General report

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RAPPORT GÉNÉRAL / ARBEITSBERICHT / GENERAL REPORT

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INTRODUCTION

Measurements and observations of effect due to shrinkage, creep and temperature changes on concrete structures are carried out for various purpose. The 14 contributions from 11 countries published prior the symposium are a proof of this. They can be divided into three main groups.

The aim of the first group is a comparison of creep and shrinkage effects assumed in the design of a structure with actual values of those phenomena in the existing structure. The second group appears to include the investigations the purpose of which is a comparison of the experimental results obtained in controlled conditions of laboratories with the results of the measurements and observations obtained on the actual structures. The third group includes the contributions reporting on measurements and observations provoked by some defect or damage on the finished structure which can be imputed to unfavourable effects of creep, shrinkage, or temperature changes, respectively a suspicion has arisen that such a defect or damage could be done owing to those phenomena. In any case, the main aim of measurements and observations is to verify whether an actual structure can serve the purpose which it is designated to. Naturally, there are many other questions which are to be clarified by measurements and observations on actual structures and in laboratories.

A comparatively great number of measurements and observations to verify the values considered in the design of a structure have been made on a comparatively large scale. It is caused by the fact that it is difficult to transfer the results of measurements from one part of the world to another. The main reason for it lies in the different climatic conditions. Kokubu, Goto, Ozaka, Okamura, and Momoshima report in their contribution results of measurements on 7 higway and 14 railway bridges the main purpose of which was the evaluation of creep coefficients and shrinkage strains of bridge girders with a box cross section and an I-shaped one. The numerous measurements during a period of 2 - 5 years make possible a comparison of time-dependent behaviour of several bridges of different types, cross sections, spans, age of prestressing, climatic conditions, concrete compositions, construction methods, etc. The authors investigated also the influence of creep an shrinkage separately. They give the results of such measurements on three bridges. Generally, much attention is devoted to the long term behaviour of bridges. It is quite comprehensible. Bridges are mostly built as structures of prestressed concrete and the prestressing force is considerably influenced by creep and shrinkage effects. By new construction methods, especially cantilever method, the concrete elements have different ages and get their final loads in many steps. It may considerably influence the development of creep and shrinkage strains. The situation of a bridge with regard to the cardinal points and local climatic conditions may have a great influence on those magnitudes. Use of prestressed concrete makes possible bridges with large spans where the sustained load forms a great part of the total one. Keijer presents the results of measurements on four bridges in Sweden. Great attention is paid to the vertical deflections of bridges and to the problem of their stabilization during their lifetime. Some measurements lasted more than 12 years. Oberti presents in this contribution the results of measurements carried out during a period of 4 years. Aichhorn continued the measurements of three bridges in Austria and informs of measurements which lasted altogether 14 years. The aim of two reinforced concrete structure measurements the results of which are given in the constribution of Ohno and Obata was the time-dependent change of expansion joint width.

The research works in which observations in laboratory conditions are combined with the measurements on actual structures are of great importance. We can find such a comparison in the contribution of Jungwirth where the results of laboratory research as well as results of measurements on bridges and other structures are presented. Swamy and Bennet report in their paper on a research programme the purpose of which is to predict the possible movements of actual structural members on the base of laboratory model tests. They compare the results of measurements on columns of a skeleton structure with the results obtained on laboratory specimens. Dilger, Ghali, and Kountouris observed creep and creep recovery on cylinder specimens to modify the principle of superposition and changes of the reactive forces on continuous prestressed concrete beams. Okada, Koyanagi, Yoshida carried out the measurements to find the effects of differential shrinkage on statical magnitudes of composite reinforced concrete beams. The object of the study presented by Gamble is the modification of the principle of superposition in order to clarify the non-linear creep and the verification of theoretical analysis on 22 specimens. Balázs and Horváth carried out the measurements on two bridges in order to compare the behaviour of structures with a normally treated and steam-cured concrete. Tertea, Oneţ, and Beuran investigated the long term behaviour of lightweight reinforced concrete beams. Results of an extensive experimental research of structures exposed to high temperatures are presented by Rickenstorf. The contribution of Cigánek and Meloun can serve an example when measurements and observations were provoked by the defects which appeared as a consequence of unfavourable effect of shrinkage on an existing structure. Similar reasons led to the measurements on a bridge and precast prestressed girders presented by Oberti.

