Present-day tendencies in large-sized reinforced concrete constructions

Autor(en): **Parvopassu, C.**

Objekttyp: **Article**

Zeitschrift: **IABSE congress report = Rapport du congrès AIPC = IVBH Kongressbericht**

Band (Jahr): **2 (1936)**

PDF erstellt am: **06.08.2024**

Persistenter Link: https://doi.org/10.5169/seals-3201

IVb 6

Present-day Tendencies in Large-sized Reinforced Concrete Constructions.

Neuere Gesichtspunkte für den Bau großer Eisenbeton-Bauwerke.

Tendances actuelles dans les grands ouvrages en béton armé.

Dr. Ing. C. Parvopassu,
Professeur à l'Ecole Royale d'Ingénieurs de Padoue.

Introduction.

The theme of the task, with the outlining of which before this gathering of distinguished engineers I have been honoured is an exacting one, since it calls for an extensive knowledge of one of the very fields in which modern structural engineering has proved most fruitful in difficult achievement.

Indeed it is a task impossible of satisfactory accomplishment without profound knowledge of and close familiarity with one of the most complicated and advanced fields of science and structural practice, and I can do no more than hope to express myself not unworthily by drawing upon the records of the study I have pursued in thirty and more years of keenest devotion, — the study of large structures in plain and reinforced concrete — both by theoretical and experimental teaching, and on site.

The claims, advantages and scope of reinforced concrete.

The use of reinforced concrete for the construction of works of any notable size dates back less than fifty years ago, namely to the time when it became possible to overcome those misgivings and criticisms to which every new idea gives rise, even among men of recognised competence. This was due to the progress made in the industrial production of slow-setting cements (both natural and artificial), an exacter understanding of the behaviour of the latter in the concrete, and the attainment of an accurate knowledge of those physical properties which enable concrete and steel to collaborate effectively in resisting the complicated stresses due to tension, compression and thrust that arise in structures exposed to bending, shear and torsion, and also due to the direct forces of compression and tension.

The unaccustomed boldness of what was being done gave rise to the impression, at first, of a disregard for those criteria of prudence which are normally and rightly given precedence over speed of construction and over economy in cost. This, however, was true only in appearance, and in a short time great progress had been realised all over the world in building large works; most notably road bridges and viaducts.

These developments of the new method of construction also became conspicuous in Italy already in the beginning of the century, for structures of medium and large size, and may justly be regarded as forming an advance guard in the attainment of various exceptional features. Italian technicians in this field are now an active and industrious body well equipped to accomplish even bolder and more remarkable works by turning the high qualities of Italian materials ot the fullest account, employing medium and high strength cements to bond together the excellent stone and the steel bars used as reinforcements in the concrete. Reinforced concrete is now accepted as offering the best qualities for combining solidity, beauty, compactness and gracefulness with speed of execution and ease of maintenance.

It is argued that the strength and permanence of cemented construction must be dependent upon the mixing of the concrete, of the arrangement of the steel reinforcements, and the maintenance of the latter in their exact positions while the concrete is being poured. This fact, however, has only the same importance as have the many delicate questions which arise in connection with steelwork construction regarding the special qualities of the steel used for rolled plate and sections, rivets, bolts, suspension cables, and bearings, and as to the proper execution of riveting or welding. In either case experience, conscientiousness and honesty have to be assumed as normal attributes of the constructor concerned; suitable individuals of proved technical capacity have to be chosen to fill each role in the planning and direction of the work whether great or small, and it is necessary to employ specialised workmen of a type who love their job and are imbued with the team spirit. Another essential, of course, is careful and prudent checking of all material supplied during the construction of the work.

Having taken these precautions, no fear need be entertained in choosing reinforced concrete as the material to be used in those works of ever increasing size which modern civilisation demands from the technician. Its marked economic advantage may be taken as certain, and it remains only to express the hope that the architectural engineers will succeed in endowing the cemented form of construction with a style which harmonises with the laws of aesthetics.

What is meant by large works in reinforced concrete are mainly those connected with road work, in the form of bridges, viaducts, retaining walls and foundations for these, but the term of course covers also building construction — especially earthquake-proof buildings — of large dimensions, such as columns, beams and cantilevers, large roofs and cupolas, skyscrapers, silos, towers, bell towers, transmission line masts and aerials, as well as hydraulic and maritime structures such as high multiple-arch dams, reservoirs aqueducts, intakes, pipe lines of large diameter, harbours, dry docks, breakwaters and jetties, and many other structures which are ancillary to industrial plants on an extensive scale.

