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Models Developed for Creep of High Strength Concrete

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***Abstract*— *The aim of this research is to study the effects of creep in High Strength Concrete HSC. Creep known as a deformation of the structure under a sustained load and is one of the major deformations that concrete face. Moreover, the study explains how creep is predicted in HSC using various methods established by different codes and researchers. The research method consists of an extensive review of all relevant literature on creep and high strength concrete. The main issue is a comparison of observed creep distortions with seven present prediction prototypes to define which of the models most precisely predict creep while using two methods of curing, accelerated curing and standard curing. The findings from the research displays that "ACI 209 Modified" code is the most precise model of predicting creep in accelerated cure applications and the AASHTO-LRFD is considered the best model for the prediction of creep. The main conclusion to be drawn from this study is that the accelerated curing technique for high strength concrete causes a higher change in time-dependent strains than standard curing. The research method consists of an extensive review of all relevant literature on creep and high strength concrete.*

Keywords*— *Creep, HSC, Concrete Creep, Models Development of HSC Creep.

I. INTRODUCTION

The utilizing of High Strength Concrete (HSC) is increased over the years. Now it is a very current construction material and greatly affects the project performance as in [1], which latterly leads in providing the innovative systems in the managing of construction projects [2] or using technologies as in [3][4]. HSC presents economic benefits more than Normal Strength Concrete (NSC) due to it is competency to reduce the cross sections for structural members resulting in reducing the substantial and the cost of transforming. When structural members become more slender, deflection will occur more easily.

As a result, deterring creep deformations for long-term very important in HSC buildings. Creep is considered as a distortion over time of viscous materials, also it considered an excess in preliminary elastic strain resulted when a sealed stress is loaded. The main aim of this report is to investigate the creep deflection of a HSC mixture as well as a comparison of the experimental creep deformations with seven different models for prediction of creep in order to measure which model is the most precise to predict the creep by using two different curing methods, accelerated curing and standard curing method.

II. GOAL

. The goal of this project is mainly focussed on surveying the creep of HSC.

III. OBJECTIVES

The objectives of the project are to:

1- Determine the most significant factors influence creep and the effect of high strength concrete on creep.

2- Determine which model is the most accurate model in the prediction of creep.

IV. HISTORY OF DEVELOPMENT OF HIGH STRENGTH CONCRETE

Over the last several decades, enhancement of characteristics of materials and progress of new materials based on cement binder have made excellent strides. Everything can be reached, altogether if the productivity technology and elaboration of the concrete microstructure are tightly connected. These days, it is expected from contemporary and advanced types of concrete to have prominent durability properties, to be amicable with the surrounding environment, cost-efficient is already prepared for usage in construction.

HSC is extensively accessible all over the world. Its usage is increasing going ahead, especially in the Far and the Middle East. There is some structural contribution of high-strength concrete in elements of wall and columns, which were used in constructed tallest buildings in the last decade. The evolution of concrete has been advanced over many years despite the fact that HSC is considered a concerned new material. As the progress has sustained, the description of HSC has altered. In the early 1950s, a high strength concrete had the compressive strength of 5000 psi or 34 Mpa. For commercial aims was used a concrete with 6000-7500psi or 41-52 Mpa in the 1960s.

A concrete with higher compressive strength with 9000psi or 62Mpa was produced in the early 1970s. A few decades ago, cast-in-place constructions have used a concrete with a compressive strength which was approaching 20000psi or 138 Mpa. The usage and application of HSC have grown up in last several years and it's been used every day throughout the world. The elaboration and design in material technology and requirement for HSC are the results of growth. Without the presence of HSC would not have a structure such as the bridge across the Ohio River for a long time (Rashid & Mansur, 2005). In the United States of America in the 1970s the inquiry for usage of high-strength concrete began, for Water Tower Place in Chicago, IL.

There was used a concrete with compressive strength 9000psi or 62 Mpa in shear walls and columns. In 1990 was completed The 311 South Wacker building in Chicago, with a compressive strength of 12000psi or 83 Mpa which was used for columns. Both of those buildings held the record for the tallest buildings in the world in that time. The highest compressive strength concrete used in Two Union Square in Seattle, in 1989, and had 19000psi or 131 Mpa [5]. Year by year, the world is increased demand for the construction of new buildings and the renovation of old and worn-out structures in the past several years have resulted in the development and use of new types of concrete - high performance concretes HPC. High-performance concrete is cement based on cement binder with higher strength and has at least one improved characteristic than normal.

