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RELIABILITY ASSESSMENT OF REINFORCED CONCRETE STRUCTURES BY USING SIX SIGMA CONCEPTS

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ABSTRACT:
The present investigation is mainly focused on reliability assessment to the Reinforced Concrete (RC) Structures by using six sigma concepts using Non-Destructive Testing (NDT) technique. Schmidt Rebound Hammer (SRH) estimating the strength on RC Structures. Now-a-days determination of reliability of complex structures is a major problem. It will take very much time and also difficult to assess the reliability of a complex structure in an economical way. NDT compressive strength results of the RC Structures can be used to calculate reliability of complex structures. NDT methods that are available show some sensitivity to concrete properties or defects. These are more common to assess condition on the RCS. Yield (Y) is an important to measure process capability and it is expressed as percentage of Defects Per Million Opportunities (DPMO). It is a measure of number of defects in terms of million opportunities. Sigma quality level is a measure of process defect rate a higher sigma level indicate the process results in lower defects where as a lower sigma level means higher defect rate. In this paper, case study of an existing building of the college campus has been considered and test results are analyzed and presented.

Keywords: NDT, SRH, DPMO, Y, Sigma level and RC

1. Introduction:

Reinforced Concrete (RC) structures are preferred because of their performance and service life which is mostly depended on strength, quality and age of concrete etc. The life expectancy of concrete depends on various physical and chemical circumstances like exposure conditions in which mild exposure results in more life of structure and vice versa. RC structures are effected by other means like alkali aggregate reactions etc. Due to many other factors, accessing the existing structure for degradation level and strength by non-destructive and destructive tests, is of importance. Modeling of RC structure with all the parameters which is time consuming and tricky job. So reliability methods which are probability based is superior for reckoning the life of RC structures. The structure may break down due to failure of one or more components which may lead to collapse of structure. So identifying the structure for strength is important for maintenance.

Sigma quality level is measure of process defect rate. The basic probability distributions are given in [6] The reliability and maintainability analysis given in [1]. Reliability analysis of RC structures in presented [3-5]. NDT of old structures has been proposed in [7]. The statistical analysis of geopolymer concrete structures using NDT method [8]. A higher sigma level indicates that the process results in fewer defects whereas a lower sigma means higher defect rate [2]. Sigma quality level can be used for benchmarking purpose and helps to measure quality of the process. Sigma quality also helps to set a realistic target for process quality improvement. Sigma level can be calculated from DPMO as well as yield [2].

In all the above methods no attempt has been made to predict the performance of RC structure using six sigma levels, which will give more accurate results. In this paper, it is proposed to assess performance of RC structure using SRH testing and Reliability analysis is carried out applying six sigma levels. In this paper, case study of a multistoried building which is situated in tropical region is considered for the failure analysis using the NDT. In this paper beams and columns of a building is assessed with rebound hammer test and evaluated for the failure analysis.

In Section 2, about SRH equipment which is used for testing the compressive strength is described. In Section 3, the proposed methodology and steps to obtain six sigma of the proposed structure are presented. In Section 4, the case study of the existing hostel building at the campus of JNTUACEA has been considered for the SRH testing to be carried out. Experimental study of the hostel building is presented in Section 5. Sample calculations are shown in Section 6 and conclusions are presented in Section 7.

