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In-situ NDT investigation to estimate degraded quality of concrete on existing structure considering time-variant uncertainties

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ABSTRACT

Concrete structures may be affected due to degradation of stiffness or strength originated from severe environmental stressors or unsystematic variations in the loads and resistances of the structure beyond the baseline conditions of the existing design. Therefore, physical changes in the performing system should be considered for assessing the future reliability and safety of the structure. In this paper an improved approach for the evaluation of time-dependent structural reliability of aged structure has been presented. Experimental investigation has been carried out using two different Non-Destructive testing (NDT) methods, such as 'Rebound hammer (RH)' and Ultrasonic pulse velocity (UPV) methods to check the deterioration of the existing structure with respect to age and load processes, however, the results have been used for the evaluation of failure probability of the structure with respect to time or ages. The quality of the degraded concrete is suitably represented by a normalized index called Concrete Quality Designation (CQD). Considering non-stationarity in the process of load and time-dependent structural resistance, the assessment for time-dependent structural reliability is performed to investigate and assess the structural degradation characteristics reliably for safety evaluation of the remaining service life of structure.

1. Introduction

Concrete being a widely used construction material popularly known for its strength, durability, accessibility, adhesiveness and affordability of the raw materials. Due to gradual evolution of large number of concrete structures, it becomes necessary to monitor the mechanical and physical properties of concrete, particularly, the compressive strength of concrete. At the later stage of the service life period of the structure, the compressive strength of concrete decreases due to several factors such as improper curing and cracks developed at the interior of the structure due to loading or environmental effects. Several testing procedures are available for evaluating the in-situ concrete strength; one of them is the NDT. The NDT involves methods such as RH, UPV, and the Probe penetration. In the present study, two methods such as RH and UPV have been used for the estimation of in-situ strength of concrete. The RH method yields a fair estimation of the compressive strength of concrete. Consecutively, in the UPV method the velocity of the wave propagation through the tested material is obtained in order to identify the quality of the material. The use of single test method such as either RH or UPV method may yield unsatisfactory results. Therefore, a combined usage of both the test methods have been made for obtaining results which relatively conclusive. However, the ACI 228.1R-03 [1] and ACI 318-14 [2] reported a combination of two or more test methods for the improvement of test results. Recent studies also reported that a combination of RH and UPV provides reliable results on compressive strength estimation, this could be justified by the fact that results of each test are affected by different properties of concrete [4,20,37,40,42].

Subsequently, for estimating the reliability of deteriorating structures, reliability analysis is carried out for acquiring a confidence that the structure could survive with adequate resistance against the extreme events during its service life period. A number of literatures have been published in the recent years considering the issue of damage and safety evaluation of aging structures [3,5,8,15,19,30,33,41,43–45]. Many factors such as variation in loading condition or load intensity over time, environmental condition and periodic repair quality and maintenance of the structure may have considerable effect on the safety of the structure [10,14,25,35,38]. However, the explicit impact of these various factors becomes difficult to predict for most of the cases. Mori and Ellingwood (1993) [31] conducted introductory research for estimating structural reliability with respect to time considering random nature of both the

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load and resistance. The method proposed by them was successfully used for predicting the time-dependent failure probability of degrading RC structures such as highway bridges, nuclear power plants (NPP) and several other civil engineering infrastructures [18,21,26,32]. However, if the variations analogous with time-dependent deterioration of structures are taken into consideration then a highly complex multi-dimensional integration becomes necessary for determining failure probability of the structure with respect to time [6,11]. In addition to this, throughout the life period of the structure, Mori and Ellingwood (1993) treated loads as stationary pulse process which consists of a series of uniformly disseminated and statistically liberated intensity of loads with events in time as illustrated by a Poisson point process. Due to the existence of time-variant behavior and related uncertainties in the resistance and loading process, it becomes essential to assess the safety and serviceability of degrading structures considering the reliability methods [7,28]. Thus, the paper presents an improved NDT based method for the evaluation of time-dependent structural reliability of aging structures during the existence of non-stationarity in the load process and time-variant structural resistance.