It may now be claimed for this vast field of work that the methods of design, the quality of the materials and the procedures followed on the site have reached such a stage of development and show such promise of further improvement as to justify the expectation, in no distant future, of works of surprising size and beauty.

The evolution of large works in reinforced concrete.

A rapid survey of the course of development of major ,works in reinforced concrete during the past thirty years may be of value for a better understanding of the present trends in their construction and design, because as already stated, the boldness of what was being undertaken even at the beginning of this period is such as to compel the admiration of engineers of today and to justify the most sanguine hopes for tomorrow.

The construction of the Pinzano bridge over the Tagliamento dates from 1906. This structure comprises three great arches each of 48 m span and 24 m rise which contain a total of 1800 m^3 of cement concrete and are provided with self-supporting reinforcement of rolled steel sections in the form of triangulated trusses. The arches are fixed at the ends and are hinged at the crown only, but actually the axis is so shaped — having been designed in such a way as to deviate little from the shape of a possible line of thrust — that the calculation could be made on the assumption that they were statically determinate like three-hinged arches. The roadway decking, which is carried on flat spandrel arches, has a width of 6 m.

The Calvene bridge on the Astico was built in 1907. This is a fixed arch of 35 m span and 2 m rise, which is made monolithic with the abutments and with the decking. This was shortly afterwards followed by a similar bridge over the Ourthe at Liége which has a span of 55 m and a rise of 3.25 m.

The three years from 1909 to 1911 are dominated by the remarkable Risorgimento Bridge over the Tiber in Rome, which is a single flat arch of 100 m span with 10 m rise, again monolithic with the roadway slab and with the two abutments. Each of the latter projects 24 m from the bank and is of cellular construction, as is the arch itself. This bridge, which is noted for its imposing yet slender character, carries a roadway 20 m wide. Great care was exercised, and special measures adopted, in order to make every part of the structure as sound as possible. Thus the reinforcing bars are of a special convex-concave section and have suitably spaced transverse projections inside and out, bonding with projections formed on the longitudinal ribs of the arch itself, to lessen the effects of shrinkage during the hardening of the concrete and also to eliminate any excessive stresses in the latter due to the variations in temperature to which the structure is periodically exposed.

April 1910 was the opening date of the Auckland Bridge in New Zealand, a single great arch of 98 m span with 56 m rise, built in at each end, supporting a roadway 12 m wide. Another similar structure built at nearly the same date is the bridge of 98 m span but only 20 m rise over Lavimer and Atherton Avenues in Pittsburgh, U.S.A. The same period of years witnessed the construction of large high buildings in reinforced concrete for use as living quarters, offices and stores in New York and other cities of the United States, and in Europe; also very tall industrial chimneys from which water reservoirs of considerable size are suspended at various levels; great siphons such as that near Albeida for the Aragon-Catalonia canal in Spain which has an internal diameter of 4 m a length of 75 m and a maximum effective pressure of three atmospheres; large balconies, roofs and cupolas for stadia, public halls and theatres.

The Centenary Palace at Breslau calls for special mention as being one of the first buildings in which the outstanding possibilities of the application of reinforced concrete have been exemplified both from a technical and an architectural point of view. This notable building (erected to mark the centenary of the victory over Napoleon) is of circular plan 100 m in diameter with a reinforced concrete skeleton. A central cupola 42 m high and 65 m diameter at the springing is supported on a ring which in turn is carried on the frontal arches of four huge apses. The 32 great meridianal ribs of the cupola are built into this ring and are continued through it into the ground as external counterforts covering over the apses. The total area of the large hall is 5500 sq.m and it provides accomodation for 6000 seated and 1000 standing spectators.

The large overhead reservoirs for aqueducts began to appear between 1915 and 1925. One of the largest, which deserves to be mentioned here, is the one built in connection with the municipal aqueduct at Padua in 1924 which has a covered basin 20 m in diameter holding 2000 cu.m at a height of more than 40 m above the street level. Here the concrete work has been bonded with a masonry sheathing and crown which give a monumental tower-like appearance, and the base of the tower has been made to include a votive chapel in memory of the victims of the air raids over Padua during the Great War, 1915—1918.

