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werden. Es wird auf die grundlegenden theoretischen Betrachtungen darüber kurz eingegangen und Ergebnisse verschiedener Arbeiten gegenübergestellt.»

Der Verfasser behandelt auch eingehend ein Bausystem, das in diesem Generalbericht vorhin nicht erwähnt wurde und das dadurch gekennzeichnet wird, daß man «nur teilweise das Bauwerk vorfertigt, indem man Fertigteile montiert und dann durch bauseitig eingebrachten Beton ergänzt».

Die grundlegenden theoretischen Betrachtungen, von denen der Verfasser ausgeht, fußen in der Hauptsache auf den *Dischinger*schen Formeln. Es wäre sehr interessant festzustellen, ob und inwiefern die Erkenntnisse der neueren Materialforschung zu Ergebnissen führen, die von den erwähnten theoretischen Betrachtungen abweichen.

Schließlich behandelt G. HERRMANN in seinem Beitrag theoretisch die Einwirkung des Kriechens des Betons auf die Instabilität der auf Druck beanspruchten Platten. Dabei nimmt er an, daß das Kriechen (die elasto-viskosen Verformungen) bei konstanter Spannung durch eine Funktion ausgedrückt werden kann, die mit der *Dischinger*schen Formel grundsätzlich übereinstimmt. Der Verfasser gelangt zu dem Ergebnis, daß, wenn die Last den Wert, welcher der elastischen Knickung bei kurzzeitiger Belastung entspricht, unterschreitet, aber einen gewissen Schwellenwert überschreitet, die Knickung nach einer gewissen, längeren oder kürzeren Zeit («Lebensdauer») eintritt.

Zur weiteren Klärung dieser Frage wäre es zweckmäßig, die neueren Errungenschaften der Materialforschung heranzuziehen, um die Zunahme der zusätzlichen Momente als Funktion der Zeit bei Säulen und Platten zu untersuchen, die mit gewissen Unvollkommenheiten, z. B. Krümmung oder außermittige Belastung, behaftet sind.

## General Report

Prefabricated elements have been used in the construction of bridges, industrial buildings, and dwelling houses to a substantial extent, especially during the past decade.

In a survey of the questions to be studied at this Congress, it may be of interest to consider the statements of problems in their mutual relations. Accordingly, some of the problems which appear to be particularly urgent in connection with the use of prefabricated elements are touched upon in what follows.

To begin with, it may be noted that the meaning of the term "prefabricated elements" is debatable. Is it to be stipulated, for instance, that a prefabricated element, such as it is at the time of delivery from a factory to a building site, shall have reached that strength which the element is required to have as a finished component of the structure, e. g. a strength corresponding to a normal curing period of 28 days? Or is it only to be required that the prefabricated element shall have reached such a strength that the element in question can be conveyed? No matter how these questions are answered, it may at all events be stated that it is incumbent on the designer (or the manufacturer) to furnish information on the following points, viz., first, how a given element shall be hoisted and conveyed, and second, what strength is required in order that the element may be conveyed. The questions are also of importance because it is necessary to decide who is to be responsible for ensuring that the strength of the prefabricated element shall be adequate in the finished structure.

The question of safety will be dealt with in Section IV at this Congress. All the same, it should be emphasised in this connection that safety in the course of conveying and hoisting is extremely important for the reasons stated in what follows. First, it has been found that the lifting connectors embedded in concrete sometimes get loose because the concrete has not reached a sufficient strength. Second, it has now and then been observed that connectors or lifting bolts are deformed several times during conveyance, and then break off, with the result that the structural component in question can fall down and cause damage. Therefore, close attention should be given to the material used for lifting bolts and to their handling during conveyance and assembly.

Another safety problem of special character is associated with the elastic stability of structural components. This problem is primarily met with during hoisting, but is also encountered in finished structures. The problem under consideration has recently been treated in a publication by LEBELLE [1]. The author has pointed out that various possible imperfections in workmanship play an important part in this connection. These imperfections are exemplified by the cases where the web of a beam is slightly bent in the longitudinal direction of the beam, or where the web is warped, i. e. deviates irregularly from the theoretical central plane. Careless handling of prefabricated elements may possibly also give rise to lateral buckling.

