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Special problems of reinforced and prestressed concrete

Charakteristische Gesichtspunkte im Eisenbeton und im vorsgespanten Beton

Questões especiais relativas ao betão armado e preesforçado

Questions spéciales relatives au béton armé et au béton précontraint

General Rapport – Generalreferat – Relatório Geral – Rapport Général

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We are in the middle of the 20th century. In the history of construction, this century will probably be known as the period of brilliant supremacy of reinforced concrete. Bridges are no longer covered with stone facing, to hide a material that fifty years hence was regarded as bastard. Formwork provides smooth surfaces, without attempting to reproduce the classical filigree chapitels so much in vogue in the earlier period, when cast iron was the appropriate medium to take compressive loads.

Reinforced concrete attained its centenary a few years ago. Technique has advanced during that period. At present cement factories place in the prosperous market of constructional materials new cement variants, and Portland cement has been supplemented with supercements, high alumina cements, slag cements and high sulphur content cements.

In these hundred years works of all types and sizes have been erected. And slowly, but in a progressively more defined manner, a style typical of concrete has crystalized. Many of these works are true monuments of modern art, and will go down to posterity as samples of a style which attained singular beauty in many of its exemplifications.

The development of reinforced concrete technique has been particulary intensive and fruitful in the course of these last fifty years. But even so, the new tendencies and the recent investigations which aim at better knowledge of constructional materials, have added to the list of problems which are still awaiting a satisfactory answer.

Among these, the question of durability has always been a source of doubt and uncertainty. Time is a variable which does not lend itself to short cuts.

Rapid freezing and defreezing tests do not reflect as accurately as might be desired the actual behaviour of a material standing in the open. Such results are rather qualitative than quantitative. Similarly as in the case of fatigue tests, the only means of looking into the future consists in repeating rapidly cycles which in actual fact occur at a much slower tempo. But only the investigation of actual structures, damaged after many years of service, can provide us with reliable facts on the true evolution of the physical properties of the materials employed.

Basing themselves on a variety of information from such tests, and taking into account all the possible sources of error inherent in these types of tests, the committees entrusted with the task of drawing up the national specifications have been able to establish a criterion on the minimum essential requirements of concretes to be used in conjunction with reinforcement. For weaker mixes there is the danger of corrosion of the reinforcement.

That happens with other than Portland cement. So far the question has not been answered with the same certainty as in the case of Portland cement.

The question of durability, considered generally, affects a wide range of materials. It has a physico-chemical nature, since the ageing process of concrete is due to complex relationships caused by the long term evolution (some of it of a cyclic nature) of the structure of the concrete. Durability also depends on mechanical reasons, since cracking bears directly on the study of the satisfactory preservation of the reinforcement, and finally, it depends on financial considerations, since the final facings and the quality of the steel are variables, which the constructor seeks to adapt to the available funds.

The importance of the problem is exemplified by the fact that the majority of papers presented in this section all deal with this subject, although each in a different manner.

Mr. R. PELTIER and Mr. J. R. ROBINSON have submitted a paper of great interest. In it a study is made of the migration of free lime in certain cements, from the point of view of the ageing of reinforced concrete.

These authors support the theory that it is principally the lime which protects the reinforcement from corrosion. The authors deplore that a large number of the experimental tests are still under way, so that their results are not yet complete. But in any case, the initial results so far obtained show facts of considerable value: whilst test specimens made with Portland cement do not show signs of corrosion in the reinforcement, after being kept in humid air (95 % humidity), specimens made with high sulphur content cement, as well as those made of slag cement, and kept in the same air, have not been so effective, and the reinforcement has shown clear indication of corrosion.

Naturally the results so far obtained cannot serve as anything more than an approximate forecast of the final ones. It would be a good thing if at the Lisbon meeting the authors could complete this initial report with the results obtained during the last 12 months. It would be of great interest if they could specify what are the minimum proportionings that will protect the reinforcement for the different atmospheric conditions and types of cements tried out.