The same period, and the succeeding decade, witnessed a noteworthy development of large building structures — especially in Germany — on the part of architects aiming at the creation of a new and appropriate style, though not, in the present writer's opinion, with success.

At the same time the construction of important bridges and viaducts both for ordinary roads and for railways was rapidly increasing, and many remarkable examples of these were built in Italy. The following types may be distinguished:

a) Straight girder "through" or "deck" spans, reaching a maximum single opening of 140 m in the case of the footbridge of Ivry near Paris.

b) Unrelieved arch spans with or without hinges. The maximum is reached in the Plougastel Bridge over the Elorn near Brest, built to the daring design of Freyssinet in 1928—9, wherein each of the three arches of cellular section covers an opening of 186 m and high-strength cement has been employed for making concrete cast under vibration. The results were so encouraging that a similar bridge was constructed over the Tranebergsund channel near Stockholm having two twin arch ribs of cellular structure, 181 m span and 26.20 m rise, 6.20 m apart internally. The decking has a total width of 27.50 m including a double track railway and an ordinary road 19 m wide. The maximum stress allowed at the crown of the arch is 120 kg/cm^2, to be resisted by concrete containing 300—400 kg of cement per cu.m.

(Smaller spans, up to 90 m, have been achieved in a fine series of Italian works such as the bridge over the Adda for the Milan-Bergamo "Motor Road" and the bridges over the Brenta at Primolano, over the Savio at Monte Castello, over the Piave at Belluno, over the Isonzo at Plava, for the canal over the Brembo, and others.)

c) Arches in which the thrust is eliminated by means of a suspended tie which serves to carry the roadway slab. The greatest span of this type is found in the bridge over the Oise at Conflans fin d'Oise in France, which has a lightened arch and a suspended intermediate decking which acts as a tie, covering an opening of 126 m.

(Smaller spans, up to more than 90 m exist in the Lot Bridge at Port d'Agrès which has a suspended lattice, and in the Oned Mellègue Bridge in Tunisia which is of triangulated construction. The considerable span of 74 m is attained by the San Bernardino ad Intra Bridge in Italy, carrying a railway with road underneath.)

d) Cellular structures in which a very thin arch carries the intrados during construction and is afterwards made solid with the permanent arch drum, with the upper decking (for which it serves partly as shuttering), and with the supports on piers and abutments. An example of this is given by the Graubünden Bridge in the Grisons, which has a considerable span and a daringly small rise.

Current tendencies.

The present trend, as already stated, is in the direction of very considerably increasing the spans both of straight girders on two or more supports and of arches with or without elimination of thrust.

As regards arches, it appeared only a few years ago that the clear opening must necessarily be limited to a few hundred metres, but today it is held feasible by high authorities to reach a span of well over a thousand metres. A proposal to build an arch of 1000 m span was brought before the Liége Congress by Freyssinet in 1930, and a span of 1400 m, which corresponds to more than seven times the existing maximum of 186 m, has been indicated by H. Lossier as a possibility for a heavily reinforced concrete arch — though at the same time the adoption of steel suspension bridges appears preferable to him in the case of spans exceeding 800 m. With straight girders on two or more supports Lossier considers that clear spans of 500 m are possible, corresponding to about four times the present maximum of 126 m.

Lossier also favours the use of mixed structures in which rustless steel would be adopted for those members which receive only tensile forces and reinforced concrete for those subject to compression and bending. The concrete members would be pre-cast, and when they were erected the joints would be made by autogenous welding applied to portions of the steel left projecting from the concrete, to be subsequently covered in high-strength rapid-hardening cement mortar. Mixed construction of this type is suggested as being particularly well suited for suspension bridges, spans of the order of 5000 m being contemplated. This would be about five times the maximum hitherto obtained, which is a suspension bridge entirely of steel spanning 1077 m — the George Washington Bridge over the Hudsonriver at New York. The latter, however, is already in course of being exceeded by the 1270 m span of the bridge of similar type now being built at Golden Gate on San Francisco Bay in California.

It is to be expected that considerable developments are to be awaited in this direction.

