THE PREDICTION OF TIME-DEPENDENT DEFORMATION OF NORMAL STRENGTH CONCRETE IN TROPICAL CLIMATE

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ABSTRACT

Realistic prediction of concrete creep and shrinkage is crucial for durability and long-term serviceability of concrete structure and also stability and safety against collapse. Creep and shrinkage may increase the deflection and curvature and may cause cracking and loss of pre-stressing force in prestressed concrete. Creep and shrinkage are known to be influenced by many factors such as the type of cement, water-cement ratio, curing condition, relative humidity, temperature, age and size of the member. Until recently, data is scarcely available on the time-dependent deformations of concrete in the tropical climate compared to those in the temperate climate where more substantial studies have been performed. The current practice of evaluating time-dependent and elastic deformations in concrete structures in Malaysia is to refer to British Standard (BS 8110) or other international standards. In the near future, reference will be made to Eurocode 2 (EC 2) that is foreseen to supersede BS 8110. Therefore, this research is carried out to improve the creep and shrinkage prediction model of Malaysian concrete. The strengths of concrete investigated are in the range of 20 to 40 N/mm^2. The testing for creep and shrinkage were carried out according to standard method provided in ASTM C512-87 and ASTM C157-91. From the comparison of experimental data collected to the existing models of EC 2, American Standard (ACI 209), CEB-FIP 1990 and Australian Standard (AS 3600), EC 2 best predicts the results followed by AS3600. With the aim of getting an accurate prediction of creep and shrinkage for concrete in tropical climate, the EC 2 models were selected and modified. The modification factors in the range of 0.85 – 1.69 for creep and 0.65 - 0.79 for shrinkage, depending on the concrete strength, are introduced based on the experimental results. These factors are proposed to be applied to EC 2 model in order to give better prediction of time-dependent deformation of normal strength concrete in tropical climate.

ABSTRAK

Jangkaan nilai rayapan dan pengecutan konkrit yang sebenar adalah amat penting untuk menghasilkan konkrit yang tahan lasak, kebolehkhidmatan jangka panjang, stabil dan selamat daripada runtuh. Rayapan dan pengecutan konkrit mengakibatkan pertambahan kadar pesongan dan lengkokan, keretakan dan kehilangan daya prategasan dalam anggota konkrit prategasan. Rayapan dan pengecutan dipengaruhi oleh pelbagai faktor antaranya jenis simen, kadar air-simen, kaedah rawatan, kandungan lembapan dan suhu persekitaran, usia konkrit dan saiz anggota. Sehingga sekarang, masih tiada lagi data ubahbentuk di kawasan beriklim tropika jika dibandingkan dengan kawasan beriklim sederhana di mana lebih banyak ujikaji dijalankan. Kebelakangan ini, amalan praktis yang dirujuk dan diguna dalam menilai ubahbentuk bersandar masa konkrit di Malaysia adalah merujuk kepada Piawaian British (BS 8110) dan rujukan piawai antarabangsa lain. Namun begitu, Eurocode 2 (EC 2) bakal menggantikan penggunaan BS 8110 dalam tempoh terdekat ini. Oleh sebab itu, penyelidikan ini dijalankan untuk menambahbaik model pemgukuran rayapan dan pengecutan konkrit di Malaysia. Kekuatan konkrit yang diuji adalah di antara 20 ke 40 N/mm^2. Ujikaji rayapan dan pengecutan dijalankan berdasarkan kepada rujukan piawai ASTM C512-87 dan ASTM C157-91. Daripada perbandingan data ujikaji yang diperolehi dengan model sedia ada seperti EC 2, ACI 209, CEB-FIP 1990 dan Piawaian Australia (AS3600), EC 2 membuat anggaran yang paling baik diikuti dengan AS3600. Dalam mendapatkan anggaran yang tepat untuk rayapan dan pengecutan konkrit di bawah pengaruh cuaca tropika, model EC 2 telah dipilih dan diubahsuai. Faktor ubahsuai di antara 0.85 – 1.69 untuk rayapan dan 0.65 – 0.79 untuk pengecutan, bergantung kepada kekuatan konkrit adalah diperkenalkan berdasarkan keputusan ujikaji. Faktor-faktor ini dicadangkan untuk diaplikasikan ke dalam model EC 2 untuk menghasilkan anggaran yang lebih tepat bagi nilai rayapan dan pengecutan konkrit berkekuatan biasa di kawasan beriklim tropika.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

One of the most uncertain and most difficult aspects of the design of reinforced and pre-stressed concrete structures is the prediction of time-dependent deformation behaviour. Realistic prediction of concrete creep and shrinkage is of crucial importance for durability and long-term serviceability of concrete structure and also for long-term stability and safety against collapse (Vandewalle, 2000). Creep and shrinkage can cause the increase in deflection and curvature, cracking, losses of pre-stress force in prestress concrete member and redistribution of stresses (Gilbert, 1988).

For the design of creep and shrinkage sensitive structures, such as long span prestressed concrete bridges, cooling towers and very tall buildings, it is very important to use a realistic creep and shrinkage model to analyse their time-dependent deformation behaviour. Creep and shrinkage are known to be influenced by many factors such as the type of cement, water-cement ratio, curing condition, relative humidity of the environment, temperature, age and size of the member (Vandewalle, 2000).

Creep is defined as a time-dependent deformation of materials under sustained loading. Total creep strain composes of two components, which are basic creep and drying creep (Neville, 1970). Shrinkage is strain associated with loss of moisture from concrete by evaporation or hydration of cement and also by carbonation, independent to loading. Basically shrinkage is divided into drying, autogeneus, plastic and carbonation shrinkage (Neville, 1990).

