DEVELOPMENT OF A MATHEMATICAL MODEL FOR CREEP OF CONCRETE WITH REFERENCE TO BAGHDAD CLIMATE

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ABSTRACT

The present investigation is concerned with the evaluation of creep behavior of concrete under variable temperature and relative humidity. It includes analytical and experimental parts. In the analytical part, BP-KX creep model is presented. As this model considers temperature and relative humidity to be constant, it was modified through considering them to be variable with time, which is the usual case. Functions for the daily variation of these two parameters, according to Baghdad climate, were developed and substituted in the model. In the experimental part, three series of cylindrical specimens (100mm × 200mm) were prepared for the creep test. In series (1), the temperature was raised and simultaneously the relative humidity was lowered just after loading. Series (2), specimens were loaded at high temperature and low relative humidity followed by low temperature and high relative humidity. Series (3) specimens were loaded at low temperature and high relative humidity followed by high temperature and low relative humidity.

Comparison between the analytical and the experimental work confirmed the need for a correction factor to be included in the proposed modified model. The results revealed that concrete specimens subjected to high temperature and low relative humidity, after the load application, will show higher creep than specimens kept at high temperature and low relative humidity before and after load application. This indicates that specimens loaded in summer show lower creep than those loaded in winter.

ألخلاصه

يهتم البحث الحالي بتقييم تصرف زحف الخرسانة تحت تأثير حرارة ورطوبة متغايرة، ويتألف من جـزأين عملي ونظري. يتضمن الجزء النظري عرض النموذج الرياضي (BP_KX)، و لكون هذا النموذج يأخـذ تأثير الحرارة والرطوبة الثابتتين على الزحف، لذا تم تحويره من خلال جعلهما متغايرتين مع الزمن وهـي الحالة الاعتيادية. وقد تم تطوير دالتين للتغير اليومي للحرارة والرطوبة لمناخ العراق ومن ثم تم تضـمينها داخل النموذج الرياضي. أما الجزء العملي فقد تم تهيئة ثلاث مجموعات من النماذج الأسطوانية الشكل بأبعاد (100 ملم للقطر × 200 ملم للارتفاع) لغرض إجراء فحص الزحف عليها. المجموعة الأولى تم رفع درجة الحرارة و خفض الرطوبة النسبية فيها مباشرة بعد إجراء عملية التحميل. أما المجموعة الثانية فقد تم تحميل النماذج فيها تحت درجة حرارة عالية ورطوبة نسبية واطئة يتبعها انخفاض بالحرارة وارتفـاع بالرطوبـة النسبية. أما المجموعة الثالثة فقد تم التحميل تحت درجة حرارة منخفضة ورطوبة نسبية عالية يتبعها ارتفاع

بالحرارة وانخفاض بالرطوبة النسبية. عند مقارنة النتائج العملية بتلك النظرية تأكدت الحاجة إلى عامل تصحيح لوضعه ضمن التعديل المقترح. أظهرت النتائج انه في حالة تعريض النماذج الخرسانية لحرارة عالية ورطوبة واطئة بعد التحميل سوف تبدي زحفا اكبر من تلك التي يتم حفظها في حرارة عالية ورطوبة واطئة قبل وبعد تسليط التحميل. تشير هذه النتيجة إلى أن النماذج التي يتم تحميلها في فصل الصيف تظهر زحفا اقل من تلك المحملة في فصل الشتاء.

KEY WORDS
Transitional thermal creep, variable temperature, variable relative humidity, BP-KX model, modified method

INTRODUCTION
Creep has a major effect on the behavior of concrete structures since it is several times greater than elastic deformation. Consequently, a lot of research has been carried out to understand the physical processes of creep. Several models were proposed for calculating creep to get a proper evaluation of its effect in the design of concrete structures.
As creep is an inherent concrete property, it is influenced by many factors. These factors include the environmental conditions. At present there is no available model of creep under variable temperature and relative humidity conditions. Therefore the wide variation in temperature and relative humidity from one season to another provides an objective for this work.

ANALYTICAL WORK
There are several models for predicting the creep of concrete. They differ in their degree of accuracy and simplicity. The most comprehensive and common models are:
1- Model of ACI committee 209 (ACI Committee 1992).
2- Model of CEB-FIP model code (CEB-FIP 1978).
3- Bazant's Models: -
3-1- BP Model (Bazant and Panula 1978-1979))
3-2- BP-KX Model (Bazant et al.1991-1992)
3-3- B3 Model (Bazant and Baweja 1998)

As Bazant's models are the only group that takes the effect of temperature and a wide range of humidity into account, one model will be chosen for calculating the creep values in this work. The recent model that takes the effect of temperature on basic creep and drying creep is the BP-KX model. Hence, this model was modified in the present work and adopted in computing the creep values.

The Method of Analysis and Boundary Conditions
Bazant's models, including BP-KX model (Bazant et al.1991-1992), assume a constant temperature and relative humidity throughout the load duration. Therefore, there would be some inaccuracy in using them for calculating the creep of concrete with variable temperature and humidity. A simple method, which would be called the modified method for the BP-KX model, is extended here to overcome this problem. The functions of BP-KX model that depend on temperature and humidity were modified by considering both temperature and relative humidity as being functions of time (as will be presented later), instead of their terms in BP-KX model.
The principle of the modified method is based on dividing the temperature and relative humidity history during load application into separate intervals, each with a specified temperature and humidity. As shown in **Fig. (1-a)** starting with a load being applied at (t'), the creep value for the

interval (t' to t_1) is (C_1). If a change in temperature or relative humidity, e.g. lowering temperature and increasing relative humidity, takes place during the interval (t_1 to t_2) the creep increment (ΔC) should be calculated and added to (C_1) to obtain (C_2). This increment is calculated by subtracting the creep value for the period (t' to t_1) from that for the period (t' to t_2).
However, this modification would not follow the same course when the variation in temperature and relative humidity results in a higher creep value compared with that of the previous interval (like the flow that happens due to the elevated in temperature). For this condition, it is recommended to compute (C_2) through the assumption that the temperature and relative humidity at the current time (t_2) was prevailing since the time of loading (t'). The creep value is calculated directly for this period (t' to t_2), as shown in **Fig. (1-b)**.
A cylindrical sample of (100mm diameter by 200mm length), as that used in the experimental work, was chosen to study creep behavior theoretically. The same type of cement, the same ultimate compressive strength and the same mix design parameters were used in the theoretical calculation of the creep values. Computer programs were used to facilitate the calculation processes.