These tests (some of which have been carried out with the aid of the most modern technique) are a sound basis to settle the problem of durability. The capacity of concretes made with Portland cement to protect the reinforcement seems to be confirmed by observing structures which have been demolished. And the fact that, under the same conditions, concretes, made with slag and high sulphur content cements have proved incapable of protecting the reinforcement against corrosion makes it evident that this is a factor which cannot be ignored when deciding what cement to use in a structure.

None the less, the problem is not yet settled. It is possible that the corrosion or reduction of the reinforcement may be affected by the stresses imposed on it. It does seem reasonable to suppose that interstitial water migrates from certain zones to others, according to the stress distribution in the material. The hypothesis can be suggested that the humidity and dryness cycles are affected by the mechanical loading of the structure under the action of the overloads.

Experience shows that one of the variables which most influences the efficient protection of the reinforcement is the thickness of the covering layer.

Certainly this action also plays an important part in the phenomenon of fissuration. But it is also true that the screen effect which the reinforcement exerts on the interstitial water's free movement implies that the covering layer over the reinforcement, and also the distribution of the forces in one or various planes, may interfere with the phenomenon observed by Messrs. PELTIER and ROBINSON.

The compactness of the material should also affect noticeably the migration of free lime. This is a matter which is difficult to measure in practice, since it involves the quantitative determination of the degree of compactness of the concrete.

Finally, the capacity which the reinforcement possesses to protect itself against damaging agents is closely related to the fissuration phenomenae. A sufficiently wide crack provides an easy path, by capilarity, for water or humidity from the exterior, and hence, an effective means of damaging the reinforcement.

It does not seem easy to fix the maximum permissible width of cracks, nor their possible correlation to the type of cement employed, when the width of the cracks is microscopical.

In general it is admitted that a crack one tenth of a milimeter in width is not a means of entry of corrosive agents, and, except in special circumstances, cracks of up to a fourth or a third of a milimeter are acceptable.

But these figures are entirely empirical, and they have not been rigourously estimated. If the problem is investigated with a little more detail the difficulties and varieties of approach inherent in the problem become immediately evident.

Cracks are a direct consequence of the distribution of the reinforcement, of the loading, and of the magnitude of the overloads.

A given reinforced concrete part may exhibit cracks of a given maximum size under a certain overload. The danger which such a crack may imply as regards corrosion of the reinforcement depends both on its width and on the circumstances which lead to it. The beams of a bridge may occasionally show large cracks without directly endangering the reinforcement, because the action of the maximum overloads is sporadic and brief. Once the overload train has passed over the bridge the cracks close up, at least partially, and the danger of corrosion disappears, since the normal loading on the bridge is only that due to its own weight.

In accordance with this, it seems reasonable to fix a limit to the permanent cracks only, without worrying about their size during the periods of maximum overload. It is the permanent cracks, and not the temporary ones, that represent the normal state of the structure.

However, this permanent cracking depends in a basic manner on the number of loading cycles which the structure has undergone. What matters is not the permanent cracks after the first cycle of maximum design overload, but the types of cracks that are permanent after this maximum overload has been repeated many times. For these loading cycles the minimum value is that of the permanent loading due to the proper weight. The maximum value will be that resulting from the most unfavourable overloads assumed in the calculations.

The dynamic cracking experiments undertaken by Mr. ABELES seem to be amply justified. The permanent cracking seems to be the clearest indication of how well a structural part will last under the effect of corrosive agents.

There are, however, other cases, in which the problem must be approached in a different manner. A roof weighed down by snow, or the flooring of a warehouse, or the walls of a reservoir are examples of structures which may be subjected during long periods to maximum overloads.

In such a case it is not the permanent cracking the one that matters in corrosion. Nor is it the cracking that develops during static overloading. It is even worse. The dangerous cracking, the one that must be feared, in such instances is that due to the sustained and lasting application of maximum overloads, causing slow deformation of the material, which creeps under the high stress. These conditions are much more severe.

