

Professor Morandi said that each material should have its characteristic structural form. Now the Maracaibo concept follows the pattern of the trussed cantilever which, although definite in its detailed performance, is similar in outline to the earliest of steel bridges, in other words the Forth bridge. I know that the mechanism is entirely different, but the profile of the bridge and the overall principle is very similar to that other bridge structure, and I should like Professor Morandi's comment on this point. Here we have two materials quite different in their nature, different in their form, but both following an outwardly similar pattern.

THE LECTURER: It is necessary at this moment that I go back to explain the two main points that I followed to design the Maracaibo bridge. (I speak only of Maracaibo.)

First, I entered the competition only for the reason that the possibility of using concrete instead of steel was an enormous advantage, because of the terrible atmosphere of the site. The atmosphere swallowed the steel! It is very hot, it is very humid, and because I knew this I tried to solve the problem with concrete first. Second, the length of the big span was essential in order to pass the big tankers through, and of course it was not possible for me to design an arch because the foundation is awful and would not take the thrust of an arch. Third, it was not possible to design a linear girder of such a length. Fourth, the compression due to the difference of the temperature in such a long girder also made it absolutely impossible, so there was born in my mind the idea to cut it in three parts to avoid shrinkage due to the variation of temperature. Five, the question of the ties. The fundamental idea of the whole bridge is a tied bridge. These ties are not steel but prestressed concrete. The steel tendons are first tensioned for dead-loading so that the dead-loading does not cause any deflection of the cantilever beams. Then, after this first tensioning, I surround the tendons with a thin casing of concrete and tension the tendons against this casing, thus prestressing it. The tendon is then grouted within the casing. In this way the live load acts against the prestressed concrete part of the tie, thus causing much smaller deflections of the cantilever than would be produced by the live load extending the tendon only. The concrete casing is never in tension so that the steel is protected against corrosion.

MR. G. B. ODDIE: I should like to make an observation on Professor Morandi's last reply. It seems to me that the fascinating account he has given us of how he approached the problem of the Maracaibo bridge is really tantamount to this: that the designer of the Forth bridge and the designer of the Maracaibo bridge were both great engineers tackling a new problem in a completely fundamental way, and they arrived at results which are similar in outline because they have approached the thing in identical ways.

Now I think that this has a great bearing on the alliance between engineering and architecture and casts some light on the difficulties that confront less brilliant minds to-day; and I should like to ask Professor Morandi whether he and his young engineers are in any way like our architects and our architectural students in this respect. Are his young engineers as assiduous in searching the pages of one glossy magazine after another for examples to inspire them, or even examples to copy, because I fancy that the account that he has given us of how his Maracaibo bridge took shape means that the answer is 'No, they most certainly are not'.

MR. A. F. GEE: I should like to return to the early part of Professor Morandi's paper when he showed us two illustrations of water towers, both to my mind very beautiful structures, and said, I think, that they were an attempt to get away from the fundamental concept of water towers. His philosophy seemed to be that one should try to do something different just for the sake of doing something different. Later on there were two occasions (I think one might say without being rude) when there were two almost identical bridges at two different places. Now I realize that even Professor Morandi, with his vast imagination, must sometime run out of ideas, but I suspect that is not the case here. Rather he feels that he has got the best structural answer, perhaps the only structural answer to a concrete girder span of 750 ft., and he is not ashamed to build it twice or even twenty times.

THE LECTURER: I think that every theme has its particular solution. For instance, the same span in Maracaibo and the same span in Fiumarella. As I have already said, in Maracaibo it was not possible to make an arch. In Fiumarella we have the rock and it was possible to make an arch. For instance, why in the Corso Francia have we made a tied bridge? Because it was necessary to reduce the height in the middle. For reasons of traffic it was not possible in this case to make an arch.

I do not think it is possible to make a free choice: only in a few cases is it possible to choose completely; otherwise it is like this. If I have the occasion to make the same type of bridge two or three or four times, each time we try to improve the type—but from the structural and the aesthetic point of view. A man who begins to repeat himself is a man finished!

THE CHAIRMAN: Obviously this discussion could go on to the extent of tiring a lecturer, and I do not want that to happen. So I propose now to fulfil my last duty in suggesting to you that we give a very hearty vote of thanks to Professor Morandi for coming such a long way to give us this very interesting and quite exciting lecture tonight.

It is quite obvious from the remarks that have been made in the discussion, and the reception of his lecture, that you consider that Professor Morandi is a remarkable man. Italy does turn out some remarkable people from time to time—it has throughout history—but quite obviously, the works with which he has been entrusted (ignoring for the moment those which were not chosen—the water tower, for instance) and particularly the solutions which he has applied to them, indicate that he is a man of great courage, the sort of courage that we find in pioneers like our own Telford, like Freyssinet and like Professor Morandi. It is only by courage which is usually allied to imagination that we do get these steps forward that we have heard about tonight. That he is a remarkable man is obvious from the way he can respond to a discussion like this and make himself understood in a language that is not his own; and although that might not be too difficult in ordinary conversation, it is usually extremely difficult in technical and artistic matters such as have been discussed here tonight.

We are very grateful indeed to you, Sir, for coming over and giving us this very memorable paper. You have an extremely good audience here tonight, and the fact that it would even have stayed longer had I not brought down the axe, is proof of the importance that the members and their friends have placed on this event.

A vote of thanks to the Lecturer was carried with acclamation and, another having been accorded to the Chairman upon the proposal of Mr. Maxwell Fry, the meeting then ended.