Referring generally to straight and arched spans, the types of bridge which in these respective categories appear preferable to the author are the *continuous girder* and the *hinged arch with thrust partly relieved.* It is agreed that in these two forms it should be possible to attain the limits of span indicated above, notwithstanding those imperfections which must inevitably attend constructional operations and those uncertainties which must enter into the calculations through the presence of defects and unascertainable conditions in the reinforced concrete. The limits put forward may well appear to be exaggerated, in the sense that one may doubt the real necessity for trying to justify the very heavy cost of overcoming the exceptional difficulties of carrying out work of such dimensions; but from the purely technical point of view they need cause no misgivings.

As things are now, when disastrous failures do occur they are the result almost invariably of errors in execution, attributable 90% to the shuttering being stripped prematurely or unreasonably and 10% to accidental defects in either the concrete or the steel reinforcement (wherein very high values of specific resistance may be obtained). So far as the calculations are concerned it is possible to eliminate practically all uncertainty by making sure that the hypotheses correspond with reality; this means interpreting theory in the light of common sense and bringing a maximum of perspicacity to bear on the study of secondary stresses, for generally it is through these that fractures occur in the compressive zones where least expected, and in the tensile zones even where abundant steel reinforcement is present in a small section of concrete.

Standards of construction and methods of design.

Stone, sand, cement and reinforcing steel must be strictly selected and their properties accurately controlled. On the site there must be good supervision of the mixing and placing of the concrete, of its protection while setting and hardening, and of the removal of shuttering from the various parts of the construction. Observance of these essentials will almost certainly ensure that the work is in accordance with plan, and that it will be fully able to bear the maximum stresses (whether static or dynamic) likely to be imposed on it in service. In the opinion of the author the compressive stresses in the concrete may reach 250 or 300 kg/cm^2 and the tensile stresses in the steel bars values ten times as great.

At the present time cements of very high strengths are being produced in all industrial countries. With gravel, stone and sand suitably chosen as regards quality and size of grain, and with the admixture of cement and water properly controlled, it is possible normally to make concrete which after a few weeks will give a cube compression strength of 400, 500, 600 or even more kg/cm^2 and likewise a considerable tensile strength. If the concrete be cast under vibration these results will be even more easily obtained. Concrete of this character has excellent elastic properties extending to the highest compressive loads imposed on it; its cycles of deformation give rapid adjustment and with well arranged steel reinforcement it has an ample capacity for undergoing expansion without damage. In all countries such reinforcement is available in the form of long bars of rustless steel offering a resistance to tensile fracture of 52 to 56 kg/mm^2, with an elastic limit of over 30 kg/mm^2 and a yield point of over 40 kg/mm^2, with an elongation of the order of 30—35% at fracture and a constriction value of 60—70%.

Such materials as these, used with the precautions indicated above, provide further remarkable possibilities for of reducing the percentage of steel in the cross section and increasing the "specific ligthtness" (ratio of unit working stress to weight) of the deposited concrete, thus increasing the principal dimensions that can be given to the load bearing members. The rigidity of the latter is favoured by the high values of the moduli of elasticity of the concrete and the steel, and this in turn implies that the deformations due to dead and live load will be small.

In large reinforced concrete structures the slenderness of the members presents a striking contrast to the effective load bearing capacity of the whole. Where this is the case, the methods of calculation tend necessarily to be based directly and entirely on the theoretical principles and experimental results reached through recent research into the equilibrium of rigid bodies or systems, and the elastic behaviour of deformable bodies or systems, in which the connections are adequate or excessive, and which change their condition of stress and strain according to more or less regular laws when subjected to static or dynamic loads or to progressive or periodical variations in temperature.

Among the systems of this kind particular mention may be made of long spans of lattice or cellular construction with or without hinges, in the form of straight girders, ordinary arches, or arches having the thrust eliminated by a tie bar; also multiple frames, continuous arches made monolithic with the supports, and slabs — flat, cylindrical, conical, spherical, ellipsoidal, paraboloidal, etc. — as applied to form ceilings, walls, vaults, blocks, and hinged or fixed bearings.