Conscious of such a danger, many engineers design some prestressed concrete structures in such a way that there shall be no tensile stresses under maximum overloads.

It is true that there are no slow creep phenomenae when the stress in the material is nill. But even neglecting the creep of the steel, whose initial stress compresses the concrete, it is evident that the compressive stresses in the concrete can evolve with time. The most loaded fibres progressively yield, and pass on part of their load to the fibres which are further away from the most loaded part. The resultant compressive force thus tends to move away owing to this redistribution of stresses. Under a constant applied moment, if the resultant of the compressive forces approaches the tension edge, the resultant tension force must increase and approach the edge. Cracking may occur if this tensile stress is sufficently high.

Recent investigations carried out by A. FREUDENTHAL, have demonstrated the pronounced non-linearity, with respect to stress, of the creep rate of concrete under sustained stresses exceeding about one quarter of the 28 day compressive strength. Such non-linearity produces non-linear stress distribution, as well as stress-relaxation in the reinforcement which, during the early stages, is far more rapid than under conditions of linear creep.

So, it should be kept in mind, that, in order to balance excessive loss of prestress by relaxation in concrete and reinforcement, a higher prestress would have to be applied than would appear necessary to eliminate concrete tension on linear theories.

Fatigue tests should be complemented or substituted by tests measuring the tiredness of the material, i, e., the strength of the material under constinuously applied loads. Time plays a most important part, and its effect cannot be predetermined by accelerating the loading cycles, as in the case of fatigue tests.

It will thus be realised that there is still a long way to go, but a start has been made. The tests by Mr. ABELES are an initial step. It would be interesting to know the distribution of cracks for various steel to concrete ratios, and for various initial prestressing intensities, as applied to the test specimens suggested by Mr. ABELES.

Once the influence of each of the variables has been determined, it would be convenient to correlate the results with those obtained by Messrs. PELTIER and ROBINSON, who have studied the dangers of cracking for various atmospheric and ambient conditions. Only thus, and making due allowances for the inevitably limited nature of the test, will it be possible to decide what dangers are involved in a particular cracking phenomenon. The mechanical aspect of the problem cannot be separated from the physico-chemical corrosion phenomenon. The same cracking tests should also be effected on reinforced concrete specimens.

At first sight it might appear that the repetition of these tests, both dynamic and of long duration, will be simpler in this case, since the variable depending on the prestressing applied by the reinforcement will be eliminated. But to make up for this variable factor, which is removed, a new unknown has got to be taken into account, whose field of variation is no smaller, namely, the type of reinforcement.

At present the tendency of technology is to take advantage, to an extent that was unsuspected even a little time ago, of corrugated rods, or of rods with special properties to reduce slippage.

The reason for its use cannot be more logical. The cost of high quality steel is not proportional to its strength. Within certain limits, the steels of highest strength are the most economical to use, for a given load. If they were not used earlier, it was because the concrete did not stretch uniformly along with the steel (if the steel was to stretch sufficiently to justify its higher cost, and thus develop a sufficiently high stress), and was forced to crack, exposing the reinforcement to the air.

There are two ways of avoiding this. One is to reduce the amount stretched in the steel, stretching the reinforcement beforehand: that is is the prestressing technique. The other method is more direct: if what is harmful is the maximum width of the cracks, then the bond between the steel and the concrete should be improved, so as to increase the number of cracks, and reduce their size.

So far the steel manufacturers have not put on the market a series of rod types, which are standardised for all countries. But even so it is necessary to insist on investigating what is the ideal cross section, and on carrying out a detailed comparison of the advantages of the various devices for increasing the steel/cement bond, so that the best result can be obtained.