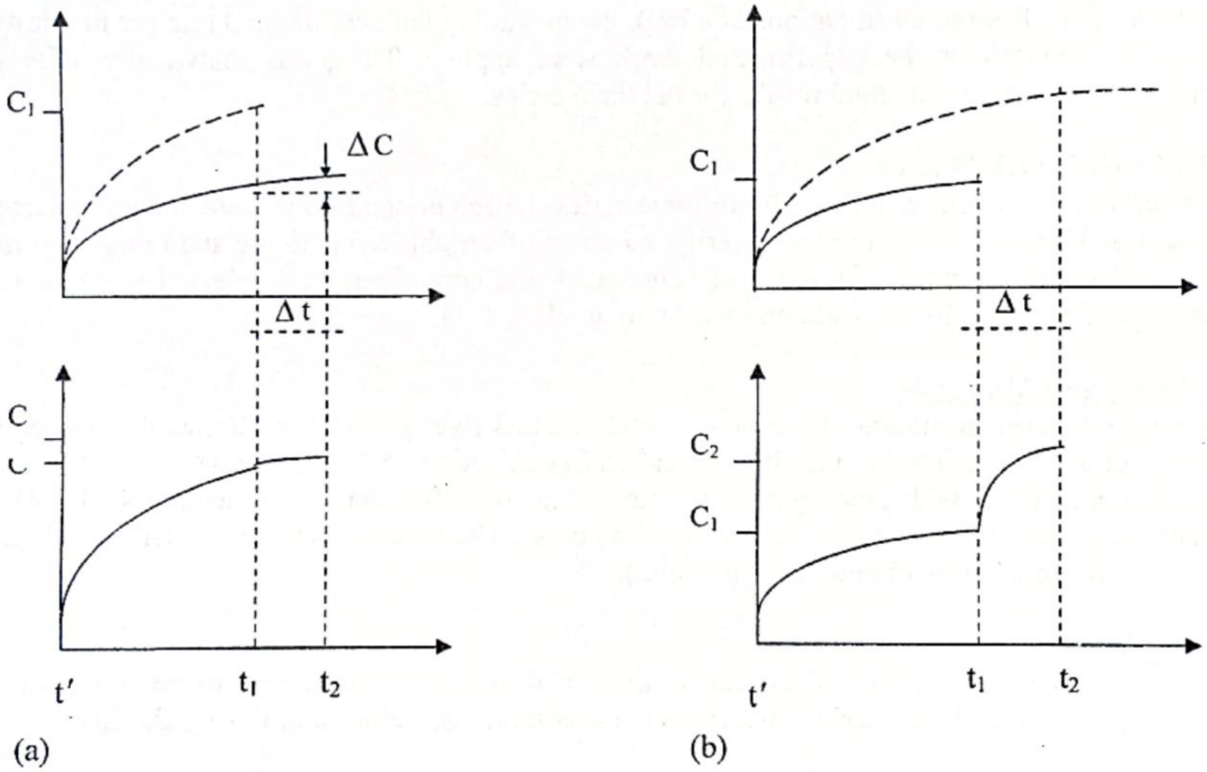

Fig. (1) a) top: dashed line: creep at elevated temperature solid line: creep at lowered temperature bottom: creep at elevated temperature followed

b) top:- dashed line: creep at elevated temperature
solid line: creep at lowered temperature
bottom:- creep at lowered temperature followed by creep at elevated temperature.

Arrangement of the Computer Program:

The values of the daily temperature and relative humidity for 5- years, from 1995 to 1999 inclusive, were taken from the Iraqi Meteorological Organization and Seismology. These data were fed to SPSS computer program under WINDOW. From these 5-years data, the average daily temperature and relative humidity throughout one year were computed and two curves of temperature and relative humidity with time were drawn. By using the nonlinear regression analysis two functions of temperature and humidity, with reference to time, throughout a year, were formulated and drawn. A computer program in QUICK BASIC under MS-DOS was designed to facilitate the calculations of BP-KX model. The computer program is able to compute the creep values for a variety of input data. Hence the program could analyze the input data for specimen size and shape, age of concrete at loading, age of drying commencement and mix design parameters needed for calculating the equations of BP-KX model. The program would analyze these data according to the functions of BP-KX model, which were modified to have the time dependent functions of temperature and humidity instead of their constant terms.

The computer program was organized to give, in its output, for each time of loading, 36 values of creep function, distributed over one year. The loading increments were chosen to be one per month and that was also for one year.

To evaluate the efficiency of the present proposed analytical method and the computer program (in analyzing the data according to this method), three computer programs were prepared for the three series of the experimental work. Yet, in addition to the data needed in calculating the equations of BP-KX model (mentioned before), the prevailing temperature and relative humidity for each series throughout the experimental work were applied. Then, the analytical results were compared with the experimental results for the three series.

EXPERIMENTAL WORK

The experimental work was divided into three series. Different conditions were accommodated for each series. This was done in order to verify the effect of variable temperature and relative humidity before and after loading on the creep of concrete. These conditions were selected to simulate the variation of Baghdad climate from one season to another.

