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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 observa-
tions to verify the values considered in the design of a structu-
re 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 evalua-
tion 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 seve-
ral 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 brid-
ges. 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 fi-
nal loads in many steps. It may considerably influence the de-
velopment of creep and shrinkage strains. The situation of
a bridge with regard to the cardinal points and local clima-
tic conditions may have a great influence on those magnitu-
des. 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 ver-
tical deflections of bridges and to the problem of their sta-
bilization 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 alto-
gether 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 compa-
rison in the contribution of Jungwirth where the results of
laboratory research as well as results of measurements on brid-
ges and other structures are presented. Swamy and Bennet re-
port in their paper on a research programme the purpose of
which is to predict the possible movements of actual structur-
al 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 measu-
rements to find the effects of differential shrinkage on static-
al 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 measure-
ments 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 extensi-
ve experimental research of structures exposed to high tem-
peratures are presented by Rickenstorf. The contribution of Ci-
gánek 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 orga-
nizing 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 expe-
rimental 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 inves-
tigation of the influence of concrete composition, material
properties, mode of reinforcing, mode of loading and its inten-
sity, different temperature and humidity conditions, size and
shape of specimens, etc., is possible only in a well equipped re-
search institute. There are some more problems the solution of which
can be expected only from a well prepared and programmed labora-
tory research. One of these problems is, for example, the deter-
mination 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 sa-
fety 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, respecti-
vely 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 pre-
pared 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 sustain-
ed 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 /Koku-
bu, 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 bet-
ter 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 speci-
mens 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 va-
lue 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 measure-
ments. In any case, it is necessary to carry out a great num-
ber 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 ob-
servations 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 gi-
ven 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 measure-
ments a value of shrinkage of 200.10^{-6} to 400.10^{-6} was obtai-
ned 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 prestre-
ssed 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 separa-
tion of shrinkage effects. In one of these bridges creep coeffi-
cients from 2 to 3 were determined for five years and in the
other bridge a value of 1.2 was found from three years' observa-
tions. 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 shrinka-
ge 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 measur-
ed 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 shrin-
kage 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 struc-
ture during its construction and after its completion. Shrin-
kage 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 expo-
sed specimens. At the age of one year this difference was re-
duced so that the shrinkage strain reached a value of more
than half of the shrinkage of specimens situated under control-
led conditions. The authors investigated also the influence of
a limestone and a granite aggregate. It showed that the limesto-
ne concretes had a greater movement than those of granite.
The authors give also the results of variation of internal tem-
perature 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 pla-
ce. 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 au-
thors claim that the shrinkage was not finished. In the second
bridge concrete specimens were steam-cured and showed the shrin-
kage 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 favoura-
ble. The long term strain curves show that the strains are re-

lated to the so called effective thickness of the body. The re-
sults namely show that the creep and shrinkage of thicker bo-
dies 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 quick-
er than in winter. Further Jungwirth remarks that not all eva-
luations 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 asses-
sed. Rotations of supports may cause considerable faults as well.
Suppleness of shutterings may lead to a greater weight of structu-
re 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 ob-
served 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 chan-
ges in continuous prestressed concrete beams produced by dif-
ferential settlement of supports. Those reactions are influen-
ced 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-depen-
dent 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 re-
lations with those derived analytically for a modified prin-
ciple 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 car-
ried 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 por-
tions 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 in-
fluence 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 mo-
ment while no influence of that shrinkage on ultimate moment

was observed. The authors give a theoretical analysis of crack-
ing moment with regard to the influence of differential shrin-
kage. The results show a good agreement with experimentally ob-
tained values. The authors recommend to create the cast-in-pla-
ce flange slab of lightweight concrete which may reduce the
stresses produced by differential shrinkage because of low mo-
dulus of elasticity of lightweight concrete.

The validity of the principle of supperposition is discus-
sed 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 de-
rived 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 move-
ments 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 expan-
sions 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 mini-
mum 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 con-
crete 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 know-
ledge 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 deter-
mine the exact values of shrinkage and creep on the base of mea-
surements 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.