By enhancing and correlating its microstructure, high characteristics and properties can be reached. The invention of high strength concrete in the 20th century has led to the development of high-performance concrete technology. High strength concrete conforms to classes of concrete compressive strength from C55/67 to C100/115. It can be called High-Performance Concrete (HPC) if HSC would have different properties or characteristics besides compressive strength. Ultra-High Strength Concretes UHSC are concreted, with a higher class of compressive strength C100/115. By retrofitting most of the available rules for scheming concrete configuration and choosing materials in HSC, the development of UHSC was began in the 20th century.

In UHSC the tensile strength, durability, and stiffness have also been improved. Besides this, they can also be called ultra-high performance concretes [6]. Advantages of high strength concrete in the rapid development is happening in our modern days, HSC is becoming very far-famed in the construction world. That is due to be having a compressive strength of at minimum 41 Mpa or 6000 psi after 28 days. To be able to achieve that, low water/cement ratio and water-reducing admixtures should be used to offer better workability. HSC offers many benefits over the normal strength concrete. Economically it allows more light members to be planned which result in low actual usage and fewer transport costs.

Moreover, it results in reducing the column size thus increasing the floor space plus due to its higher compressive strength per element amount will also help in reducing the total dead load on the structure foundation. It is also effective in buildings and constructions such as plates, shells, plates, domes, and arches where big in-plane compressive strength occur. High strength concrete typically has a higher modulus of elasticity which increases the stability of the construction and reduces deflections. This means that in most cases, high strength concrete is able to resist loads that can't be resisted with normal strength concrete. In order to achieve the perfect HSC mixture, several factors should be taken into consideration: Higher quality control is needed to obtain the special properties desired, high-quality materials to be used, and finally a special curing treatment for the low water/cement ratio mix

4.1 APPLICATION OF HIGH STRENGTH CONCRETE

The main objectives of construction automation are to improve productivity, quality, and safety and reduce labor requirement on the construction site.

High-strength concrete is required in engineering projects that have concrete components and must resist high compressive loads. HSC is typically used in the erection of high-rise structures. It has been used in components such as columns (especially on lower floors where the loads will be greatest), shear walls, and foundations. High strengths are also occasionally used in bridge applications as well.

In multi-story constructions, HSC has been effectively used in many U.S. cities. A high-rise structure suitable for HSC use is measured to be a structure over 30 stories. Not only has special concrete made such developments viable due to load size, it has also permitted for the deduction of the column and beam size and shape. Lower dead loads result, reducing the loads associated with foundation design. Also, holders benefit financially since the amount of rentable floor place, primarily on the lower floors, increases as the space occupied by the columns decreases.

HSC is occasionally used in the construction of highway bridges. High-strength concrete permits reinforced or pre-stressed concrete girders to span greater lengths than normal strength concrete girders. Also, the greater individual girder capacities may enable a decrease in the number of girders required. Thus, an economical advantage is created for concrete producers, so concrete is promoted for use in a particular bridge project as opposed to steel.

There are a lot of applications for HSC: foundries, dam spillways, parking garages, warehouses, bridge deck

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overlays and heavy duty industrial floors. HSC with these applications is being used to ensure the resistance of concrete to chemical attack, improve durability of freeze-thaw, resist to abrasion and reduce permeability.

V. INTRODUCTION TO CREEP

Creep is definite as a strain in depending on time in the hardened concrete under constant stress [7]. When a material such as plastic is exposed to loading (constant load) results with creep, so creep is mutilated continuously. Furthermore, the strain which is initial was consistently foreseen by its modulus of stress and strain. As a result, the substantial will stay to consist gradually with taking the time to consideration indeterminately or till the time. Afterward, it elongates a stable level which named the secondary creep level is rapidly increase and breakage. This phenomenon of buckle under load and time is called creep. Unquestionably, this is an idealized curve. However, some substantial do not have the second stage, the third creep only ensues at great stress levels specialized for the materials are flexible. Moreover, all creep which has plastic behavior should increase to a conceived level. The progression depends on many factors, like plastic types, the amount of temperature, time with a load. Creep is memorable from low-temperature warp by its time dependence [8]. The standard test method for creep characterization is ASTM D2990. Additionally, Creep is considered into drying and basic creep. The basic type follows underneath circumstances devoid of dampness movement among the specimen and the environment.