2. Schmidt rebound hammer (SRH): The Schmidt Rebound Hammer diagram and its parts are shown in Fig.1.

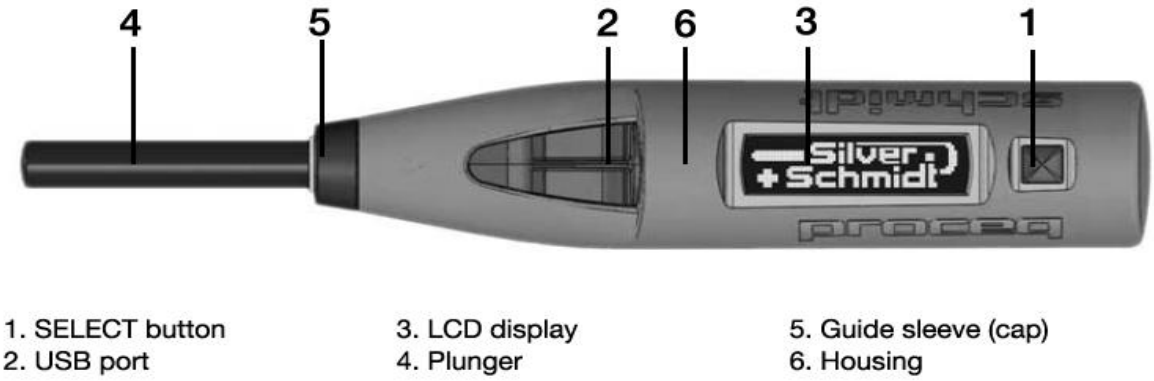

Fig. 1 Schmidt Rebound Hammer

In this section, SRH which is used for testing the compressive strength is described. The device is based on the rebound principle, which is an indicator to the hardness of concrete. In the rebound test, a spring loaded mass has fixed amount of energy imparted by extending the impact spring to affixed position, this is achieved by, pressing the plunger against the surface of the concrete under test. Upon release, the mass impacts on the plunger, rebounds and the distance traveled by the mass expressed as a percentage of the initial extension of the spring, is called the rebound number. The rebound hammer is measured strength on an arbitrary scale marked from 10 to 100 (Kolek, 1958, Casino, 1974). Schmidt standardized the hammer blow by developing a spring –loaded hammer and devised a method to measure the rebound. Several models of the device were built. The rebound hammer is a surface hardness tester. With this instrument, the user presses a plunger against the surface under test a spring then releases a mass to impact on plunger. Inside the instrument a spring provides a defined impact energy for each measurement. After the impact the mass rebounds a certain distance and this is shown on the scale by a pointer. SRH number reflects the surface strength of concrete and the number indicates strength of about first 30 mm depth of concrete.as shown Fig. 1. The rebound number results obtained are only representative of the outer concrete layer with a thickness of 30-50mm the SRH test is effected by various factors, viz.: surface smoothness, size, shape, rigidity, age and internal moisture condition of test specimen. Also it is effected by selecting the type of aggregate and type of cement.
The rebound hammer calibrated compressive strength age differs from ± 15 to ± 20% with the actual values the estimation of strength of concrete. The SRH test procedure, data collection and processing of test results are described in respective codes (IS 13311-1 1992). Based on past research on the quality concrete as a function of the rebound number [8] is shown in Table 1.

Table 1. Quality of concrete by rebound number

Average rebound number	Quality of concrete
>40	Very good hard layer
30-40	Good layer
20-30	Fair
<20	Poor concrete
0	Delaminated

3. Proposed Methodology:
The compressive strength of RC structure is to be evaluated Destructive Method and NDT method. In this study NDT method instrument used is SRH. To take the readings of each component of RC structure Six to Nine readings taken and average value is taken as actual strength of that component. For the various components of hostel building i.e., plinth beam, column, beam and slab the strength values are measured using SRH by considering perpendicular direction to the component under consideration.

To calculate the sigma value, the following formulas of Yield Y, DPMO, Sigma level values are to be used.

Modeling Formulas [2]

$$\textbf{DPMO} = \frac{\text{Number of defects}}{\text{Number of opportunites}} x10^6 \quad \ldots . (1)$$

$$\textbf{Yield (Y)} = \frac{\text{Number of defect free units}}{\text{Number of opportunites}} x100 \quad \ldots (2)$$

(Or)

$$= 1\text{-DPMO} \quad \ldots . (3)$$

Conversion of DPMO to sigma level:

$$\text{Sigma level} = 0.8406 + \sqrt{29.34 - 2.22 * \ln(\text{DPMO})} \quad \ldots . (4)$$

Conversion of yield to sigma level:

$$\text{Sigma Level} = 1.5 + \left(P - \frac{C_0 + C_1 P + C_2 P^2}{1 + d_1 P + d_2 P^2 + d_3 P^3} \right) \quad \ldots . (5)$$

The sample data of coefficients of C_i, i=0 to 2 and d_i, i=1 to 3 have been taken from [5].