Specimens and Materials

The materials used in making the concrete were crushed river gravel from Samarah quarries with grading zone (5-19mm) satisfying (Iraqi Standard Specification 45/1984). While the sand was from Al-Akhaidher quarry with grading zone (2) satisfying (Iraqi Standard Specification 45/1984). The cement was Ordinary Portland cement from Al-Kubaisa. The specimens were molded in cylindrical shapes of (100mm diameter and 200mm length).

Environment

The specimens, after the end of the curing time in water, were transferred to be stored in three different conditions. Three series of different test conditions, before and during the loading time, were chosen.

Series (1) was chosen to manifest the effect of raising the temperature and lowers the relative humidity immediately after loading, on the creep behavior of concrete. So, after curing in water (till age of 28 days), the specimens were stored for 6 days at temperature of $(21\pm3)^{o}$C and (50 ± 5)% R.H. .As soon as load was applied the temperature in the controlled hot room was raised to $(42\pm1)^{o}$C and the R.H. was (23 ± 3)%. After 80 days the temperature was lowered to $(21\pm3)^{o}$C and the R.H. was (50 ± 5)%. To identify the effect of next raise in temperature, after 7-day storage in the previous conditions, the temperature was raised again to $(42\pm1)^{o}$C and R.H. (23 ± 3)%.

Series (2) was chosen to represent the effect of the condition prevailing during the summer season followed by winter season on the creep behavior of concrete. Therefore, the specimens were stored in a controlled hot room for 6 days at $(42\pm1)^{o}$C with (23 ± 3)% R.H.. Then the specimens were loaded and kept under these conditions for (60 days). To simulate the subsequent effect of winter season, the temperature was then lowered to $(21\pm3)^{o}$C with (50 ± 5)% R.H. till the end of testing.

Series (3) was chosen to simulate the effect of the conditions of winter season, followed by summer season on the creep behavior of concrete. Hence the specimens were stored for 6 days at temperature (21 ± 3)°C and (50 ± 5)% R.H., then they were loaded under the same conditions. After 20 days the temperature was raised to (42 ± 1)°C with (23 ± 3)% R.H., to show the subsequent effect of summer season.

Creep Measurement:

When the specimens had reached the specified age, the compressive strength test was carried out according to (ASTM C873-80) before starting the creep test. Then the specimens were loaded for creep measurement and the test was performed according to (ASTM C512-87). There were two cylinders of (100 mm diameter by 200 mm length) provided for each series. Companion to each loading test, there were two more cylindrical specimens of the same shape and size, and stored under the same conditions to those loaded. These specimens were prepared for each test as control specimens. They were used for measuring the strain-taking place without any external load, i.e. shrinkage and thermal expansion.

Two strain gauges of 30mm length were fixed, by active glue, on each opposite side of the loaded and unloaded specimens.

The cylinders were inserted in the creep frame tester to construct a two-cylinder column. Then the strain gauges were connected to the digital strain meter type (TDS-100), for measuring the strain. This measured strain represents the total strain due to elastic strain, creep, shrinkage and thermal expansion.

The uniaxial compressive load of 16000 lb (7273 kg) was applied by using a hydraulic jack with a hand pump. It was accommodated with a gauge of (216mm-diameter and 60000 lb (27273 kg) capacity) to control the magnitude of the applied load. The same load was applied for each test loading, but due to the difference in compressive strength, the stress/strength ratio was varied from one series to another, the stress/strength ratio of series (1) and (3) was 0.3 and for series (2) was 0.26. The loading period was 94 days for series (1) and 80 days for series (2) and (3), then the load was released and the readings (that represent the relaxation value) were recorded for the next 10 days.

The values of creep were obtained by subtracting the average strain reading of control specimens from that of the loaded specimens at each time of testing.

RESULTS AND DISCUSIONS

The results are submitted into two parts experimental and analytical.

Analytical Results

At the age of 34 days the average compressive strength was 4396 psi (30.3 MPa) for series (1) and (3) and 4983 psi (34.4 MPa) for series (2). It can be seen that, at the same age of 34 days, the average compressive strength of the specimens subjected to higher temperature and low relative humidity (series (1) and (3)) is greater than that of specimens subjected to lower temperature and higher relative humidity (series (2)) by about (13.3%). This result could be related to the effect of heating on accelerating water movement out of the specimen. Hence, the unheated specimens have more water than the heated ones. As a result, this water will initiate additional internal stresses, causing failure at a lower external applied stress. Also, the losses of water results in a lower volume of voids and because of shrinkage the gel particles become closer to each other, resulting in a higher compressive strength.

The total (elastic + creep) strain could be obtained by subtracting the strain of the unloaded (control) specimen, which represents the shrinkage and thermal deformations, from the average strain of the loaded specimen. This process was followed till the end time of testing.

The behavior of total (elastic + creep) strain of series (1) with time under load is shown in **Fig. (2)**, while **Fig. (3)** shows the creep strain for this series after subtracting the elastic strain from the total strain. This series represents specimens subjected to a high temperature of (42 ± 1)°C and low relative humidity of (23 ± 3)% just after the load application. It can be seen that a high magnitude of

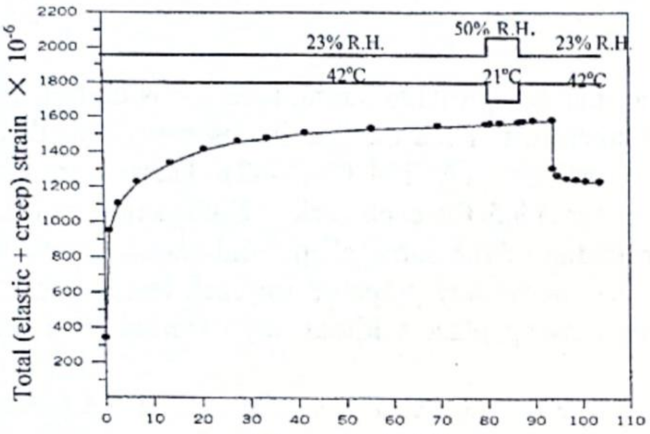

Fig. (2) Observed total (elastic + creep) strain vs. time under load for series (1)