The final stage of the creeping development is creeping rupture tests. Due to modifications of the creep testing apparatus, lots of beneficial tests can be progressive such as the constant stress with the constant strain rate test. From test's result of creep, another note of creep response has been seen; it is the stress relaxation over time [9]. In such condition, if a creeping material is strained to itemized level, the strain was well-kept-up fixed at that level, then the stress grew some decays from its initial value. Furthermore, cyclic loading is repeatedly connected with significant tiredness processes which ultimately may cause the failure of the loaded module. So at high temperatures, creep existences appear and they contain a significant effect on the fatigue process. The results under a load of creep modification and relaxation stages touch the fatigue answer of the material depending on their imitation duration according to the obvious form of the cycling shape examining this final stage of the creep process called creep rupture tests. Some suitable changes of the creep testing equipment, other useful tests can be advanced such as the constant stress tests and the constant strain rate test [10].

Through the results of creep tests, some additional show of creep response has been seen; namely, the relaxation of stress over time. In the cause when the creeping material is strained to a specified level and also if the strain is preserved fixed at that level, the stress gotten decays from its opening value. At the end, Cyclic loading is often linked with material weariness processes which ultimately can cause the failure of the loaded component. At high temperatures, creep phenomena seem and they have a significant influence on the tiredness process. Beneath cyclic loading, the deformation resulting of creep with relaxation points disturb the fatigue response of the material based on their qualified period and according to the specific form of the cycling shape [11].

The loading the instantaneous strain under normal condition documented by basing on the speed of application of the load and including both the elastic strain with creep. Usually, it is not that much easy to distinguish in details between early creep the immediate elastic strain, but it is not very significant as the total strain tempted by the presentation of the load. When drying of specimen occurs during loading, we presumed that shrinkage and creep are additive; then creep intended as the change between the shrinkage and the whole time-deformation of the loading specimen of a same unloaded specimen kept under similar conditions for the same time [12].

5.1 FACTORS INFLUENCING CREEP IN HSC

Especially after the removing of stress, many loads and sustained load do not concert indeterminately. As a result, concrete undergoes by instantaneous recovery. The instantaneous recovery is considered as a time-dependent recovery mentioned as creep recovery. Usually is appropriate to symbolize the creep recovery by r as well as reducing subscripts of creep (Creep and structural concrete book). At the time which the non-stop load removed, the strain decrease also by a quantity same as the elasticity strain at the same time, less than the elastic strain in applying the load. Creep recovery is the immediate recovery monitored through a regular deduct in strain. The creep recovery curve shape is same as the creep curve, with a maximum rescue [11].

Creep recovery is of significant to predict distortion of concrete under various stress with time. Creep recovery is proportional to the stress previously applied. Small growing in mass was perceived during the period of creep or creep recovery resulted by carbonation. We can recognize that some recovery in the creep is characterized through the variance between the strain and the strain which is actual would contemporary the same period, and the sample still in exposing to the unique compressive stress. Both creep and recovery creep of PAC were

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resolute by experiment and compared with normal weight concrete in 2004 by (W.C. Tang H.Z. Cui M. Wu). The results displayed that creep of polystyrene aggregate concrete enlarged with the intensification of PA content in the mix. The ratios of creep recovery to creep strains diminished slightly with an increase in PA content [12]

In the research of [13], the curing and storage showed notable impacts on the creep of PAC, but not creep recovery itself. The compressive basic creep recovery and creep of concrete built on ternary blends plus Portland cement, fly ash and blast furnace slag are experimentally studied by [14].

The creep recovery is smaller than the preceding creep. Creep appears to be only a partly recoverable phenomenon. This statement does not, however, make it clear whether the mechanism of creep and creep recovery are different from one another or whether the creep recovery is simply a negative creep but the properties of concrete relevant to creep have changed while the concrete was under the sustained load. Many theories postulating a reversible or a party reversible mechanism of creep axis on the relative between creep and the subsequent creep recovery. For the usual type of recovery test, the strain or a removal load or instantaneous recovery is that which corresponds to the secant modulus of the unloading curve at the time of the removal of the load. Apart from the obvious, but often difficult to achieve a solution of very fast loading, the elastic strain can be resolute by extrapolating back to zero time from a series of short-term creep curves at each increment of stress. But even this method includes some non-elastic deformation in the derived elastic strain. The elastic strain calculated from the dynamic modulus of elasticity has probably a correct value from the theoretical standpoint but is not always convenient to use [15].