$C_0 = 2.515517$ $C_1 = 0.802853$ $C_2 = 0.010328$

$d_1 = 1.432788$ $d_2 = 0.189269$ $d_3 = 0.001308$

$$P = \sqrt{\ln\left(\frac{1}{\left(1 - \frac{Y}{100}\right)^2}\right)} \quad \ldots . (6)$$

The steps for obtain Six Sigma

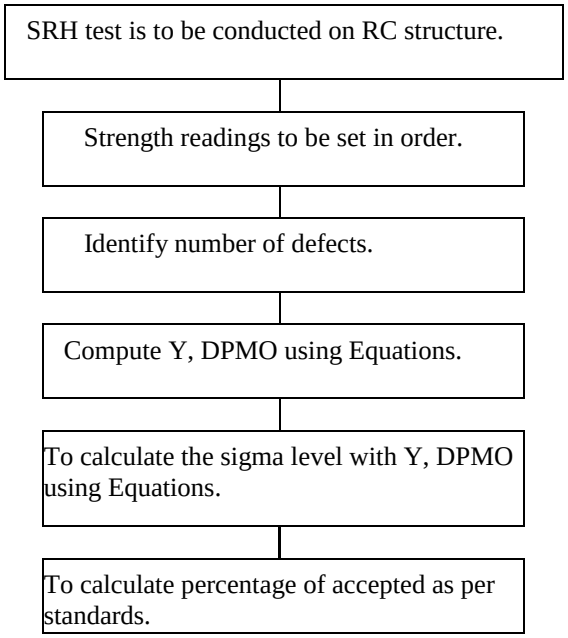

Fig. 2. Steps to assess the sigma level of RC structure

4. Case Study:

The existing Hostel Building at the campus of JNTUA CEA has been considered for the SRH testing to be carried out. PG students (Boys) hostel at JNTU CEA i.e. Takshashila hostel building is considered. This is multistoried building consisting of G+2 floors. Hostel Building plan line diagram is shown in Fig 3. As per Table 1, if strength is less than 20 it is considered as poor concrete. The data of measured strengths of Plinth Beam, column, beam and slab data are mentioned in Table 4.

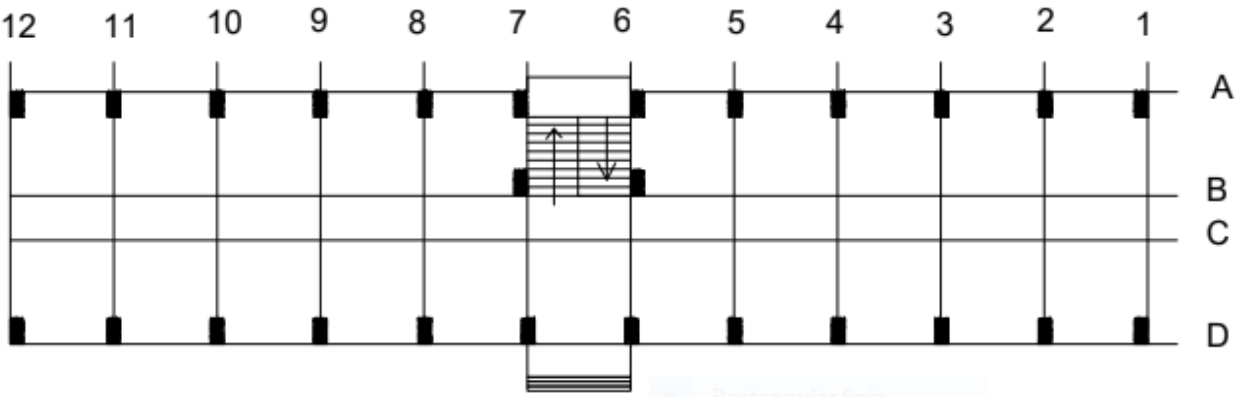

Fig 3. Hostel Building Plan in JNTU CEA

The normal distribution at different sigma (σ) levels percentage of accepted and percentage of rejected is represented is Fig 4. The area of distribution curve will be in between the lower specification limit and upper specification limit. Each sigma level contain certain percentage value for example 1σ is 68.3% area is accepted [2].

