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Measurement and prediction of correction factors for very high core compressive strength by using the adaptive neuro-fuzzy techniques

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HIGHLIGHTS

- Cores with different h/d were extracted from a slab block of HSC.
- Molded samples from the same mixes were also prepared.
- Correction factors were changed between 1.06 and 1.21 for slab.
- A comparative study was made using the adaptive neuro-fuzzy techniques.
- Outcomes were assessed statistically to evaluate the performance of ANFIS models.

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ABSTRACT

In this study the relationship between the core compressive strength with respect to reference samples and different core sizes with different slenderness ratio, length to diameter (L/D) were investigated. In addition, a comparative study was carried out by a hybrid neuro-fuzzy (ANFIS) technique, the core correction factors were evaluated by statistical methods for comparing the performance of four different ANFIS approaches. The Gaussian membership functions were used for defining linguistic terms. The back propagation multi layer (BPML) and hybrid learning algorithms with grid partition were employed for the development of the ANFIS models. Experimental results showed that the core strength was increased with the decrease of slenderness ratio and have ranged between 0.95 and 1.21. The ANFIS model results showed that it could be used an efficient tool for the estimation of the core correction factor of very high strength concrete. The ANFIS model in the current study performs sufficiently in the estimation of core correction factor of high strength concrete, which particularly estimates closely following the actual values. The ANFIS model with hybrid learning algorithm of grid partition was able to produce the most accurate model outcomes for estimating the correction factor among the examined models.

1. Introduction

The compressive strength of concrete is a generally used an important criteria for the mix design of concrete. But, the compressive strength tests take time. In addition, it is impossible to correct even if tests result do not meet the design compressive strength, because the test is usually performed on the 7th and 28th day after placing of concrete into the form at construction site. That is why, realistic and precise strength estimation before casting of concrete are very significant, also for some structural cases, after long service life exposure to different environmental conditions, evaluation for concrete strength is needed.

There are currently many methods used to estimate in-situ strength, each providing unique benefits such as economics, prevent delaying of estimation of strength, etc. However, many of these techniques can introduce all variables that affect accurate estimation.

A simple method is presented for the determination of an equivalent specified strength of concrete, using a number of core tests, which can be substituted directly for the specified strength in conventional design equations to assess the safety of an existing structure. The method is developed from investigations concerned with the interpretation of core strength data and the strength of concrete in structures. High compressive strength of concrete ranges from 50 to 125 MPa is used in the construction of high-rise buildings and long span bridges in many parts of the world. There is great deal of differences in behavior between normal

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strength concrete (NSC) and high strength concrete (HSC), e.g. stress strain relationships, modulus of elasticity and along with others. For this reason, we cannot use the same correction factors that are mentioned in ASTM-C42/C42M for HSC and therefore it is necessary to investigate HSC slabs correction factors.

The compressive strength of the concrete cores is affected by sampling, moisture condition, casting direction and adopted testing procedures. Some investigators reported the sensitivity of measured strength to the L/D ratio, the core moisture condition, the core diameter and the orientation of core axis with respect to direction of casting.

Test results of Bartlet et al. [1], indicated that the average compressive strength of cores with 50 mm diameter equaled to 92 and 94 percent of that of the cores with 150 mm and 100 mm diameter, respectively. It was concluded that concrete cores with smaller diameters have smaller compressive strength.

Tuncan et al. [2] reported that for concrete cores with 46 and 69 mm diameters and height to diameter ratios changing between 0.75 and 2.0, which were drilled from concrete blocks produced in the laboratory condition using aggregates with different types and sizes, the concrete compressive strength decreased as the maximum aggregate size increased. For instance, for two cylindrical concrete specimens with 46 mm diameter and $\lambda = 2.0$, it was observed that the relative strengths of 46 mm diameter cores with respect to standard cylinder specimen were 72 and 85 percent for cores extracted from concretes produced with 30 and 10 mm maximum aggregate sizes, respectively.

Ergun et al. [3] studied the relation between the compressive strength of cores drilled from concrete elements and molded cylinder and cube concrete specimens. The effects of diameters, length to core diameter ratio (λ), test age, and coring orientation on the compressive strength of cores were analyzed with respect to the molded cylinder and cube concrete specimens. The compressive strength of all specimens was in the range of 15–25 MPa for the three different core sizes (50–75–100) mm. They found that the coefficient of correction factor values increased with the decrease in core diameters, changes in the compressive strength for 100 and 75 mm diameter cores were found to be more significant and reliable when compared to those of 50 mm diameter cores.