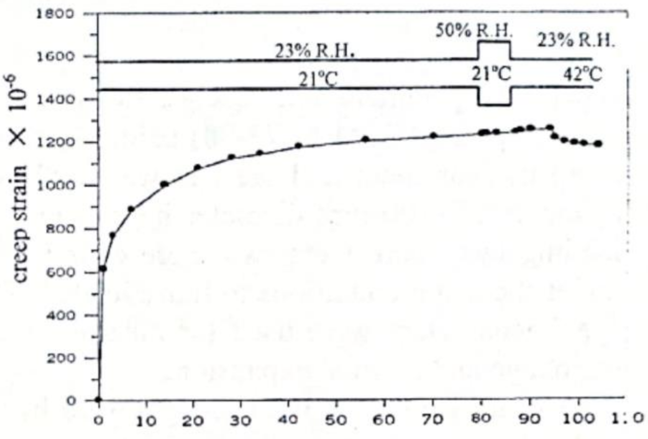

Fig. (3) Observed creep strain vs. time under load for series (1).

creep is observed during the first day under the load. The creep rate continues to be high during the next few days. Thereafter the rate decreases to take the normal shape of the creep curve at this temperature. After 80 days of load duration combined with heat exposure, the creep value was about (3.65) times the value of the initial elastic strain. The initial high increase in the creep strain could be directly related to what is called " transitional thermal creep ". This component which was proposed by Illston and Sanders (1973,1974) for creep in torsion, appears to be also applicable for creep in compression as the result of the present work show. It occurs rapidly during and immediately following a rise in temperature to a previously unattained level. Illston and Sanders (1973,1974) attributed the transitional thermal creep to the disturbance that occurs due to the rise in temperature. Bazant (1982) attributed the transient thermal creep to special mechanisms. One of these mechanisms could be related to the thermal gradient that occurs due to a temperature change, which is followed by a hygral gradient. The resulting internal stress distribution changes the creep rate (Bazant 1982). However, for series (1) the creep values are still rather high because, the low relative humidity coinciding with the high temperature will increase the amount of water movement out of the specimen, causing an increase of drying creep value. In the present work the following mechanism is proposed to contribute to transitional thermal creep. The high coefficient of thermal expansion of water compared with that of hardened concrete may lead to fast movement of water from gel pores to capillary pores, resulting in a significant increase in creep.

As shown in **Fig. (2)** and **Fig. (3)** after load duration of 80 days, the temperature was lowered to (21 ± 3)°C with R.H of (50 ± 5)% for 7 days. Later, it was raised again to (42 ± 1)°C with R.H. of (23 ± 3)% till the end of testing. Although the rate of creep seems to be rather different, there was not any sudden increase or decrease in the creep rate. These results confirm the conclusion of (Illston and Sanders 1973), that the "transitional thermal creep component is associated only with a rise in temperature to a previously unreached level". This component neither occurs when the temperature decreases nor when the temperature is raised to the previous level for the second or subsequent time.

The creep behavior of series (2) at a constant elevated temperature of (42 ± 1)°C and (23 ± 3)% R.H., is shown in **Fig. (4)** for total (elastic + creep) strain and **Fig. (5)** for creep strain.

This series represents the creep behavior for specimen loaded after being subjected to hot weathe

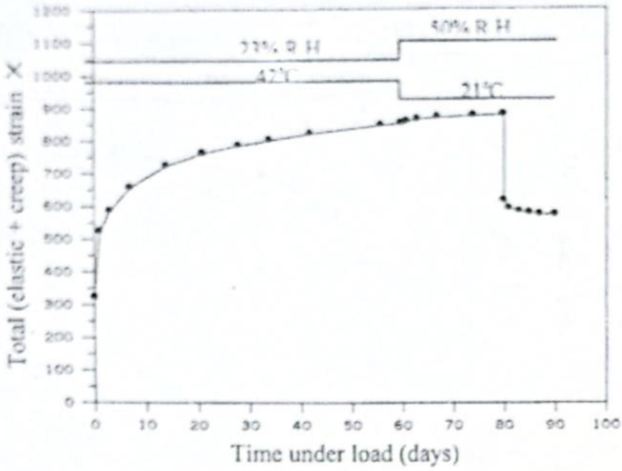

Fig. (4) The observed total (elastic + creep) strain vs. time under load for series (2).

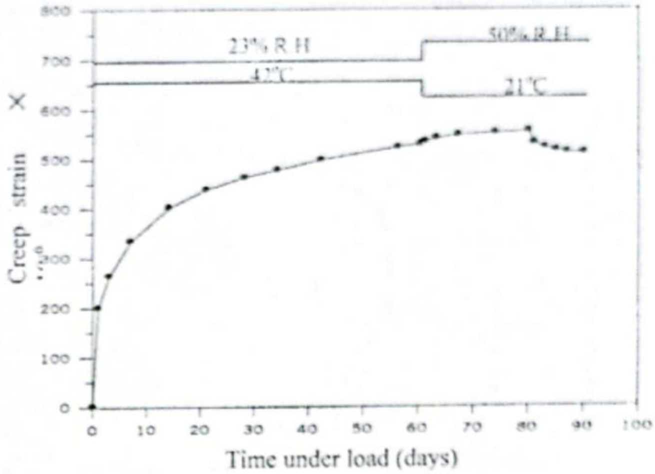

Fig. (5) Observed creep strain vs. time under load for series (2).

as in summer season. It can be seen that creep values increase with time at a decreasing rate. The creep values of this series are smaller than that of series (1). This behavior as proposed by Illston and Sanders (1973,1974) is attributed to the fact that the disturbance caused by the temperature rise takes place before the load application. If the particles are moved in the xerogel skeleton (due to external applied force or elevated temperature) they are more strongly fixed in their new position (Bazant and Wittmann 1982). So, after the load application the transitional thermal creep component will no longer be occurring. This might probably be the explanation for the constant-temperature behavior of the creep curve when the thermal perturbation occurs before the load application.