In prefabricated structures, the requirements stipulated for the dimensional accuracy of the elements must, as a rule, be more severe than the analogous requirements in the case of cast-in-situ concrete structures. This implies that the accuracy, the rigidity, and the durability of the forms for prefabricated elements also have to comply with more rigorous requirements. Furthermore, the dimensional accuracy required in the manufacture of prefabricated elements in the factory should be brought into proper relation with the requisite accuracy in conforming with certain specified dimensions on the site.

The *connections methods* used for the assembly of prefabricated elements in the structure constitute a problem of vital importance. The conclusions relating to Section VIa at the Congress of the IABSE in Lissabon contain the following statement, among others: "The experience from erected structures shows that the joints between prefabricated elements can be very dangerous and even cause collapse. Such joints often need to be improved in order to get monolithic structures." This question is to be discussed more closely at the Stockholm Congress, see further on.

Another momentous question which is to be discussed in particular is the *redistribution of stresses due to creep*. In the above-mentioned conclusions of the Lissabon Congress, it was likewise pointed out that this question is in urgent need of being clarified by further research. The relevant passage of the conclusions runs as follows: "In reinforced concrete structures, where different parts of the sections are cast during different periods of time, a considerable redistribution of stresses takes place, due to the shrinkage, creep and relaxation in the concrete and to a certain degree also due to the creep in the steel. Similar problems arise in the fields of prestressed concrete and composite structures. These effects have been studied during recent years, and it is now in many cases possible to predict them by calculation. Further fundamental research on the nature and amount of the creep and relaxation of both materials is however needed, as well as more data from observations on structures." See further on.

## Connection Methods

The finished structure is in a high degree characterised by strength and rigidity of joints.

The most primitive method of connection is simply to lay one prefabricated element on another. A structure built up in this way is more sensitive to overloads and alternating lateral forces than a monolithic structure. Moreover, under unfavourable circumstances, a structure of the former kind can progressively break down if a single load-bearing component is seriously damaged.

The best method of connection is that which ensures a monolithic behaviour of the structure. In principle, such methods of connection are to be aimed at. As a rule, however, this requirement must be moderated in some measure. This means that the joints are usually to be regarded as weak points of the structure.

In a prefabricated structure where the elements are connected together by means of weak joints, the eccentricities of all kinds, i. e. those in the prefabricated elements themselves, in their assembly, and in the application of forces, play a much greater part than in a monolithic structure. In a structure of the former type, the additional stresses can reach a considerable magnitude, whereas such stresses in a monolithic structure may ordinarily be disregarded. Furthermore, additional stresses are set up on account of the redistribution of stresses which gradually takes place when the prefabricated elements are connected together on the site by the aid of cast-in-situ concrete. Similar phenomena are also met with in the case of structures which are entirely made of cast-in-situ concrete. In addition, weak points can also be formed because the green concrete, which is mixed on the site, sets in relation to the prefabricated elements, and for the reason that its shrinkage is to a certain extent delayed. This can lead to crack formation, and the bond between old and new concrete becomes inadequate. Moreover, the hardening of cast-in-situ concrete can also be delayed or impaired by unfavourable weather conditions, e. g. by low temperature. It is important to take account of these circumstances in the design and construction of connections. It must be possible to utilise one of the advantages of prefabricated structures, namely, the fact that this method of construction is on the whole more independent of weather conditions than the older, traditional procedures, since the work is for the most part transferred from the site to the factories.

It may often be difficult to *control* the actual construction of the joints. This is due to the design of the joints, and also to the circumstance that they are crammed together in the smallest spaces. However, it should be possible to overcome this difficulty if the workmen are trained to carry out construction in accordance with definite specified procedures.

In each individual case, careful consideration should be given to the question how far the requirements which a monolithic joint shall fulfil need to be advanced form a safety point of view. As these requirements become more severe, the construction of joints grows more complicated, the costs increase, and the time needed for construction becomes longer.