The review of contributions to the present symposium shows that there is a variety of reasons which lead to organizing measurements and observations on actual structures or in

laboratories. Though the main aim of the measurements on actual structures is to make sure of the correct function and to compare the assumptions of design, they often require supplementary experimental research in controlled conditions of laboratories.
On the other hand, an experimental laboratory research may be carried out to clarify some other problems. The detailed investigation of the influence of concrete composition, material properties, mode of reinforcing, mode of loading and its intensity, different temperature and humidity conditions, size and shape of specimens, etc., is possible only in a well equipped research institute. There are some more problems the solution of which can be expected only from a well prepared and programmed laboratory research. One of these problems is, for example, the determination of the limit of stable increase of displacements. It may be supposed that there is a certain ratio of the sustained load to the ultimate load at which the increment of displacement, e.g. of deflections, begin to be constant or increasing for the constant time interval. Another question connected with the safety of structures against undesirable displacements is the time-dependent change of statistical parameters. From the point of view of design philosophy it would be desirable to know the change of the distribution curve of strains or displacements at certain load and constant climatic conditions. A similar question is the investigation of creep and shrinkage effects on ultimate load where the change of statistical parameters would influence the safety of a structure against collapse.
An experimental investigation of time-dependent change of standard deviation for deflection or cracking limit, respectively crack width, could answer the question of influence of creep and shrinkage on increasing or decreasing of dissipation of those values. Prestressed concrete structures are often reinforced with a supplementary reinforcement of mild steel. A redistribution of stresses between concrete and reinforcement due to creep may reduce the cracking limit of those structures. This is also a problem which can be solved only by a well prepared experimental research. As we can see from the presented papers, most of the research work concern with structural members subjected to flexural and compressive stresses.

An attention should be devoted to the other kinds of stresses, e.g. to the torsional one. Certainly, the problem of the influence of creep and shrinkage on structures stressed with repeated loading is of a great importance. In some cases it would be useful to examine by an experimental research the difference between the long term behaviour of structures under uniform and concentrated loads and investigate how the total deflections are influenced by a local concentrated stress.

TECHNIQUE OF MEASUREMENT AND INTERPRETATION OF RESULTS

An experimental program includes time-dependet measurement of several physical magnitudes. The measurement of displacements and strains should be considered as the most important together with the measurement of temperature and humidity of environment. As it is indicated by several authors /Oberti, Jungwirth, Rickenstorf/ the following quantities should be measured: vertical and horizontal displacements as a rule in the spots where these quantities are expected to obtain the greatest values, rotations of cross sections, local strains of concrete and those of steel, crack spacing and crack width, the value and situation of loads, temperature and humidity of environment and of the structure itself. The measurement of those quantities on the actual structure or in laboratory does not represent any substantial difficulties. The geodetical methods may be used for measurement of vertical and horizontal deflections on large constructions. Otherwise the simple dial gauges are used for the measurement of deflections /Tertea, Oneţ, Beuran/. As far as the measurement of strains is concerned, Jungwirth emphasizes that the greatest measuring length is necessary to use. A long steel bar is advisable for this purpose /Kokubu, Goto, Ozaka, Okamura, Momoshima/. Very often, however, contact gauges /Kokubu, Goto, Ozaka, Okamura, Momoshima; Oberti/, mechanical strain gauges /Swamy, Bennet; Cigánek, Meloun; Tertea, Oneţ, Beuran; Balázs, Horváth/, acoustic strain gauges /Swamy, Bennet/, resistance or inductance strain gauges /Oberti/ are used.

Certain difficulties arise at the evaluation of measured long term values when it is necessary to separate the creep values from those of shrinkage. Those difficulties are caused by the fact that besides these effects the time-dependent strains are influenced by the initial state of stress and strain which must be estimated but the accuracy of such an estimation is unknown. The initial stress and strain distribution depends also on loads and effects occuring during the construction. The total strain due to creep and shrinkage is related with the value of sustained loads and thus the separation of those phenomena would be correct. Shrinkage strain may be observed on unloaded specimens situated in the same environment as the loaded structure /Kokubu, Goto, Ozaka Okamura, Momoshima; Okada, Koyanagi, Yoshioka; Cigánek, Meloun; Balázs, Horváth/. Though the results of such measurements are not fully satisfying, we have not another better way at present. Naturally, we are interested in the stress distribution in a structure at some age of it. The direct measurement of this distribution is very difficult. Kokubu, Goto, Ozaka, Okamura, and Momoshima used for that purpose the specimens cut out from the flanges of bridge girders. The flanges were made with appendages. In the case of prestressed concrete structures it is also necessary to separate the effects of steel relaxation which can be observed on specimens taken from the steel delivery and at an initial stress corresponding to the value of initial prestressing.

We can say that further attention to the improvement of measurement methods of time-dependent values should be devoted. The measurements are rather expensive, require much working effort and the results often do not fulfil expectations. All this is connected with the question of economy of measurements. In any case, it is necessary to carry out a great number of measurements when the evaluation of results is to be improved. Perhaps it would be possible to organize a research program based on the telemetrical transmission of measuring data from several structures to one point, where all changes of deflections, strains, temperature and humidity of structure and its environment would be registered. The obstacle to such a program form the above-mentioned difficulties in separation of several influences.

