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Strength Assessment of Concrete Bridge at Elevated Temperature using Destructive and Non-Destructive Methods

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Abstract

Concrete bridge structure when subjected to fire, exhibit good behaviour as a result of their low thermal conductivity associated with their great capacity of thermal insulation. However, there is a fundamental problem of ‘spalling’ caused by high temperatures on concrete (separation of concrete masses from the body of the concrete element). To investigate this fundamental problem caused by high temperatures, concrete cubes of grade 25 were prepared, cured in water for 28 days and subjected to elevated temperature at varying degrees ranging from 100 to 600 ^{o}C for various timing of ½, 1, 1½, 2, 2½ and 3hrs, after which non-destructive (Rebounds Hammer and Ultrasonic Pulse Velocity) and destructive (Compression) testing methods were carried out to compare the compressive strengths obtained. Direct and deductive results obtained show that there was a drop in the compressive strength of the specimen after it had been subjected to elevated temperature for all methods. The result also showed that the non-destructive testing method is more reliable as it also allows a physical examination of the interior properties of the samples. In addition, the combined pulse velocity and rebound index method has no effect on the accuracy of the interpretation. However, it is clear that any of the three methods can be adopted depending on the situation at hand.

Keywords: Concrete, temperature, strength, non-destructive, destructive, Fire.

1. Introduction

Concrete is one of the composite materials that have been regarded as the most versatile construction material known to man and used in civil engineering structures and application (concrete centre, 2010). It is a durable material with a design life of about 60 years and environmentally friendly (Concrete centre, 2010). It is of various uses that include bridge, columns, beams, slab, foundation, road pavement and retaining walls construction. Concrete has many good properties among them is good fire-resistant property, due to its inherent non-combustibility and poor thermal conductivity. However, when it is subjected to prolonged fire exposure or unusually high temperatures, concrete can suffer significant distress.

Interest in the behaviour of concrete at a high temperature mainly results from the many cases of fire outbreaks taking place on bridges as a result of constant fuel transportation on road and in buildings, high-rise buildings, tunnels, and drilling platform structures. During a fire incident, the temperature may reach up to 1,100^{O}C in buildings and even up to 1350 ^{O}C in tunnels, leading to severe damage to concrete structure (Lausanne, 2007). However, in some special cases, even much lower temperature, may cause explosive destruction of concrete, thus endangering the bearing capacity of the concrete element. Nevertheless, concrete is considered a construction material that satisfactorily preserves its properties at high temperature. Owing to concrete’s fairly low coefficient of thermal conductivity, the movement of heat through concrete is slow, and thus reinforced steel, which is sensitive to high temperature, is protected for a relatively long period of time.

Due to the fact that concretes pre-fire compressive strength often exceeds design requirement, a modest strength reduction can be tolerated. However large temperature can reduce the compressive strength of the concrete so much that the material retains no useful structural strength (Chen, et al, 2009).

Furthermore, increase in temperature results in water evaporation, full calcium silicate hydrate gel (C-S-H) dehydration, calcium hydroxide and calcium aluminates decomposition. Along with the increase in temperature, a change in the aggregate also takes place. As a result of these changes, concrete strength and modulus of elasticity gradually decrease, when temperature rises up 300 ^{O}C, then decline in strength becomes more rapid. When the temperature of threshold value of 500 ^{O}C is passed, the compressive strength of concrete usually drops by 50 to 60 %, and the concrete is considered fully damaged. The method of calculating the load bearing capacity of reinforced concrete members subjected to a fire is based on this assumption (Euro code 2, 2004).

The performance of reinforced concrete bridge structure under high temperature is mainly affected by the strength of the concrete, the changes in material properties and explosive spalling. The hardened concrete is dense, homogeneous and has at-least same engineering properties and durability as traditionally vibrated concrete. However, high temperatures affect the strength of the concrete by explosive spalling and so affect the integrity of the concrete structure (Huismann et al., 2011).

In recent years, many researchers studied the fire behaviour of concrete elements. Their Studies included experimental and analytical evaluations for concrete elements that has been subjected to varying degrees of explosive materials (Klontz and Jain, 2013). Several non-destructive testing methods have been developed in the past for on-site concrete strength assessment, like the rebound hammer and the ultrasonic pulse velocity (UPV) tests which are the most commonly used by Malhotra and Carino, 1991; Bungey and Soutos, 2001; Tay and Tam, 1996.