In most cases, time-dependent deformation values need not be taken into account at the ultimate limit state. However, the deformation due to temperature, creep and shrinkage shall be checked in the design during the serviceability limit state. This is important to ensure the safety at the serviceability limit state such as durability and performance of the structure. In order to show an example of the seriousness of those deformations in the design of concrete structures, two cases are considered below.

In the high rise buildings, vertical members are subjected to a large axial shortening due to elastic, creep and shrinkage deformations. It is estimated that the maximum vertical shortening of exterior column of a 70-storey concrete building is approximately 91.44mm (3.6 in), and maximum differential shortening between exterior columns with interior wall is approximately 25.4mm (1 in) (Park, 2003). Thus, to avoid unexpected damage, the elastic and inelastic shortening of vertical members should be accurately predicted and properly compensated for.

Creep and shrinkage are of primary importance in the design of prestressed concrete members as the shortening of concrete reduces the compressive stress induced by the prestressing force. Such reduction may affect the formation of cracks in members (Neville, 1970). The losses may reach up to about 45% for concrete prestressed at 60% of its compressive strength and cured in relative humidity of 50% (Petersen et al., 1968). It is therefore essential to be able to predict the magnitude of creep and shrinkage deformation and its effects on prestressing force to an acceptable accuracy.

Another significant influence of creep and shrinkage in reinforced and prestressed concrete design is the deflection of the structural members. The magnitude of deflection changes with time due to the effect of creep and shrinkage and also the way the elastic modulus of concrete is predicted. Deflection may affect the serviceability and also the aesthetic value of the structures. Inaccurate prediction of deflection such as excessive pre-camber in prestressed concrete beam may incur additional costs to the construction.

1.2 Problem Statement

The design practice for creep and shrinkage until today in Malaysia is based on the values recommended by standard codes, such as BS 8110. The accuracy of values in the BS 8110, derived from United Kingdom environment and climate to be applied for Malaysian concrete is questionable because the difference in temperature and relative humidity of the environment. In BS 8110, the values given are based on tests carried out in temperature of 23^{o}C and RH of 50% as refer to Clause 7.2.1 in BS 6319: Part II: 1993. Based on data provided by the Malaysian Meteorological Department, the mean monthly relative humidity of Malaysian environment is between 70% to 90% and the average maximum daily temperature in major cities is 31 ^{o}C - 33 ^{o}C whereas average daily minimum is at 22 ^{o}C – 23.5 ^{o}C. The degree of the difference and how critical the problem of our practice in referring to foreign codes is never significantly verified. Therefore, it is important to investigate the accuracy of creep and shrinkage prediction based on BS 8110 to local concrete.

1.3 The Objectives of the Study

The current practice of evaluating time-dependent and elastic deformations in concrete structures in Malaysia is to refer to BS 8110 or other foreign standards. In the near future, reference will have to be made to Eurocode 2 that is foreseen to replace BS 8110. National Annex of Eurocode 2 allows Nationally Determined Parameters (NDPs), which is left open for national choice if there are variations in climatic, geographical and geological condition. Therefore, this study is carried out to achieve the following objectives:

i) To obtain reliable creep, shrinkage and modulus of elasticity data for tropical normal strength concrete,

ii) To compare with the values recommended in BS 8110 and Eurocode 2 for tropical concrete,

iii) To propose modification factors for creep and shrinkage prediction of normal strength concrete (NSC) which is intended to be used as Malaysian Annex for Eurocode 2.

1.4 The Scope of The Study

The research was part of a study on creep, shrinkage and elastic modulus data of Malaysian concrete carried out in the Faculty of Civil Engineering, Universiti Teknologi Malaysia. The research covers the behaviour of time-dependent deformation in normal strength concrete with concrete strength between 20 N/mm^2 to 40 N/mm^2. The testing was performed according to the ASTM C512-87, ASTM C157-91 and ASTM C469-87a, the standard testing of creep, shrinkage and modulus of elasticity, respectively.

The testing was carried out in a controlled environment with temperature set at 27 ± 2^oC and RH of 50 ± 4 %. The International Organization for Standardization, ISO specify the temperature in tropical country climate is at 27^oC. The RH was set at 50% in order to compare with codes prediction which was given at RH 50%. It was also applied to provide a safe margin because it will result in a more severe creep and shrinkage value. Test was also carried out in the natural environment condition to better simulate Malaysian concrete behaviour. The measurement of creep and shrinkage strain was taken for six months.

1.5 Significance of Research

The demand for the standard reference of creep and shrinkage data and time-dependent deformation prediction model calculation for Malaysian concrete is on the rise considering the advance in the construction of massive concrete structures such as high-rise building and long span bridges. A dedicated time-dependent deformation testing was carried out during the construction of the Petronas Twin Tower as the calculation models of time-dependent deformation of local concrete was not available. It is neither practical nor economical for engineers to carry out testing for each project because a standard model is not available for Malaysian concrete. Thus this research in developing local experimental data for normal strength concrete is the first step in developing a standard creep and shrinkage calculation model for Malaysian concrete.

The experimental data can be a standard reference for the development of time-dependent deformation design model for tropical countries. Ultimately, with the data obtained through this research and the work in the future, the local practitioners will be able to predict the magnitude of deformation in concrete structures. This will also lead to better prediction of the losses of prestressing force, cambering, deflection of structural members and better prediction of deflection in the construction of box-girder cantilever bridge.

1.6 Presentation of Thesis

A literature review giving the background of creep and shrinkage of concrete is presented in Chapter 2. Chapter 3 describes the experimental work. Results and the analysis of results are presented in Chapter 4. Chapter 5 contains the discussion of results and comparison with the codes prediction. The proposed model for predicting the value of creep and shrinkage of concrete is presented in Chapter 6. Chapter 7 contains the conclusion and recommendation of future works.

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