After 60 days of loading the temperature was lowered to $(21 \pm 3)^{o}$C with R.H. of (50 ± 5) %, in order to reflect the effect of cool weather of winter season. There seems no sudden change in the rate of creep curve because the transitional thermal creep does not occur when the temperature is being lowered, as mentioned previously. In fact, the rate of the creep (at the beginning of cooling period) looks to be slightly increasing. This increase in creep could be related to the thermal and hygral gradient that occur due to heating or cooling the concrete (Bazant and Wittmann 1982). In addition, it might be probably related to the cracks formation at the cement-aggregate interface due to the difference in their coefficients of thermal expansion. The creep value at 80 days of load duration was about (1.72) times the elastic strain.

The performance of series (3) is shown in **Fig. (6)** for total strain and **Fig. (7)** for creep strain. This series represents the creep behavior when the specimen is loaded while being subjected to cool weather as in winter season. It is quite clear that under this condition of $(21 \pm 3)^{o}$C and of (50 ± 5) %R.H., the creep values are smaller than those observed at higher temperature for series (1) and (2),

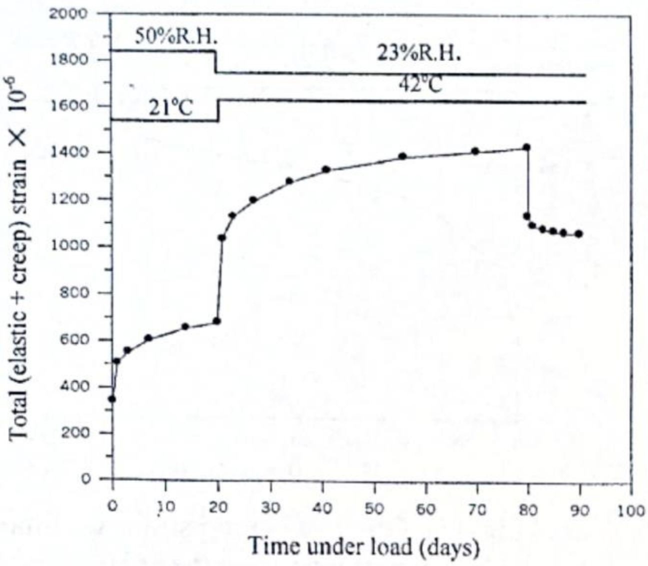

Fig.(6) Observed total (elastic + creep) strain vs. time under load for series (3)

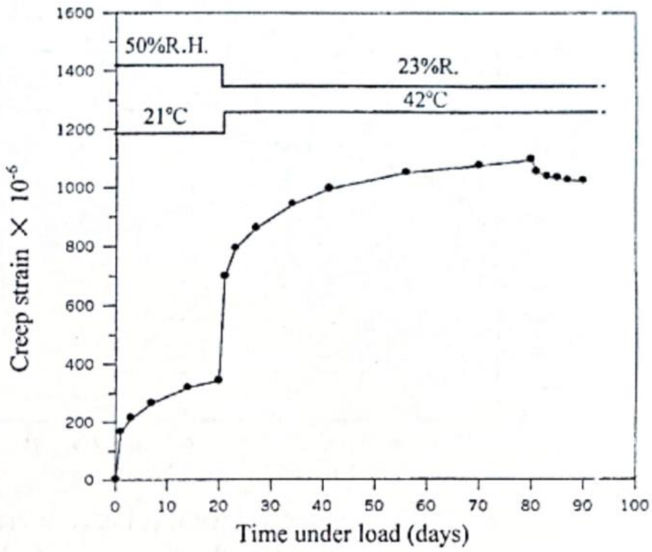

Fig.(7) Observed creep strain vs. time under load for series (3).

as shown in **Fig. (8)**. This behavior is in agreement with previous literature (Nasser and Marzouk 1981), (Neville and Diliger 1970), which indicates that the temperature rise increases the rate of creep process resulting in higher creep values. After 20 days the temperature was raised to (42±1)°C with R.H. of (23±3)%, in order to represent the subsequent effect of summer season. There was a sudden high increase in the creep value due to the transitional thermal creep, which occurs, immediately in a loaded specimen after a temperature rise. It can be seen that the rate of creep is still very high approaching the limiting value of series (1). This behavior complies with the approach of Illston and Sanders (1973). Their results have shown that the transitional thermal creep is of the same magnitude, regardless of the age at the time of occurrence. But, its rate of development decreases as the age (i.e. maturity) at which the temperature rise takes place is increased. The creep value at 80 days of load duration was about (3.22) times the elastic strain.

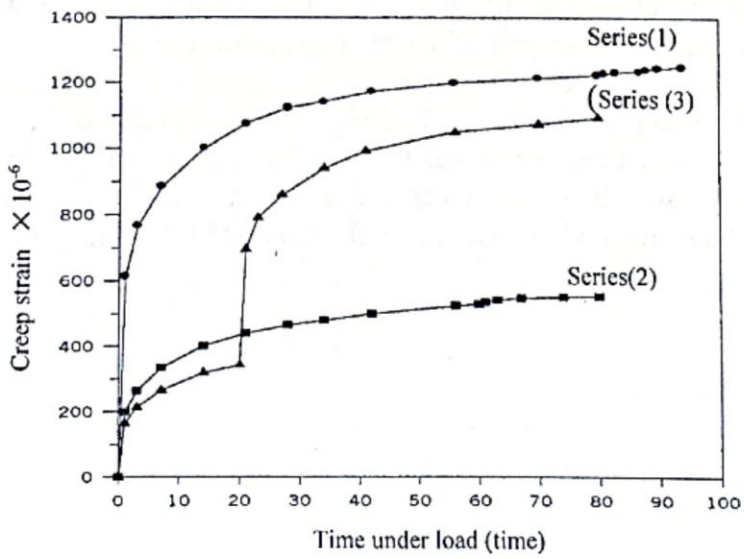

Fig.(8) Comparison of the observed creep strain vs. time under load relationship for series (1), (2) and (3).