Compression tests are however affected by a number of factors, which result in uncertainties in the concrete strength determination. Besides, measured concrete compression strength is strongly dependent on testing standards adopted and in some case far from the intrinsic strength of concrete, if an intrinsic strength of concrete could be defined (Neville, 2005), Much of the current knowledge on high temperature properties of normal strength concrete (NSC) is based on limited material property test (Neville and Brook, 2009).

There are limited tests on high temperature properties, or there are considerable variations and discrepancies in the high-temperature test data for other properties of concrete. These discrepancies and variations are mainly due to the environmental parameters (for example, curing and relative humidity) accompanying the tests. Thus at present there are no reliable constitutive relationships in code and standards for many of the high temperature properties of concrete (Long and Nicholas, 2000). There is limited information available on high temperature properties such as strength, modulus of elasticity, thermal conductivity and specific heat. There are also no reliable data on properties, such as high-temperature creep and porosity.

Furthermore, there is no standard test methods for evaluating the high-temperature, thermal, mechanical and special properties of concrete (Malhotra, 1958). Concrete though not a refractory material is incombustible and has good fire resistant properties (Shetty, 2005). Fire resistance of concrete structure is determined by three main factors -the capacity of the concrete itself to withstand heat and the subsequent action of water without loosing strength unduly, raking or spalling In the case of reinforced concrete, the fire resistance is not only dependent on the type of concrete but also on the thickness of the cover to reinforcement (Paul et al., 2014).

The study is aim at assessing changes in physical state of concrete using destructive and non-destructive methods and consequent deterioration in the compressive strength with increase in temperature. The objectives are therefore to (i) prepare Grade 25 concrete and cure for 28 days, (ii) subject the cured concrete to temperatures ranging between 100 – 600 ^{o}C for timing of ½ to 3hrs in steps of ½ hr., (iii) conduct non-destructive and destructive test on the specimen and hence (iv) determine the direct and indirect compressive strengths of concrete

2. Materials and Methods

The materials used in this study were obtained locally and checked for their engineering properties. These materials include, Ordinary Portland Cement (OPC) selected in accordance to BS 12. (1996) (Specification for Portland cement). The fine and coarse aggregate were obtained in accordance with requirements specified by BS1200 (Specifications for building sands from natural resources) and BS 5328: Part 1. (1997) respectively in order to achieve concrete that will meet both the strength and durability criteria. The water used is fit for drinking and was obtained from source that proved satisfactory.

Concrete was produced at 1 : 2 : 4 mix ratio for the batching and mixing. Table 1 shows the batching quantity of each material. Cubes were produced and cured for 28 days in water tank. The specimen were weighed and placed in an oven to achieve a temperature range 100, 200, 300, 450, 500 and 600 ^{O}C at time durations of 30 mins, 1hour, 1.5 hours, 2 hours, 2.5 hours and 3 hours respectively.

Table 1 - Batch Quantities

Materials	Quantity (g/m^3)
Ordinary Portland Cement	24.30
Fine Aggregate	48.60
Coarse Aggregates	97.23
Water	12.15

The specimens were allowed to cool naturally to room temperature. Then, the Non-destructive test (NDT) and destructive test (DT) were conducted according to BS EN 12504 (2001), IS 13311 (1992) and BS 1881 (1990). Plate 1 and II show the NDT performed using Schmidt rebound hammer and UPV Machine, respectively.

Plate I: Testing Using Schmidt Rebound Hammer

Plate II. Testing Using UPV Machine

3. Results and Discussion

Figure 1 show the results of the compressive strength of the concrete and heating temperature range for rebound hammer, UPV machine and crushing machine.

From Figure 1, the results of the NDT, show a speedy reduction in strength of the concrete with increase in duration of heating and temperatures, while the DT (compression test) carried out on the samples showed high values even after heating. This can be attributed to certain factors as moisture condition, position of aggregates in the specimen, voids, position of testing, size of specimen, surface type, stress state, inner temperature state, compaction and vibrations.

Considerations of these factors suggest that the non-destructive test methods are mostly suitable to investigating the interior properties of the concrete element as in-situ test on bridges. The compression (DT) test on the other hand, which involved a direct application of loading to determine the compressive strength of the concrete sample cannot be said to give the true strength of the concrete's interior.