Mr. SAILLARD has understood this need, and he has started a series of experiments with this purpose in view. In spite of the illness which he has unfortunately suffered in recent months, Mr. SAILLARD has shown great perseverance in seeking for the optimum length of thread for reinforcement rods. It is a pity that personal circumstances have prevented him from extending his research to other types of steel, and that he has been unable to complete his huge task of comparing the results obtained for different depths of thread and helicoidal outlines. The technician needs simple formulae and rules, enabling him to calculate with adequate accuracy the probable cracking.

In this sense Prof. RÜSCH holds a different opinion. With his keen critical spirit, he has carried out a program of tests with specimens reinforced with smooth and corrugated rods. After analysing the bonding stress in tearing out (slippage) tests, he has considered the cracking that may result in members under tensile stress, or in beams subjected to bending. The distribution of cracks in these two cases corresponds closely, so that he suggests tensile tests as a rapid means of estimating the amount of cracking for different depths of corrugation in the rods.

The contribution presented by Prof. RÜSCH is of the highest value. It summarises the numerous results obtained at München. His analysis on the influence of the covering layers, the positioning of the reinforcement, the quality of the concrete, the type of bars, etc., makes this a document of outstanding value. There is every justification for hoping that soon engineers will be able to estimate the bending moment which causes cracking with the same accuracy, and understanding of the phenomenon, with which we know at present the ultimate or breaking bending moment.

Certainly, the limiting bending moment which causes cracking depends, among others things, on the type of corrugation of the reinforcement. In this respect it would greatly help our knowledge of the limiting bending moment for which cracking begins, if the most suitable type of corrugation had been selected and adopted for general use. Naturally, this limiting bending moment would also depend on the conditions of work, overloads and nature of the ambient.

A. LAZARD, H. E. LEWIS and E. FRIEDRICH have also carried out important series of tests on different types of reinforcement bars.

E. FRIEDRICH has shown originality in the kinds of bars tested. These have protuberances, and bond is improved by using couples of bars, running parallel to each other, mutually conected by means of welded distance pieces.

The interaction between the reinforcement and the concrete no longer depends on bond, but on the distance pieces. In this manner the cracks are distributed rather than concentrated, as might be expected, at the singular points where there is a distance piece. By this system Friedrich has estimated that the reinforcement can reach a permissible stress of 4500 kg/cm^2 without causing cracks of more than 2 mm.

Railway bridges, and particularly bridges over railway lines, where steam engines are used, constitute one of the most representative problems in which cracking is involved. The aggresive properties of the sulphurous gases given out by the locomotives, together with the humidity induced by the vapour, make it essential to protect the reinforcement against their effects. A sufficiently wide crack means a weak point where a relentless corrosive action may start.

In these circumstances, the use of steels with a high yield stress should be proscribed, in spite of the saving in cost which they imply.

M. LAZARD, who is chief of the Division of Railway Works of the French Railways, is of opinion that special steels may be employed, so long as their use does not cause wider cracks than those, due to ordinary steels.

In support of this criterion M. LAZARD has undertaken a series of comparative tests between beams with plain round mild steel bars, and beams with cold twisted steel bars of circular section and 40 kg/cm^2 yield stress. The cross section of the latter reinforcement is 65 % of the ordinary steel cross section (ratio of the respective yield stresses).

The results obtained by M. LAZARD show similar cracking phenomenae for both kinds of reinforcement, in spite of the above mentioned difference in reinforcement weight. Close to the ultimate load the behaviour of the beams reinforced with cold twisted steel bars improves in relation to that of those reinforced with mild steel, with an increase in the number of cracks, which continue to be narrow, rather than a development in the size of the existing ones.

The experimental work conduced by H. E. LEWIS is of similar nature to that of M. LAZARD. The cross section of the reinforcements was in the ratio of 23:13, which was the ratio of the yield stresses of the steels (their yield stresses were 46 and 26 kg/mm^2 respectively). The experimental results lead to the same conclusions as those obtained by M. LAZARD.