The Analytical Results

The analytical results were obtained by applying the present modified method which is based on BP-KX model with the assistance of computer programs that were built up for this purpose. They include the following information: -

The Analytical Results According to the Data of Experimental Work

The creep functions (the total (elastic + creep) strain per 1 psi) were computer-formulated by applying the conditions and variables of the experimental work for the three series. The computed creep functions, according to these effects, will be presented with a comparison with the observed values of the experimental work.

Fig. (9) shows the computed and experimental results of creep functions for series (1). The wide gap between them is quite evident and the ratio of experimental to the predicted creep function values is between (1.039- 2.047). This divergence can be related to the fact that the BP-KX model considers

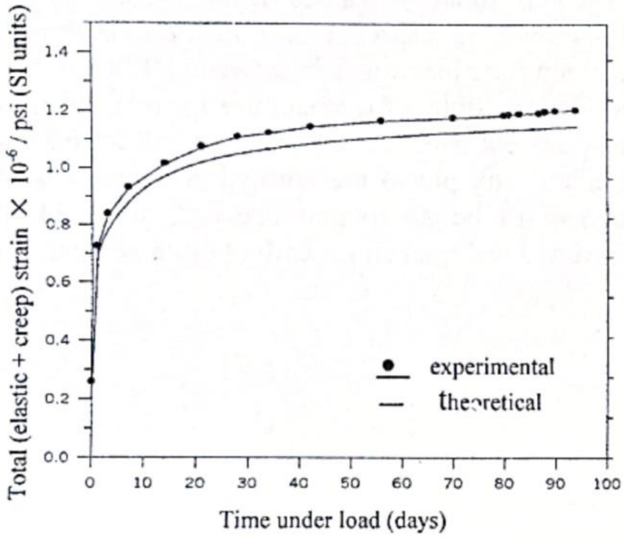

Fig.(10) Comparison between observed and calculated creep function vs. time under load for series (1), after adding the correction factor.

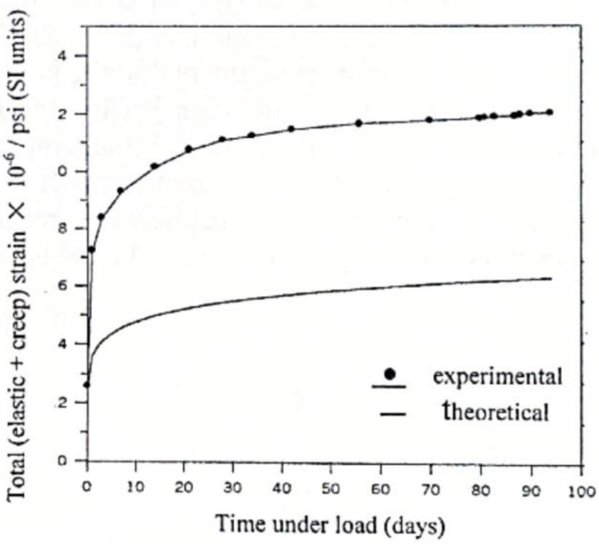

Fig.(9) Comparison between observed and calculated creep function vs. time under load for series (1), before adding the correction factor.

a constant temperature before and through out the loading period. Hence, the contribution of the transitional thermal creep is not taken into account in the BP-KX model. As shown earlier, the transitional thermal creep component is of a high value, which adds to the observed creep values computed when the temperature is constant. So, a correction factor was furnished to be added to the parameters of the creep function equation for the present modified model of the BP-KX model. This factor should be included only when the temperature is being raised (after the load application) to a particular level for the first time.

The transitional thermal creep component occurs in a loaded specimen during and immediately after a temperature rise to a level not previously attained. Furthermore, it is treated as an independent component, which is simply added to the creep value at a constant temperature. It follows that the transitional thermal creep can be expressed as a function solely of the change of temperature (Illston and Sanders 1974). Hence, a correction factor was presented, which depends on the difference between temperature prevailing before the time of load application and the subsequent elevated temperature.

A factor (F) given in the following formula was found relatively satisfactory:

$$F = (1.51(T_a - T_b) + 0.952(T_a - T_b)(1 - \exp(-0.11 \times t))) \times 10^{-8} \quad (1)$$

T_b = prevailing temperature before the time of loading (in Kelvin).
T_a = raised temperature to a previously unattained level (in Kelvin).
t = time after raising the temperature (days).

Fig. (10) shows the observed and computed creep function values after including the correction factor into the analytical calculations. It can be seen that the difference between the two curves becomes more acceptable as the ratio of experimental to the predicted creep function values is improved to become between (1.033-1.069). Also, the coefficient of correlation is increased from(R=0.970) to (R=0.999).