2. Non-destructive test methods

2.1. Rebound hammer (Schmidt hammer) method

The RH (Schmidt hammer) method was developed early in 1948 by a Swiss engineer Ernst Schmidt. The RH method is considered as a surface hardness method which measures the rebound of a particular mass consisting of specified kinetic energy while impacting the surface of concrete. The testing procedure for hardened concrete using RH is prompt and easy. The standards followed for carrying out the NDT test using RH is as per IS 13311-2 (1992) [23]. While conducting the test, the factors affecting rebound number and its correlation with strength have been taken into consideration such as effect of gravity, smoothness of test surface, effect of concrete moisture, and effect of coarse aggregate such that the errors which are accounted during the test could be nullified to a reasonable extent. The correlation between strength of concrete and rebound number as per Proceq SA (2017) [36] may be obtained from the conversion curves as shown in Fig. 1(a).

2.2. Ultrasonic pulse velocity (UPV) method

The UPV method is a stress wave propagation method which becomes based on determining the longitudinal pulse wave velocity in which pulses or throbs produced in concrete through electro-acoustical transducer. The basic principle of UPV method is to introduce generated pulses in concrete with the help of transmitting transducer held on the surface of the concrete and to quantify the transit time, t, of the longitudinal waves to a receiving transducer. The UPV of the longitudinal waves, V_p, having a path length, l, is given by as:

$$V_p = \frac{l}{t} \tag{1}$$

However, in the present study, standards conforming to IS 13311-1 (1992) [22] have been followed for carrying out the testing of concrete using the UPV technique. The parameters such as coarse aggregates, moisture content, age of concrete, temperature of concrete, crack and voids, transducer frequency, and reinforcing bars responsible for affecting the test results are also considered in order to counterfeit the errors which become prevalent during testing. The theoretical relationship between UPV of longitudinal waves (V_p), and the elastic properties of solid through which it propagates is given by as:

$$E = \frac{\rho(1+\mu)(1-2\mu)}{1-\mu} V_p^2 \tag{2}$$

Where,

E = Dynamic Young's modulus of elasticity in MPa.
ρ = Density in kg/m^3.
V_p = Pulse velocity in m/sec.
μ = Poisson ratio

2.3. Type of instruments used and its characteristics

For RH method, original Schmidt hammer of N type model has been used. However, the hammer weighs 1.7 kg and has impact energy of 2.207 N-m. The hammer is suitable for testing the compressive strength of concrete in the range of 10–70 MPa [36]. Consecutively, for UPV

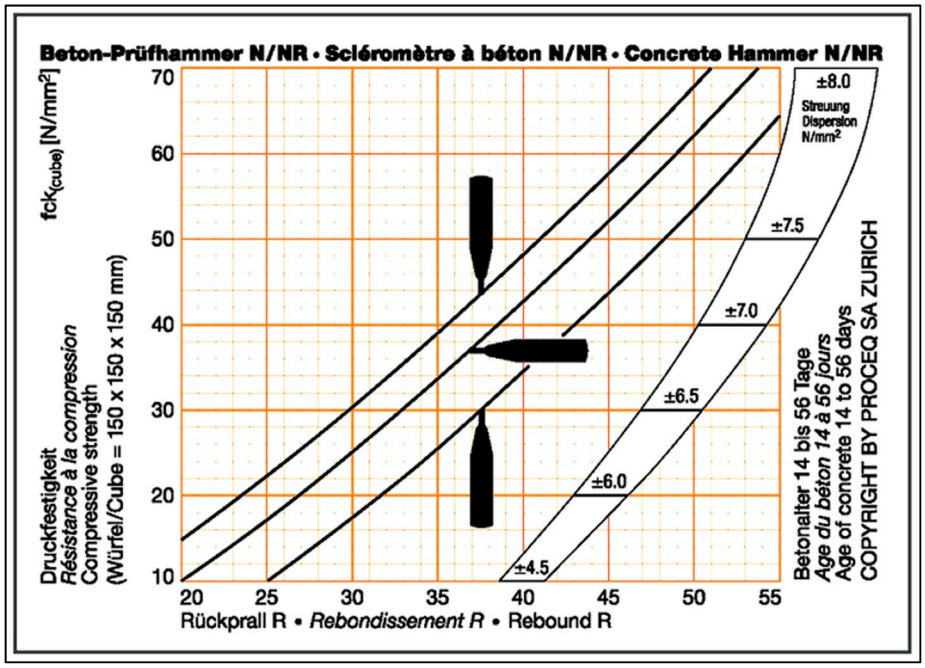

Fig. 1(a). Rebound Vs Compressive strength of concrete [36].