Collected experience and test results can serve as a basis in formulating a series of *detailed* recommendations and requirements for design and construction of connections. These questions have been dealt with by several authors in the two volumes which were published by the two international congresses on prefabricated structures in Dresden, in 1954 and 1957 («Die Montagebauweise mit Stahlbetonfertigteilen und ihre aktuellen Fragen»). In particular, reference is to be made to a comprehensive survey and discussion of such requirements by W. Herrmann [2].

E. Lewicki [3] has summarised some *general* requirements for connection methods, and has drawn up a schematic classification of various connection methods. An English translation of the relevant passage from his publication is given in what follows.

"The connections must comply with the following requirements:

1. Completely adequate capability to take shearing forces.
2. Economical prefabrication of elements.
3. Simple conveyance and piling storage of prefabricated elements.
4. Simple assembly, particularly avoidance of auxiliary supports.
5. Stability, also in the assembly stage.

6. Rapid transmission of forces to accelerate assembly, and hence to increase the availability of mechanical equipment used for assembly.

The various connections which are employed all over the world are as follows:

I. Connections which cannot take any bending moments:

1. Friction.
2. Dowels.
3. Screw fastenings using steel screw bolts.

II. Connections which can take bending moments:

4. Bolting together by means of reinforced concrete bolts.
5. Projecting reinforcement loops.
6. Overlapping of projecting reinforcing bars and subsequent embedment of these bars in concrete.
7. Welding together of projecting steel parts, viz.:
   - 7.1. Reinforcing bars.
   - 7.2. Form steel or sheet steel parts which are welded together with the reinforcement.
8. Screw fastenings used to connect projecting steel parts which are welded together with the reinforcement.
9. Wedging.
10. Prestressing."

A distinction might be drawn between the connections enumerated in the above and the *joints* which are formed in the assembly of slabs and walls built up of prefabricated elements. It can be required, for instance, that such joints should be able to transmit shearing forces which act at right angles to the joint or parallel to its longitudinal direction. Furthermore, it can be required that these joints shall be air-proof and gas-proof (impervious to air-borne sound), and that they shall not form any objectionable cracks.

Detailed elaboration of the recommendations for the connection methods to be used for prefabricated elements and the requirements to be stipulated for these connection methods seems to be an appropriate subject to be dealt with by a working commission of the IABSE.

## Redistribution of Stresses Due to Creep

The redistribution of stresses which is referred to in the extract from the conclusions of the Lissabon Congress reproduced in the above is that which takes place in the same reinforced concrete cross section that is made up of concretes differing in age and in properties.

On the other hand, the heading of the present chapter, "Redistribution of Stresses Due to Creep", has a somewhat broader sense. In the first place, this heading again relates to the redistribution of stresses in a cross section which is composed of a prefabricated element and cast-in-situ concrete, and which is or is not submitted to the action of an external load or a forced deformation (Case 1). In the second place, this heading relates to that redistribution of stresses which occurs in a structure in the course of time, and which gives rise to a change in structural behaviour. Again, as regards the changes of the last-mentioned kind, a distinction can be drawn between two cases. First, there is the case where a structure is subjected to a given sustained load, i. e. a load acting during a long period of time (Case 2). Second, there is the case where a structure is submitted to a given forced deformation (Case 3).

There is no doubt that a considerable redistribution of stresses takes place in Cases 1 and 3. This redistribution of stresses is due to a rheological property of the materials concrete and steel which is known under the name of stress relaxation.

On the other hand, it is questionable, for example, whether Case 2 is in any way applicable to a statically indeterminate structure, that is to say, whether any appreciable redistribution of stresses occurs in the course of time in such a structure under the action of a constant load. In slender structures which are subjected to eccentric compression, e. g. columns and plates, the additional moments which are caused by the deflection can be increased as a result of long-time deformations.

The problems which arise in this connection are very difficult. In principle, their sphere of application extends far beyond the field of prefabricated structures alone. Thus, the same problems are met with, for instance, in dealing with all kinds of prestressed concrete structures and composite structures. If these problems are to be clarified, then it is necessary to take the rheological properties of materials as a point of departure.

The rheological properties of concrete have been discussed at a RILEM Symposium in Munich, in November, 1958. The contributions to this Symposium are being published in the current RILEM Bulletins 1959. The rheological properties of concrete can be schematically classified in the following three groups, viz., (a) visco-elastic deformations under a constant or variable stress, (b) plastic deformations under a constant stress exceeding a certain definite threshold value, which are caused by the microscopic cracks developed in the material, and (c) stress relaxation under the action of a forced deformation.