Indelicato [4], estimated concrete cube strength by means of different diameter cores by a statistical approach. He prepared 1270 samples from 16 concrete mixes of classes ranging from, 20 to 50 MPa and using siliceous river aggregate of different origins and with maximum aggregate size of 30 mm. There were very strong linear correlations between mean cube strength values and the mean strength values determined on cores of the three diameters studied (28, 45 and 70 mm). He found that the correlation formulas were very close, with straight lines displaying angular coefficients very close to 1, but with increasing specimen diameter, the identity between cube and core mean strength improves, albeit slightly.

Bartlett et al. [5] conducted a study to investigate the effect of moisture condition on the strength of mature cores extracted from concrete blocks. They constructed four medium-sized beams and four large beams. The strengths of block concrete ranged from 45 to 90 MPa with maximum coarse aggregates of 19 mm and 14 mm. They reported that the strength of air-dried cores was 14 percent larger than that of soaked cores. The core with axes parallel to the direction of casting was 14 percent stronger than that of perpendicular to casting direction. They found also that the core strength through thickness of beam was attributed to variation of in-situ concrete strength. The core strength decreased when the sample was left to soak in water unlike the samples that were sealed and left in air until any excess water absorbed during drilling evaporated to prevent further moisture change. Results indicated that correction factors for moisture curing condition were 1.09 and for immersed and air-dried cores were 0.96.

In another study, Bartlett et al. [6], reported that the compressive strength of a concrete core with a 100 mm diameter and $\lambda = 2.0$ was equal to in-situ compressive concrete strength by multiplying 1.06 correction factor for damage sustained during drilling of the core.

Ramaiah et al. [7] conducted very extensive study to estimate in-situ strength of concrete pavements under various field conditions and reevaluated factors that affect inaccurate estimation of in-situ pavement concrete strength. The factors were, the effects of core diameter, cylinder curing regime, pavement curing history, presence of reinforcement in a core, vertical location of core, aggregate type, and surface evaporation on both compressive and tensile strength. For above purposes they cast a slab block that had a size of $(7.3 \times 4.5 \times 0.35)$ m and used core size 100×200 (L/D = 2:1) diameter cores in lieu of 150×300 cores for compressive and tensile strength tests. They also used two different aggregate type limestone and siliceous river gravel to show the effect of this aggregate on the concrete strength. The designed strength is about 28 MPa after 28 days. They found that the use of small-diameter cores increased compressive and tensile strength by approximately 10 percent. In addition, variability of small-diameter will be increased and can only be compensated for by increasing the number of small-diameter test specimens.

Bartlett et al. [8] reanalyzed many data from previous studies about the effect of specimen diameter on magnitude of core strength. They also investigated the bias theory, that the bending deformations of the loading platen may be more severe for large specimens. They explained that these deformations may cause the load to be concentrated near the center of the specimen instead of being uniformly distributed over the entire cross section. This causes a splitting effect, which reduces the strength of the specimen considerably. On the other hand, the weakest link theory stresses that samples that have large volumes are more probably to contain a defect and therefore fail at lower applied stress. However, the effect of damage produced in surface area of cores during drilling process is proportionally much larger for small core than for large core and will reduce the strength. Their experimental data represent tests of 1080 core specimens obtained from elements of moderate size with standard cylinder strengths varying from 10 to 92 MPa. They predicted that the average strength of 50 mm-diameter core was 94 and 92 percent of the predicted average strength of a 100 and 150 mm-diameter cores, respectively.

Viso et al. [9], conducted a study on HSC of around 100 MPa compressive strength and they were particularly investigated the effect samples' the shape and the size on the strength (f'_c) of concrete. They derived a simple model to describe the influence of the size on the strength of cubes and a relationship between the strength of the standard cylinder and the strength of cubes of any size.

Nowadays, advancements in concrete technology have made it easier to reach very high strength concrete (HSC) such as 100 MPa and over. If the safety of a structure made up of HSC is a matter of concern, detailed evaluation is warranted so that resources are not wasted on unnecessary rehabilitation. As part of the evaluation process, it is common to drill samples from the structure for testing to assess the quality of concrete. The primary and more reliable technique for assessing the compressive strength of concrete is the core test. For a realistic prediction of the compressive strength of core samples, the effect of all the above-mentioned parameters should be taken into consideration. This is achieved for normal concrete by using correction factors present in ASTM C 42/C 42M-04, but this standard was not intended for HSC slabs. Technical literature contains very limited studies related to the HSC core compressive strength. In fact for 100 MPa strength, only a study has been done by Viso et al. [9], and there is no study at all for above 100 MPa strength. Generally, compressive strength test is conducted with the core size of 100×200 mm, but it is difficult