Both Mr. H. E. LEWIS and Mr. A. LAZARD found that the deflections in the beams reinforced with cold twisted steel bars were about twice those for the beams with plain bars. The tests by Lewis on slabs show considerable deflections under working loads, and for this reason he suggests that the depth of slabs reinforced with twisted bars should not be less than 1/28 of the free span. Otherwise, for thinner slabs, the deflections would be too large. Neither Lewis nor Lazard provide information about permanent set and residual cracks.

It would be an advantage if the tests on these problems could be unified, so that within a short period of time the constructors themselves could instruct the steel manufacturers on the most appropriate types of bars for reinforced concrete. Otherwise we shall be supplied with material which is not exactly suitable, and we shall always feel that it is due to a lack of coordination that we are without the best possible type of reinforcement.

It is evident, in view of the foregoing remarks, that there is still a lot of difficult ground to cover. But precisely therefore must this question be pursued with enterprise and tenacity.

One of the advantageous methods for saving time and work would be, as suggested by Prof. RÜSCH, the standardisation of slippage tests. A first step in this direction might be to establish a type of test, which though conventional in the procedure, would provide results in agreement with the expensive slow and dynamic cracking tests on beams which have been practiced so far. Such a type of test should give some hint as to the efficiency of a particular kind of reinforcement. It should also, if possible, be suitable for adoption in the national specifications, as an indication of the measure of bond between steel and concrete, to use Mr. SAILLARD'S terminology.

If this could be achieved, the importance of this advance would be enormous. The engineer would be able to predict the maximum size of cracks under given static or dynamic loading conditions.

In the national specifications standardised overloads are fixed and in a similar manner a certain set of limiting conditions might define the maximum permissible size of cracks.

And just as factors of safety are fixed, based on the ultimate strength, suitable margins should be allowed, as Mr. A. FREUDENTAHL proposes, with respect to the limiting conditions of cracking and deformation.

The fixing of a minimum thickness for slabs, as proposed by Mr. H. A. LEWIS, is an important aspect of this general problem of safety, as well as the experimental confirmation of this need, which has been also voiced by Mr. H. RÜSCH in his Madrid lecture.

The problem of excessive deformation, and its relationship with the phenomenon of cracking constitute the theme of the paper presented by Mr. F. SZEPE. The need to reach agreement on the method of quantitative calculation of these phenomenae makes the effective collaboration of the scientists of various countries in this matter more urgent every day.

The problem of durability would be solved, in its general aspect, if, in addition to fixing conditions or specifications about maximum cracking and deformation, the richness and compactness of concretes were also regulated. This should apply both to Portland, high sulphur content, slag, and other cements. For this purpose, the program of tests prepared by Mr. A. RÖHNISCH and the device designed by Mr. M. PROT may constitute a basis for the study of the durability of materials under the action of weathering.

It is evident that before all these problems are settled several years will have to ellapse, and meanwhile constructional engineering will have to continue. It is also a fact that many structures which are at present in use are in need of repairs, and in this respect it is not always satisfactory to merely apply a coating of cement to mend a leakage, or to fill up a road hole.

The procedure proposed by Messrs. BOUTRON and BERTRAND for these types of repairs seems to be more effective and lasting. Their experience in this matter is evident in the paper which they have submitted to the V-b section. It should be a very useful contribution, owing to its wealth of data, clear presentation and keen appreciation of the problems considered.

Finally, and bearing slightly less directly on these problems of durability, Messrs. V. GUYON, E. RAUSCH and R. BÜHRER have submitted contributions of no mean technical interest.

Mr. V. GUYON applying his profound knowledge of matters related to reinforced concrete considers the phenomenon of elastic deformation of continuous beams and slabs during the prefissuration phase. The theory proposed by Mr. GUYON is that many phenomenae which might be interpreted as due to plastic deformation are in fact states of microfissuration during the phase of elastic deformation.