5.2 Effects of Aggregate on Creep of HSC

Aggregate are one of the most important components of a concrete mixture and create up approximately 65% - 80% of the mix. The aggregate may be of all kinds but are classified into two core types; the rough aggregate and fine aggregate sand. Total may be prepared of core types of rock resources, such as basalt, granite, limestone or straight sandstone. Though the dissimilar types of rock have diverse chattels they basically carry out the major function of the aggregates, i.e. to fill the void between the cement matrixes to make concrete.

Generally, the mixes of high strength concrete contain a lower amount of aggregate in comparison with normal concrete. In normal concrete, the creep affected to the tough cement paste due to the total is more rigid than cement paste. The major rule of aggregate is to control the creep in cement paste, the influence regarding the elastic modulus of the aggregate and volumetric ratio in mix contain. Since, the rigid total and higher ratio in mix decrease the amount of creep [8].

The porosity of aggregate has a great effect on the amount of creep in concrete for the reason that of its ability to convert the moisture inside concrete. This may be the main reason of higher early creep happening with some light weight aggregate mix in hot dry weather.

The elastic modules of aggregate are the most factors controlling the amount of creep, the higher modulus the greater control aggregate to probable of creep in cement paste [16]. The extraordinary absorbency will typically have a low elastic modulus which will lead to upper relative creep. The aggregate has for that reason a direct influence on the long-term deformations of concrete since a high elastic modulus aggregate will generate more rigid concrete that will have a rather greater strength to distortion [16].

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5.4 Water/Cement Ratio

Creep is roughly proportionate to the square of the water/cement ratio, other aspects being persistent. The change of the water/cement ratio involves variation in the cement paste.

5.5 Age of Application of the Load

By comparing the creep of similar water stored concrete (type 1) which subjected to the same stress. Pujadas in [17] noted that the rate of creep during the first few weeks under load is much greater for concrete loaded at an early stage. Also, it has been found that the subsequent rate of creep after a month under load is independent of the age of the age at application of load.

There is no relation between the increases in strength and the pattern of the process of creep on the concrete because no significant differences have been observed between the strength of unloaded specimens and specimens previously subjected to stress.

5.6 Shape, Size and Isotropy of Specimen

The shape and size of the concrete member are important features of that member and the importance of these aspects deceits in making an evolution between the outcomes of creeps in the laboratory samples to the creep of full-size members. It can be observed that when the size of specimen increases the creep decrease but when the specimen thickness exceeds 0.9m this decreasing becomes negligible.

For the volume of concrete specimen, it has been found that on the whole, the shape factor of the concrete is of very much lesser importance than the size of the concrete. Therefore, it can be neglected in practical use.

5.7 Re-vibration of concrete

The hardening of the concrete is affected by its vibration or re-vibration and how much affect these two has on the creep of concrete. It is reasonable to conclude that drying creep was reduced when re-vibrating the specimen of the concrete maybe it's due to the increases in strength of cement paste due to re-vibration. This increase is largest when shrinkage is largest as re-vibration would reduce the early shrinkage stresses. Mehta in [18] found that the effect of re-vibration of concrete on creep being about 10 percent, and the effect of re-vibration on creep is ascent in well- compacted concrete.

5.8 Influence of humidity on creep

Humidity and temperature have a great influence on the creep effect related to concrete. They also affect the dimensions of it like those of loading and unloading on specimens. Changes in moisture and temperature in concrete are essentially a diffusion process so that any change introduces gradients. These gradients induce stresses which are accompanied by creep age and it follows the moisture and temperature deformations are not really independent of stress but include some creep deformation.

5.9 Stress/Strength Ratio

Creep is relational to the practical stress and contrariwise relational to the strength at the time of application of the load. For the same type of aggregate and constant mix proportions. Before establishing the limitations of this rule it is preferable to study the influence of creep on the level of stress.

Several experimental results concluded that there is a linear relation between creep and the practical stress, except for the samples loaded at the early age of one to three days.

5.10 Drying creep and shrinkage

Drying creep is when the concrete is permitted to dry while under load, creep is increased which means creep is greater than basic creep even after shrinkage has been deducted from the total time-dependent strain. It has been observed that the degree of creep is exaggerated by simultaneous shrinkage as tested on a load-free companion specimen. The must not be inferred essentially to mean that shrinkage in itself effects creep but only the two marvels are partial by a communal process during drying. Moreover, shrinkage and creep are affected by many common aspects in a related way and can rarely be detached. Authors of [19] considers creep to be covariant through shrinkage, which means that creep is not added to shrinkage but pools with it "with a lowest of action".

5.11 Carbonation

Carbonation is by reason of the creation of carbonates in the hardened cement paste caused by a response to carbon dioxide in the troposphere in the existence of moisture. The process of carbonation consequences an increase in drying shrinkage.