Fig. (11) verifies the convergence of predicted creep function values from those observed experimentally for series (2). The predicted results show a fair agreement with the experimental results as the ratio of experimental to the predicted creep function values is between (1.003-1.165) and the coefficient of correlation is (R=0.996). As the conditions of temperature for this series are identical to those of BP-KX model (the temperature was kept constant before, upon and for 60 days after load application and no transitional thermal creep took place) the correction factor was not included in the predicted results. The results appear to be acceptable because, some of the parameters necessary to be evaluated for this model were developed empirically. For an accurate

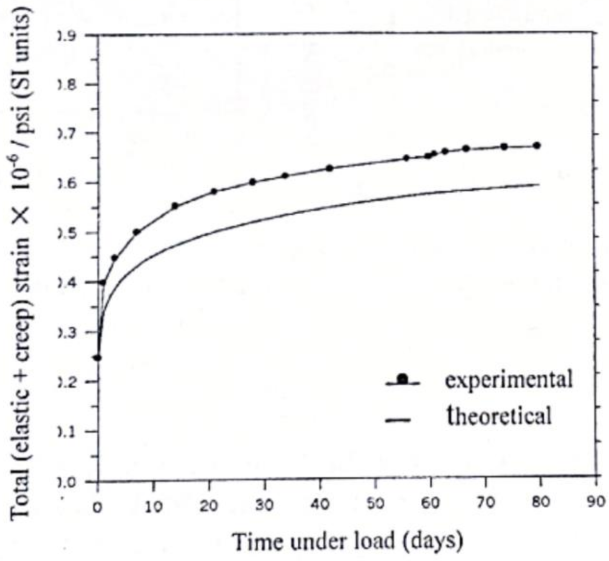

Fig. (11) Comparison between observed and calculated creep function vs. time under load for series (2), without correction factor.

evaluation, it is believed that the local material characteristics should be taken into account.
Fig. (12) shows the calculated and experimental creep function values of series (3). There seems to be a similar trend to that noticed for series (1). The temperature was raised from (21°C) to (42°C) 20 days after the load application. It can be seen that a wide gap exists between the observed and the calculated values and the ratio of experimental to the predicted creep function results is between (1.052-1.781). The transitional thermal creep(which is found to be identical for the same temperature rise regardless the time of its application) stands explains this gap. Since the magnitude of the transitional thermal creep component for a particular temperature increment is unaffected by the maturity of concrete when the temperature is increased of (Illston and Sanders 1973) and regardless the difference in the development of the transitional thermal creep between

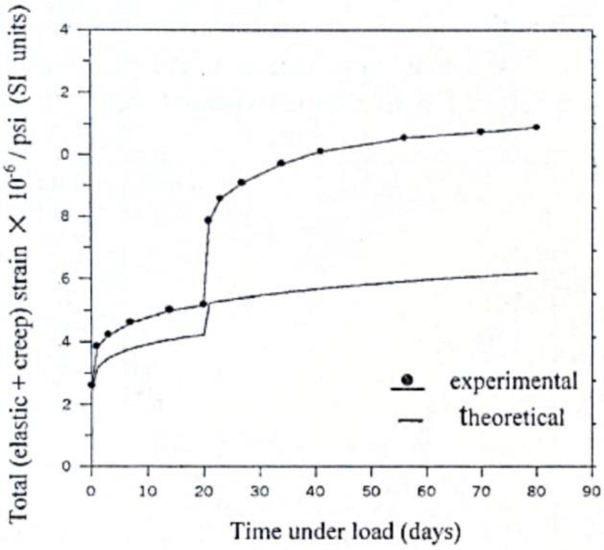

Fig.(12) Comparison between observed and calculated creep function vs. time under load for series (3), before adding the correction factor.

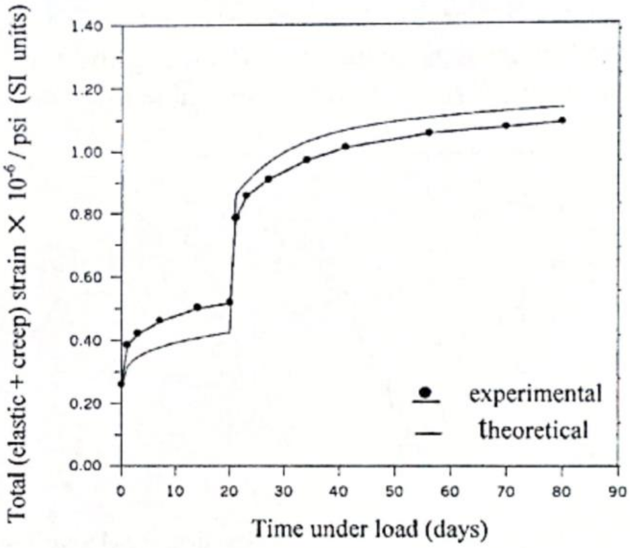

Fig. (13) Comparison between observed and calculated creep function vs. time under load for series (3), after adding the correction factor.

series (1) and (3), the same correction factor of eq. (1) was applied here. **Fig. (13)** shows the analytical and experimental creep function values after including the correction factor into the analytical calculations. It can be seen that the difference between the two curves tend to be more acceptable as the ratio of experimental to the predicted creep function values is improved to be between (0.913-1.227) and the coefficient of correlation is increased from (R=0.985) to (R=0.994).

Analytical Results Throughout One Year According to Baghdad Conditions

The functions of temperature and relative humidity with time throughout one year, which were obtained with the assistance of SPSS program as explained in earlier, are as follows: -

$$T = 29.815 - 15.291 \times \cos(0.893\ t) \quad (2)$$

$$R.H. = 48.512 + 23.057 \times \cos(0.939\ t) \quad (3)$$

T = ambiant temperature (°C)
R.H. = relative humidity (%)
t = time (days).

The coefficient of determination of the first equation is ($R^2 = 0.979$) and of the second equation is ($R^2 = 0.934$). The two curves of temperature and relative humidity with time are shown in **Fig. (14)** and **Fig. (15)** respectively.