RESULTS OF MEASUREMENTS AND OBSERVATIONS

In order to compare the results of measurements and observations on actual structures it would be necessary to take into account all main factors influencing the value and curve of creep and shrinkage. As the variation of those factors is very extensive, it is clear that the comparison of values given in the reports presented to the symposium is not possible. The measurements were made on different types of structures, under different conditions and duration of observations.

Measurements of creep and shrinkage strains, reported by Kokubu, Goto, Ozaka, Okamura, and Momoshima, were taken from a comparatively great number of bridges. From the measurements a value of shrinkage of 200.10^{-6} to 400.10^{-6} was obtained for the period from 3 to 5 years. The authors emphasize the importance of situation of a bridge from the point of vief of climatic conditions. A difference of 150.10^{-6} in shrinkage strains between each side of the cantilever prestressed concrete girders was found as a result of the effects of sunshine, wind, rain, and snow. The measurements on two prestressed concrete bridges were carried out with the separation of shrinkage effects. In one of these bridges creep coefficients from 2 to 3 were determined for five years and in the other bridge a value of 1.2 was found from three years' observations. Creep coefficients derived from the measurements on twenty bridges in Japan varied from 1.5 to 2.5, which can be considered as a very good result of measurements. Oberti gives the results of measurements on pavement structure of Mont Blanc tunnel. The average horizontal strain reached a value of 550.10^{-6} at the age of four years. In this structure the values of shrinkage strain at the end of the tunnel were found greater than in its middle. In the case of Bradano bridge, which had to be unloaded because of large long term deflections, 2.5 to 3 times higher values than those considered by the design were found. Oberti gives another example of prestressed precast beams in which about double creep and shrinkege strains were observed than those calculated by the design. Cigánek and Meloun measured shrinkage strain on vertical bearing walls of a multistorey building and obtained values varying from 400.10^{-6} to 600.10^{-6}. A damage of a building is described due to differential shrinkage of cast-in-place walls and precast ceiling slabs. Swamy and Bennet report on the results of a programme of investigation of creep and shrinkage strains on a reinforced concrete structure during its construction and after its completion. Shrinkage strains were measured immediately after casting columns. Comparison of shrinkage and creep strains measured on columns and laboratory models shows that the laboratory specimens shrunk several times more at the initial stage than the exposed specimens. At the age of one year this difference was reduced so that the shrinkage strain reached a value of more than half of the shrinkage of specimens situated under controlled conditions. The authors investigated also the influence of a limestone and a granite aggregate. It showed that the limestone concretes had a greater movement than those of granite. The authors give also the results of variation of internal temperature and internal steel strains. Balázs and Horváth measured creep and shrinkage strains on two bridges, one of which was constructed of precast girders and the other was cast in place. In the first bridge values of 250.10^{-6} and 550.10^{-6} were found at the age of 100 and 1500 days respectively. The authors claim that the shrinkage was not finished. In the second bridge concrete specimens were steam-cured and showed the shrinkage 15 to 20 per cent lower than the normally treated ones. The authors compared the shrinkage of specimens situated inside of box girders with that of specimens situated on their surface. It was proved that the inside situated specimens showed lower shrinkage than the specimens situated on the surface of girders. In the case of steam-cured specimens the creep coefficients were 0.7 and 1.5 at the age of 100 and 1500 days respectively. In the case of normally treated concrete the coefficient of creep showed a value of 0.6 at the age of 100 days and 2.15 at 1500 days.

Jungwirth summarized various measurements and came to the conclusion that the end values of creep and shrinkage agreed at an accuracy of $\pm$ 15 per cent with the CEB Recommandations. The agreement of the time-dependent relations is less favourable. The long term strain curves show that the strains are related to the so called effective thickness of the body. The results namely show that the creep and shrinkage of thicker bodies is slower than those of thinner. The increase or decrease of temperature produces acceleration or retardation of creep at about 10 per cent. In summer the creep is 24 per cent quicker than in winter. Further Jungwirth remarks that not all evaluations give unambiguous results. It may be clarified by the fact that there is a considerable uncertainty as to temperature corrections. The effects of temperature are often merely assessed. Rotations of supports may cause considerable faults as well. Suppleness of shutterings may lead to a greater weight of structure than supposed in the evaluation. Authors presents a system of curves for creep and shrinkage strains suggested to be included into the improved Recommandations CEB.

Keijer in his contribution presents the time-deflection curves of bridges constructed by the cantilever method. The investigation showed that the creep coefficient of concrete has the prevailing influence on the magnitude and development of deflections. He remarks that the creep function containing logaritmic time-function shows a good agreement with the observed values. The conclusion that even after more than ten years stabilization of total deflection was not observed, is remarkable. Aichhorn presents results of measurements of creep and shrinkage at the age of 14 years. He remarks that the strain increment during the last 7 years was about 10 per cent, so that a conclusion results from it that the development of creep and shrinkage ceases aproximately after 8 years and the four years' period considered in existing design is not sufficient. A different influence of seasons can be seen on the creep-time curves. That difference varies at a value of about 15 per cent. The similar tendency was observed for concretes of different strength.