5.12 Portal Cement type and composition

Cement is the most vital aspect in the creep of the concrete phenomenon. Physical and chemical features of the cement are what influence the role of cement to creep.
Glass content affects strength development, the structure of the products of hydration and the creep behaviour. However, there are some board influences on creep of the cement compositions as characterized by the type of cement of the ASTM classification. In general, creep

appears to be comparative to the rapidity of hardening of the cement used. Thus, for a given age of loading, creep is in an increasing order of magnitude for concretes made with the following cement: high-alumina, rapid-hardening Portland (Type III), ordinary Portland (Type I), Portland blast furnace, low heat (Type IV) and Portland-pozzolana. The order of the last three is not clearly established since the rest conditions were not directly comparable. Of course, at the same age, the cement have achieved varying proportions of their final strengths, and it seems logical that the more hardened the paste the further rigid it is and the inferior its creep latent at a specified applied stress.

5.13 Admixtures

5.13.1 Plasticizer

Plasticizing or water-reducing admixtures, some of which are also set-retarding, have the capacity to disperse the agglomerations of hydrated cement when cement is mixed with water. The consequent increase in fluidity of the fresh cement paste results in a higher workability or, alternatively, allows a reduction in the water required to obtain a workability equal to that of an admixture-free concrete.

Tests in [12] and [15] were carried out on creep of concrete with water-reducing and set retarding admixtures, using both trivial and normal weight collective concretes. The types of admixture used were based on lignosulphonate acid derivatives (class 1 of ASTM), hydroxylated carboxylic acid derivatives (class 3), and the concretes. The admixture were compared with admixture-free concretes having the same nominal strength and workability

5.13.2 Super plasticizers

Superplasticizer admixtures know in the United States as high-range water reducers, are chemically different from normal plasticizers, and have been introduced to overcome problems associated with the use of high dosage rates of conventional plasticizers. The broad categories of superplasticizers range from sulfonated melamine formaldehyde condensates, sulfated naphthalene formaldehyde condensates and modify lignosulphonates to mixtures of saccharides and acid amides. The additional benefits claimed are increased workability, less set-retardation, and less air entrainment. Superplasticizers are used to produce not only high workability (flowing) concrete but also a water reduced (high-strength) concrete

5.13.3 Air entrainment

The question of the influence of air entrainment on creep is of importance. Work at the US Army Engineers Laboratories indicates an increase in creep due to air entrainment. However, the presence of entrained air affected the mix proportions. This would, at least in part, explain the higher creep of the concrete with entrained air [20].

Jones in [21] investigated the effects of air entrainment in lightweight aggregate (expanded clay) concrete and concluded that the net effect of air entrainment is usually to increase the creep. However, with air entrainment of below 5 or 6 percent, which is the normal practical range, the reduction in water requirement arising from air entrainment compensates the effects of the voids on strength and on stress concentration, and may even result in lower creep

5.13.4 Accelerators

The accelerators calcium chloride and triethanolamine increase creep, and substantially so in some cases. Consequently, these admixtures should be used with caution in creep-sensitive situations.

The effects of creep increase of the accelerating admixtures were investigated by Hope and Manning [22].

5.13.5 Temperature

Creep is classified into the basic creep and drying creep. Basic creep happens under situations without moisture effort between the specimen and the situation. Drying creep is the supplementary creep due to the moisture movement between the specimen and the environment.

Temperature is the most important environmental factor in creep after relative humidity. The temperature effect is less significant than relative humidity because in most of the structures the temperature functioning is small. The effect of temperature can be classified into during the duration of curing previous the load application and the temperature when the concrete is under load [16].

VI. CONCLUSION

Nowadays the using of high strength concrete (HSC) is rapidly increased. A reason is due to it is positive economic behaviour with reducing the cross section for structural members. Also minimizing the transportation costs. Creep must be considered during the design of buildings for providing the safety in the structures. Usually, the HSC is better than NSC under long-term period, because the creep is lower in HSC more than NSC at all stress/strength ratios. The main reason for this performance is that HSC contains a lower volume of hydrates and water, causing in a higher strength and rigid structure with better resistance to deformations. For accelerated cure applications, the best model for creep prediction is ACI 209 Modified by Huo. The technique of accelerated curing causes a higher change of time-dependent creep strains than a standard curing method.

For standard cure applications, the best model for creep prediction is AASHTO-LRFD for HSC mixtures.

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