The current present modified method which is based on the BP-KX model and included the correction factor of eq. (1) has been used to evaluate the effect of Baghdad climatic conditions on the creep development. The creep function values throughout one year were computed with the aid of eqs. (2) and (3) to substitute the appropriate values of temperature and relative humidity in the equations of the modified BP-KX model. **Fig. (16)** shows the trend for these calculations for the months of January and July. The same variables of the experimental work such as mix proportion, curing time and time of load application, were adopted in the calculations.. A comparison between these two curves shows clearly that the greatest creep function values are expected to occur when the concrete is to be loaded during the winter season. If the load application takes place in the summer season, a much lower value of creep shall be expected. The available explanation for this

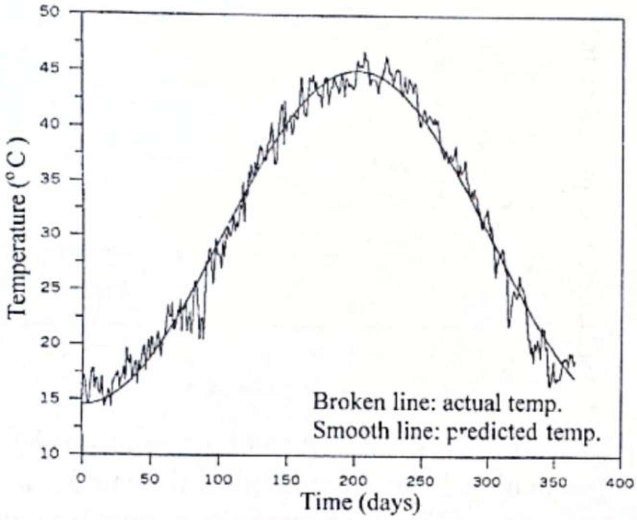

Fig. (14) Actual and predicted temperature vs. time throughout a year, starting on the first of January.

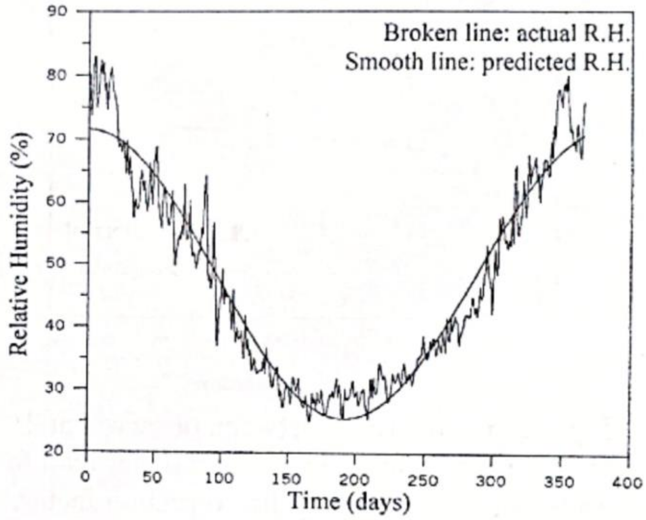

Fig. (15) Actual and predicted relative humidity vs. time throughout a year, starting on the first of January.

predicted behavior (assisted by the observed experimental results) is that if concrete is loaded at low temperature level then subjected to a higher temperature level, the transitional thermal creep takes place. But when the situation is reversed, i.e. for concrete loaded at higher temperature followed by a cold season, the thermal disturbance takes place before load application, the effect of transitional thermal creep has no existence in this case leading to lower expected (and observed) creep values.

CONCLUSIONS

1- 1 Based on the observed values, the BP-KX model proposed by Bazant for predicting the creep value was found to be not applicable for the case of variable temperature. The proposed modified model with its correction factor takes in to account any temperature raise to previously unattained level gave good correlation between observed and corrected creep.

2- 2 Depending on the readings of Iraqi Meteorological Organization and Seismology, two equations of temperature and relative humidity were developed. The values of these equations were substituted into the modified BP-KX model formulas. It was found that loading a concrete specimen in winter would result in higher creep values compared with the case of summer loading. It is thought that the thermal disturbance taking place before load application plays a role in this respect.

REFERENCES

ACI Committee 209R-921, (1992), Prediction of Creep, Shrinkage and Temperature Effects in Concrete Structures, Detroit.

Bazant, Z.P. and Panula L., (1978, 1979), Practical Prediction of Time-Dependent Deformations of Concrete, Materials and Structures, RILEM, Part (1)- Shrinkage and Part (2)-Basic Creep: Vol.11, No.65, pp. 307-328; Part (3)-Drying Creep and Part (4)-Temperature Effect on Basic Creep: Vol. 11, No.66, pp. 415-434; Part (5)-Temperature Effect on Drying Creep: Vol.12, No.69, pp. 169-182.

Bazant, Z.P. and Wittmann, F.M., (1982), Creep and Shrinkage in Concrete Structures, A Wiley-Interscience Publication.

Bazant, Z.P., Kim, J.-K. and Panula L., (1991, 1992), Improved Prediction Model for Time Dependent Deformations of Concrete, Materials and Structures , RILEM, Part (1)-Shrinkage: Vol. 24, No. 143, 1991, pp. 327-345; Part (2)-Basic Creep: Vol. 24, No. 144, 1991, pp. 409-421; Part (3)-Creep at Drying: Vol. 25, No. 145, pp. 21-28; Part (4)-Temperature Effects: Vol.25, No. 146, pp. 84-94.

Bazant, Z.P., and Baweja, S., (1998), Creep and Shrinkage Prediction Model for Analysis and Design of Concrete Structures: Model B3, Structural Engineering Report 96-3/ITIc, Northwestern University.

CEB-FIP, (1978), Model Code for Concrete Structures, Comité Euro-International du Béton, Paris.

Illston, J.M. and Sanders, P.D., (1973), The Effect of Temperature Change Upon the Creep of Mortar under Torsional Loading, Magazine of Concrete Research, Vol. 25, No. 84, pp. 136-143.

Illston, J.M. and Sanders, P.D., (1974), Characteristics and Prediction of Creep of a Saturated Mortar under Variable Temperature, Magazine of Concrete Research, Vol. 26, No. 88, pp. 169-179.

Nasser, K.W. and Marzouk, H.M., (1981), Creep of Concrete at Temperature from 70 to 450°C, Under Ambient Pressure, ACI Journal, Vol. 78, pp. 147-150.

Neville, A.M. and Diliger, W., (1970) Creep of Concrete Plain, Reinforced and Prestressed, North-Holland, Publishing Company-Amsterdam,