The rheological properties are in a high degree dependent on the composition and on the age of the concrete as well as on the time at which the stress or the deformation is applied to the concrete. Furthermore, these properties are influenced by the moisture conditions in the concrete body and in the ambient air. Moreover, the time functions are also dependent on the dimensions of the concrete body.

The relaxation properties of steel are likewise to be regarded as a relatively important factor in this connection. These properties have in part been dealt with at another RILEM Symposium, in Liège, in July, 1958 ("RILEM Symposium on Special Reinforcements for Reinforced Concrete and on Prestressing Reinforcements"). The contributions to this Symposium have been collected in a separate volume.

Finally, it may be presumed that the *bond* itself between concrete and steel possesses similar rheological properties. It appears, however, that nothing is known at present about these properties.

Accordingly, it seems that much is to be gained by establishing closer contacts between specialists in materials research and in statics. It may therefore be suggested that a working commission consisting of experts in materials research and in statics should be set up for the important purpose of coordinating knowledge, experience, and results of static calculations in order that it may be possible to arrive at certain conclusions which would be applicable to various types of structures.

## Congress Reports

C. Fernandez Casado has described in his report the construction of some very large one-storeyed industrial buildings, and has dealt in particular with the constructional details of connections between prefabricated parts. The author has put special stress on the necessity of ensuring the stability of the load-bearing structure against lateral forces in the assembly stage as well as in the finished state. He has shown, among other things, how the stability during various assembly phases can be studied on small models of the buildings in question.

T. Koncz has schematically touched in his report on the various load-bearing structural systems which can be used for multi-storeyed prefabricated concrete industrial buildings. Furthermore, the author has made several detailed suggestions concerning the design and construction of connections, and has stated his views on the conditions under which this or that method of connection can be employed.

H. Rühle has presented in his report a comprehensive survey of the problem of stresses («Zwängungsspannungen») due to creep and shrinkage in prefabricated reinforced concrete structures and the practical importance of this problem.

An English translation of an extract from a summary by the author is given in what follows:

"This report deals, in the first place, with the permanent stresses and deformations which remain in structures that, after positioning of prefabricated elements, are connected by means of flexurally rigid or articulated joints so as to form load-bearing systems. As is generally known, creep and shrinkage cause a redistribution of shearing forces, whose practical effects are demonstrated in the report. The fundamental theoretical considerations on this subject are briefly touched upon, and a comparison is made between the results of various investigations."

Furthermore, the author has also treated at some length a construction system which has not previously been mentioned in this General Report, and which is characterised by the fact that "the structure is prefabricated in part only, in that the prefabricated elements are assembled, and are then supplemented with cast-in-situ concrete".

The fundamental theoretical considerations which the author has used as a point of departure are in the main based on *Dischinger*'s formulæ. It would be very interesting to find out whether and to what extent the knowledge gained from recent research in materials leads to results which deviate from the above-mentioned theoretical considerations.

Finally, G. Herrmann has made in his report a theoretical study of the effect produced by creep of concrete on the instability of compressed plates. For this purpose, he has assumed that the creep (the visco-elastic deformations) under constant stress can be expressed by a function which agrees in principle with *Dischinger*'s formula. The author has come to the conclusion that if the load is lower than the value which corresponds to elastic buckling under short-time loading, but exceeds a certain definite threshold value, buckling occurs after a certain definite, longer or shorter lapse of time (critical time or life-time).

With a view to further elucidation of this problem, it would be of interest to utilise the recent knowledge derived from research in materials in order to study the increase in additional moments as a function of the time in plates and columns having certain imperfections, e. g. in the form of initial curvature or eccentric loading.

## Rapport général

Des éléments préfabriqués ont été utilisés sur une grande échelle dans la construction des ponts, des bâtiments industriels et des maisons d'habitation, surtout au cours de la dernière décade.

Dans une revue des questions dont doit s'occuper ce congrès, il peut être utile de considérer les problèmes posés sous l'aspect de leurs rapports mutuels.