Examining Figure 1 and the errors generated by both NDT and DT methods it shows that any of the methods can be adopted depending on what property is to be determined.

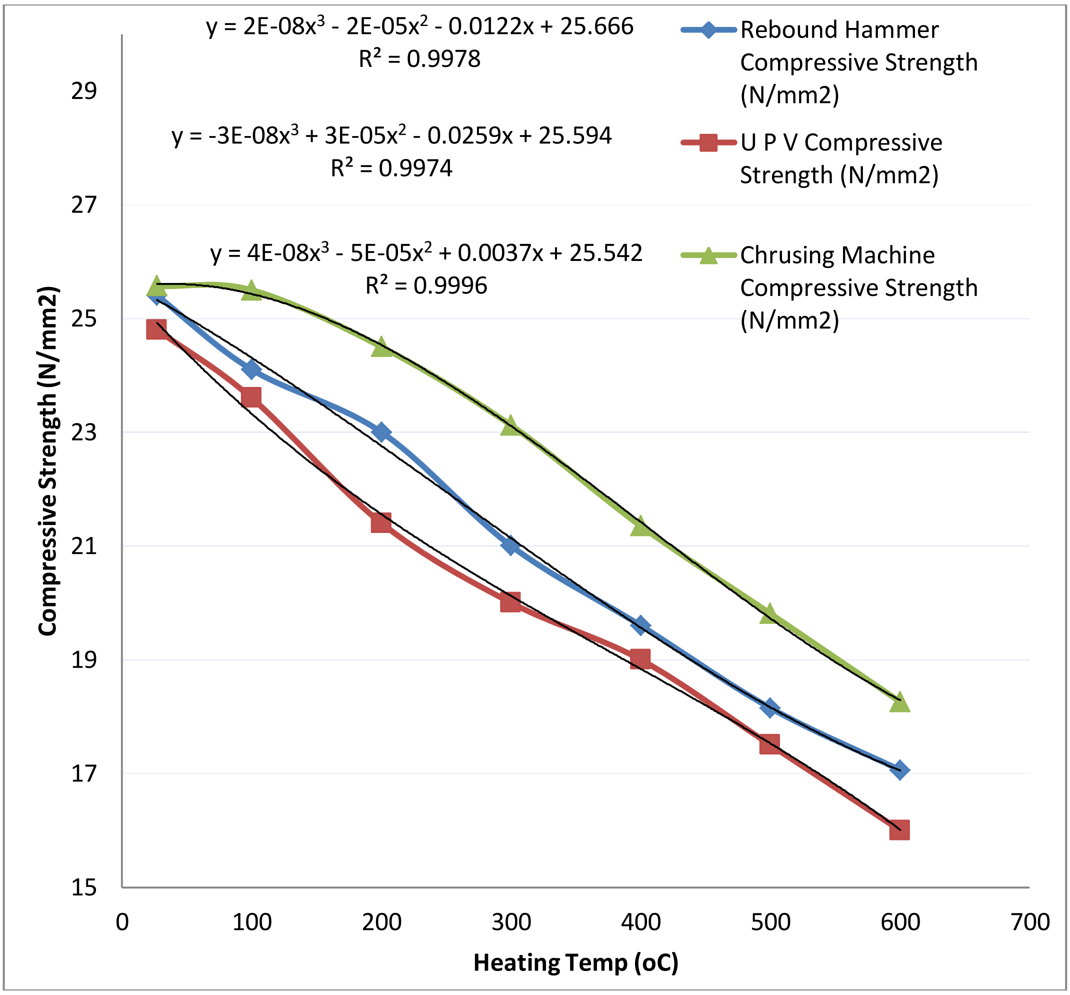

Figure 1: Compressive Strength against Heating Temperature

4. Conclusions and Recommendations

The following conclusion can be drawn from the outcome of the study:

(i) Concrete structures lose their strength after, prolong heating period at temperature beyond 300°C, and hence should be demolished or reinforced.

(ii) Mathematically, any of the methods of test can be used since their error state is very negligible, confirming the authenticity of the methods.

(iii) The strength of concrete at temperature above 300 °C decrease speedily and at temperature above 500 °C the strength of concrete is below 50 – 60 % of its original strength.

(iv) The results obtained are only limited to the tested area, and hence the determinant factors must be standardized for any method used

(v) The approach may be used as an acceptance criterion in relation to the removal of temporary supports from structural concrete.

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