Mr. E. RAUSCH applies principles which are accepted in the analysis of beams subjected to bending to the problems of torsion of reinforced concrete structural members. According to him, the most suitable arrangement of the reinforcement to withstand torsion is to provide a longitudinal reinforcement, and a transversal one. Helicoidally shaped reinforcement he considers as too complicated to erect. He makes the following calculation hypothesis: the tensile strength of concrete is negligible; the concrete can be supposed to consist of helicoidal fibres, working in compression; and longitudinal and transversal fibres, working in tension, represented by the reinforcement.

Finally, Mr. R. BÜHRER considers the difficult problem of cement/ /steel bond in prestressed concrete structures. The complexity of the subject renders his investigation of the bond between the prestressed steel, the injected cement, and the metal tubing of considerable interest for the specialists in the subject.

Let us hope very sincerely that these contributions shall not be finally neglected owing to the indifference of others. The nature of the subjects under investigation affects directly the financial aspect of reinforced and prestressed concrete structures. The results so far submitted signify the beginning of a fecund stage of progress which, because of its great significance, should be enthusiastically continued.

SUMMARY

One of the main features of modern technology is the use of high tensile steels in reinforcement bars. The reason for this new tendency is the greater saving in cost made possible by the use of these special steels.

Both prestressing and the use of corrugated reinforcements seek to solve the problem of crack formation which arises with the use of high tensile steels. Estimation of the maximum permissible width of crack is therefore becoming more important every day.

It follows that it seems logical to ascertain what will be the consequences of tolerating a given limit width of cracks. To reach a definite criterion on this point would complement the investigations which are being at present pursued on the kind of cracking produced by different types of reinforcement.

ZUSAMMENFASSUNG

Eine der am stärksten hervortretenden Tendenzen der gegenwärtigen Technik ist die Verwendung von hochwertigen Stählen für die Bewehrung

des Betons. Der Grund hiefür ist in dem grösseren wirtschaftlichen Nutzungswert der Spezialstähle zu erblicken.

Sowohl beim Spannbeton, als auch bei gerippter Bewehrung wird versucht, das Problem der Rissbildung zu lösen, welches bei Verwendung dieser Stähle auftritt Die Festlegung der grössten zulässigen Rissbreite gewinnt täglich grösseres Interesse.

Eine möglichst genaue Kenntnis der Folgen, welche sich aus einer festgelegten Begrenzung der Rissbreite ergeben, ist daher sehr erwünscht. Die Schlussfolgerungen einer Untersuchung in diesem Sinne würden die gegebene Ergänzung der praktischen Versuche darstellen, welche gegenwärtig bei Verwendung der verschiedenen Bewehrungsarten durchgeführt werden.

RESUMO

Uma das principais características da técnica moderna é o emprego de aços de alta qualidade em armaduras para betão. Esta nova orientação é devida ao melhor rendimento económico dos aços especiais.

Tanto o betão preesforçado como as armaduras de tipo especial, tentam resolver o problema da fissuração posto pelo emprego desses aços. A determinação da largura máxima admissível para as fissuras, apresenta assim um interesse cada vez maior.

Parece portanto lógico, caso se admita um determinado estado limite de fissuração, tentar determinar as respectivas consequências. As conclusões de um estudo orientado nesse sentido seriam um complemento bem adaptado às experiências actualmente em curso no que diz respeito à fissuração produzida pelo emprego dos diferentes tipos de armaduras.

RÉSUMÉ

Une des tendances les plus remarquables de la technique actuelle est celle de l'emploi d'aciers de haute qualité en armatures. Cette nouvelle orientation est due au meilleur rendement économique des aciers spéciaux.

Aussi bien le béton précontraint que les armatures crénélées, essaient de résoudre les problèmes de la fissuration posés par ces aciers. L'estimation de la largeur maximum admissible pour les fissures, présente ainsi, chaque jour, un plus grand interêt.

Il semble donc logique si l'on se permet un certain état limite de fissuration d'essayer d'en déterminer les conséquences. Les conclusions d'une étude orientée dans cette direction seraient un complément bien adapté aux expériences développées actuellement en ce qui concerne la fissuration produite par l'emploi de différents types d'armatures.