Researches on the physical and mechanical properties of hydraulic cements, coarse and fine aggregates, concrete, metal reinforcing bars, and reinforced concrete as such, are the basis of all others, and remain capable of further useful development even today. Such work may well be directed towards the study of granulimetry, proportioning of cement and water, and percentage of steel reinforcement in the cross section. Another problem is to determine the best methods of casting the concrete so as to ensure that it shall be dense, shall undergo little deformation through shrinkage while setting and hardening, and shall have a high modulus of elasticity, high compressive strength, good adhesion to the steel, and ability to cooperate with the latter without sustaining damage under high tensile stresses. On account of their importance is becoming more and more usual to associate researches of this kind with others on the elastic behaviour of finished structures under heavy moving loads, comparisons in this respect being made between works that have been in service since first constructed some tens of years ago with the cement and steel then available, and other works of recent date, bolder in type and size, built with the better materials available today.

The theoretical methods for forecasting the conditions of stress and strain have been improved in a way which facilitates the design and checking of reinforced concrete structures, and this in turn has lead to further developments in the most complicated and difficult branches of the theory of elasticity.

For structures which are not homogeneous, still less isotropic, the difficulties to be overcome in formulating a satisfactory theoretical system as regards the physical and mechanical properties of their constituent materials, are still very great (particularly when account has to be taken of structures containing hyperstatic connections), and progress must necessarily be slow. On the other hand the urge to overcome these difficulties is both strong and productive.

The lack of homogeneity and isotropy of the concrete, which leads to uncertainties in applying the theory, can partly be corrected by combining a suitable choice of the cement and aggregate with attention to the granulometric composition of the stone or gravel and sand and the admixture of cement and water, which determines the density of the concrete. The essential requirement is to grade the gravel or stone in such a way as to minimise the voids and therefore the amount of cement-sand mortar necessary to fill them, give adequate bond between the particles, and eliminate porosity. If these conditions are secured there will also be a reduction in the ratio between the volume of cement mortar and the volume of the resistant nuclei und the mass of concrete itself. Consequently there will be an increase in the breaking strength and mean elastic modulus in compression and tension, which characteristics will tend to approximate more closely to the values they reach in the hard strong nuclei themselves. (The latter, of course, are of a different nature from the more or less plastic cement mortar which serves to bind them together.)

So far as compressive stresses are concerned the resulting concrete will then be practically equivalent to a homogeneous and isotropic mass, metal reinforcement being included mainly with a view to resisting tensile stresses. An increase in compressive strength can be obtained by means of spiral hooping. The necessary resistance to tension can be supplied by rods arranged in the appropriate directions, namely one direction in the case of thin beams, two at right angles in the case of flat or curved thin slabs, three at right angles (perhaps coinciding with the probable isostatic lines) in the case of three dimensional structures.

The high internal temperatures that are apt to arise while the concrete is setting, followed by natural cooling under conditions which cannot be defined, may result in non-uniform thermal expansions and contractions. These in turn may result in the initial internal stresses remaining and causing very heavy latent compressions or tensions in the concrete or steel reinforcement.

Partial correctives to these effects may be found in the use of low-heat cements as already specified in the official specifications of certain countries, and employing these in smaller quantities relatively to the specific strengths which the concrete is required to develop. Large masses may further be divided into blocks, by leaving joints to be closed after seasoning.

Another cause of ill-defined latent stresses being established in the concrete, and in the reinforcement embedded therein, is the shrinkage of the concrete during its curing and hardening process — a phenomenon attributable mainly to the elimination of the excess mixing water which has not entered into combination. In non-reinforced concrete these stresses may amount to more than 20 to 30 kg/cm^2 in tension, alternating with much higher values in compression. In reinforced concrete, where the shrinkage is less pronounced as the result of the presence of the reinforcement, the stresses may correspond to an order of magnitude of 5 to 15 kg/cm^2, and become greater if the percentage of steel in the section is increased; they are balanced by compressive stresses in the steel of between 100 and 20 times as great, and the latter become smaller if the percentage of steel is decreased.

These effects, again, may be partially corrected by reducing the percentage of steel to a minimum or by introducing suitable contraction joints; also by using concrete in which the cement content is not excessive and in which the quantity of water used is the minimum strictly necessary to enable the concrete to flow into the forms and between the steel bars. Finally the concrete should be kept damp by suitable sprinkling throughout the curing period and until the shuttering is struck.

Summary.

The author briefly outlines the development of the engineering of major works in reinforced concrete and proceeds to discuss present tendencies in their design and construction, giving examples of the attendant difficulties and doubtful points and of how these may be overcome or mitigated.

Leere Seite
Blank page
Page vide