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Creep behaviour of self-compacting concrete incorporating high volume fly ash and its effect on the long-term deflection of reinforced concrete beam

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Abstract

Sustainable infrastructures may be achieved by utilizing green construction materials. In term of reinforced concrete structure, this could be attained by the use of concrete with less cement content. In this research, self-compacting concrete has been developed with an inclusion of high volume fly ash as cement replacement. The benefit of incorporating high volume fly ash on the creep behavior self-compacting concrete was investigated through experimental laboratory. The short-term data were then used to estimate long-term creeps with the ACI 209 model. A computation of creep effect on the long-term deflection of reinforced self-compacting concrete beam was accomplished to study the influence of major parameters on the magnitude of deflection.

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Keywords: creep; deflection; deformation; fly ash; self-compacting concrete

1. Introduction

Infrastructure has a significant impact on sustainability, and promoting sustainable infrastructure is an urgent need. Sustainable infrastructure may be achieved by utilizing green construction materials. It is recognized that concrete, one of the major construction materials utilized for the development of various infrastructures, is not sustainable for a variety of reasons. First, the production of concrete consumes a huge quantities of virgin materials.

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Second, the principle binder of concrete is Portland cement, the production of which is a major contributor to greenhouse gas emissions that are implicated in global warming and climate change. Third, many concrete structures suffer from lack of durability which has an adverse effect on the resource productivity of industry [1].

A special type of concrete, namely self-compacting concrete (SCC), has been developed and widely used in the concrete industry to efficiently reduce the need for vibration in order to obtain a good quality of hardened concrete. The ability of SCC to flow, pass through obstacle, and fill any spaces in the congested area offers advantages in term of concreting practices over conventional concrete. However, the composition of SCC tends to have a higher cement content compared to that of normal concrete. Hence, a reduction of cement content in the SCC composition becomes necessary to promote more sustainable concrete. The reduction can be accomplished by a partial replacement of cement with a high volume fly ash i.e. at least 50% by weight of cement is replaced with fly ash.

SCC incorporating high volume fly ash has been the subject of various investigations. Based on the previous works [2-5], the strength of SCC could be expected to reach in the range of 15-25 MPa at 28 day; but the compressive strength is still increased to 25-32 MPa at 90 day. A high strength SCC with high volume fly ash is also possible. An inclusion of high volume fly ash in SCC could improves the durability of the concrete. The chloride penetration resistance of this concrete is optimum at about 55% fly ash replacement level. A better resistance of this concrete against sulfuric acid attack is found when a higher volume fly ash is incorporated. The present of high volume fly ash could also reduce the shrinkage of SCC. In addition to all of these properties, the design and utilization of structural SCC containing high volume fly ash should also consider time-dependent effect of creep which control serviceability of structural member.

Concrete with higher cement content as that of SCC tends to show a higher creep than that of normal concrete. A higher creep leads to a higher long-term deflection. In the normal reinforced concrete element, creep contributes to the long-term deflection of reinforced concrete beam by a factor of 2. If SCC is used instead of normal concrete, the portion of deflection due to creep will be much higher [6]. Hence, to reduce the deflection of reinforced self-compacting concrete element, a modification in the ingredients of SCC is proposed. It is known that the influencing parameters that affect creep are similar with that of shrinkage [7]. One of the major influencing parameters is cement content. Since cement is the source of both shrinkage and creep in the concrete, replacing a portion of cement with fly ash at high volume level could be justified to lower creep [5].

Modern design codes of structures require that a structure must be designed to simultaneously satisfy a number of different limit states including strength and serviceability. One of the specified criteria to satisfy the serviceability limit states is that the magnitude of deflection must be limited [8]. To be able to assess the deflection of reinforced concrete element that utilizing SCC with high volume fly ash, it is necessary to, first, quantify the creep behavior of this type of concrete. Two methods may be employed to quantify creep i.e. quantification of creep based on the mix composition of concrete and quantification of creep based on the short-term data. The ACI 209.2R-08 [9] model for estimating long-term creep does not recognize the influence of fly ash as cement replacement at high volume level. Most of other codes have also been developed using data of normal concrete. Hence, for the current research the best way to quantify the long-term creep behavior of SCC containing high volume fly ash is by measurement of this concrete for short-term period. The obtained short-term data of creep are then used to estimate the magnitude of long-term creep using ACI 209 model. The procedure of estimating long-term creep adopted in this research is similar to that for shrinkage [5,10-11]. After creep has been quantified, the next step is to calculate creep effect on the structural concrete and check if the serviceability limit is satisfied.

Method to calculate long-term deflection with respect to the effect of creep proposed in the ACI 209R-92 [12] is to calculate the time-dependent deflection based on empirical formula that gives the time-dependent deflection as the instant deflection multiplied by the factor λ where λ representing the effect of creep and reinforcement ratio. The effect of creep may also be calculated using analytical model instead of empirical formula [8,13]. The gradual development of creep strain in the compression zone of a reinforced concrete cross-section causes an increases of curvature and a consequent increase in the deflection of the member. Creep in the compression zone causes a lowering of the neutral axis and a consequent reduction in the compressive stress level. Creep is slowed down as the compressive stress reduces, and the increase in curvature is proportional to a small of the creep coefficient. For a cracked beam, the tensile zone of concrete below the neutral axis is assumed to carry no load and thus, does not creep. For this reason, the relative increase in deflection caused by creep is greater in an uncracked beam than in a cracked beam, although the total deflection in the cracked beam is significantly greater [8]. For the current research,