Dilger, Ghali, and Kountouris report on very interesting experiments the aim of which was to observe the reaction changes in continuous prestressed concrete beams produced by differential settlement of supports. Those reactions are influenced by creep, change of the modulus of elasticity, and by the settlement-time curve. Experiments were carried out on five pairs of beams in such a way that a pair of beams were given a constant deflection which was maintained and the time-dependent changes of force were measured. For one of the pairs the constant deflection was maintained during the whole period of observation while in the rest the deflection was changed at certain intervals. Authors compare the obtained force-time relations with those derived analytically for a modified principle of superposition which led to a good agreement between calculated and measured values.

The contribution of Tertea, Onet, and Beuran is devoted to the influence of creep and shrinkage on cracking and deflection development of lightweight reinforced concrete. Tests were carried out on two series of beams with simple respectively double reinforcement. Beams were subjected to sustained concentrated loads at the third-span points. Tests were carried out during a year period. The obtained results show that the total crack width grows and the number of cracks increases. In comparison with normal concrete the beams of lightweight concrete showed about 35 per cent greater crack width. For the production of testing beams two kinds of aggregates were used. The authors recommend that the depth of lightweight may be 1/15 of their span. The experiments showed that the maximum crack width lies in admissible limits and thus reliability of such beams in construction is assured. The tested beams had also different steel percentage and the sustained load formed different portions of ultimate load. The long term deflections proved to have similar caracter of development for different values of sustained load.

Creep and shrinkage of lightweight prestressed concrete girder were investigated by Kokubu, Goto, Ozaka, Okamura and Momoshima. They found that creep of lightweght concrete is similar to that of normal concrete while the shrinkage was considerably lower.

Okada, Koyanagi, and Yoshioka were concerned with the influence of differential shrinkage on composite beams created in such a way that on the precast prestressed beam a slab was cast presenting the upper flange of the beam.Results of the experiments showed that the differential shrinkage reduce the cracking moment while no influence of that shrinkage on ultimate moment was observed. The authors give a theoretical analysis of cracking moment with regard to the influence of differential shrinkage. The results show a good agreement with experimentally obtained values. The authors recommend to create the cast-in-place flange slab of lightweight concrete which may reduce the stresses produced by differential shrinkage because of low modulus of elasticity of lightweight concrete.

The validity of the principle of supperposition is discussed by several authors /Jungwirth; Swamy, Bennet/. The study of Gamble is concerned with the modification of that principle in order to take into account non-linear creep. The validity of derived relations depends on determination of time function.
The determination of that function is shown on example of 22 experiments data.

Ohne and Obata present the results of expansion joint movements during a year. The observations were carried out on two buildings. It was proved that the expansion joints show daily movements having a retardation of three hours in comparison with the extremal temperature. The changes of expansion joints diminish towards the column feet. The annual movements of expansions joints correspond with the atmospheric temperature and that of the roof slab. In the second building similar daily and annual movements were observed. The differences between the different parts of building exposed on differential cardinal points were noted. An approximately linear relation was found through a year between the daily minimum length of building and the daily minimum temperature.

The contribution of Rickenstorf is devoted to the study of long term effects of higher temperature /up to 300 centigrades/. The measurements on 81 reinforced and 4 prestresed concrete slabs and on 4 experimental chimneys present an extraordinary large programme and lead to many interesting conclusions. The speed of creep and shrinkage is accelerated by higher temperatures. The tendency to the higher permanent strains is shown even by heating old concretes. The thermal stress proved to be the main influence while the other factors and composition of concrete had a second-rate importance. The author presents also a mode of calculation of time-dependent stresses in thermal stressed concrete structures.

CONCLUSION

The review of the contributions shows that measurements and observations of structures enable broadening of our knowledge on behaviour of structures under sustained load and on shrinkage of concrete. The comparison of the results given in these contributions is, however, very difficult because of different types of structures, climatic conditions, duration of measurements, etc.

Some authors emphasize that it is very difficult to determine the exact values of shrinkage and creep on the base of measurements on actual structures. The difficulties also arise when the laboratory results are to be transferred on actual structures. However, damages on actual structures due to creep, shrinkage, and temperature changes lead to the conclusion that it is necessary to devote a concentrated attention to these questions. Oberti proposes that research and investigation among the laboratories and a cooperation among them should be organized.

I should like to add that besides the physical point of the problem it would be necessary to concern with criteria determininig the admissible limits according to which a designer can judge the danger due to long term effects on structures.