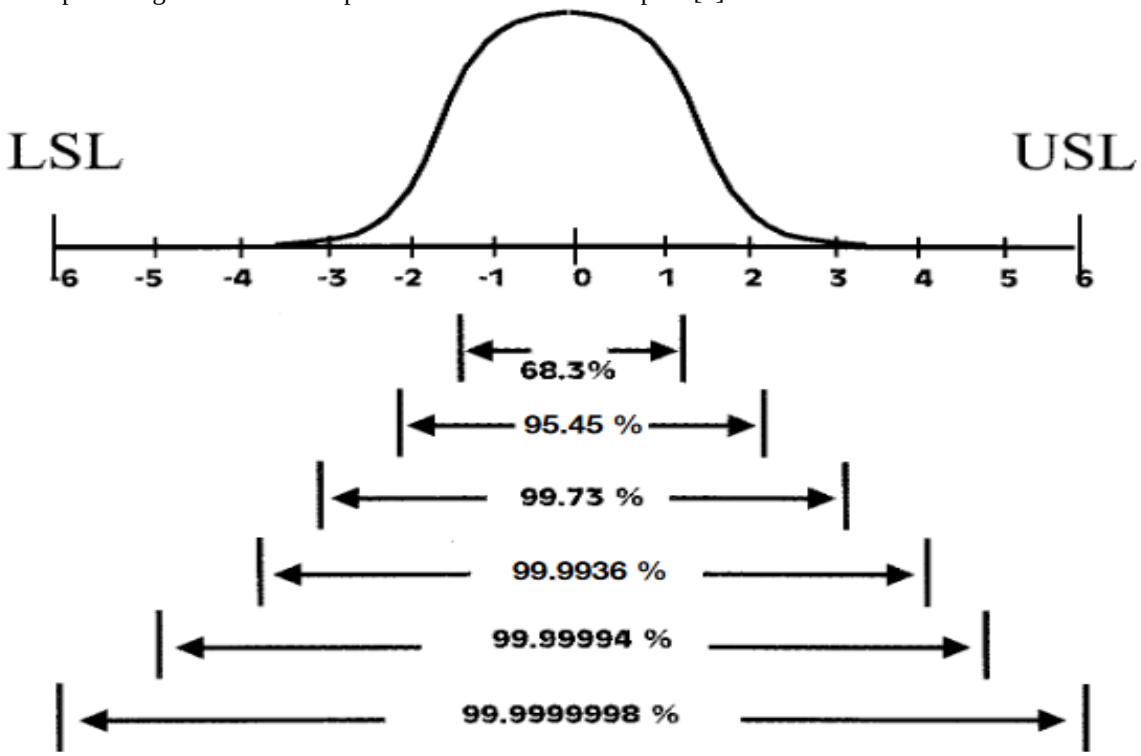

Fig 4. Graphical presentation of normal distribution with parts compliance percentage and σ limits

5. Experimental study:

The main objective of study is to determine the sigma level of reinforced concrete structure where as a high sigma value when the structure is reliable when the low sigma level structure is less reliable to the experimental study by using Non-Destructive method. Rebound hammer is used to find the strength values taken to the entire structural components of plinth beam, columns, beams, and slabs all components to be tested strength values are arranged in order test results are described in respective code (IS 13311-1 1992) based on the quality of concrete and strength of concrete is defined.

Six sigma level will be calculated based on the definitions of DPMO, yield, and using the appropriate formula is to compute sigma level. For an existing building in the campus, five cases have been considered vit, plinth beam, column, beam, and slab. And combination of these, and sigma level has been computed for each of the above case and for the building.

6. Sample Calculation results:

Total number of sample readings taken as 364
As per table 1 greater than 20 strength readings 358
As per table 1 less than 20 strength readings 6

Conversion of DPOMO to sigma level:

DPMO $= \frac{6}{364} x10^6$ = 16483.516

Sigma level = 3.628

Conversion of yield to sigma level:

Yield (Y) $= \frac{358}{364} x100$ = 98.35%

P = 2.865

Sigma level = 3.630

Based on the experimental data, the sigma level has been obtained and compared with MATLAB programing. The standards of the Yield corresponding to different sigma levels is given [2] in Table 2. Similarly, the standards of DPMO vs sigma level [2] have been shown in Table 3. The rebound hammer readings are presented in Table 4.

Table 2. Yield corresponding to different sigma levels.

Sigma level	Yield (Y)
1	30.23
2	69.13
3	93.32
4	99.3790
5	99.97670
6	99.999660

Table 3 Sigma level and Defects per Million Opportunities.

Sigma level	DPMO
1	697672
2	308770
3	66811
4	6210
5	233
6	3.4

Table 4. Rebound hammer strength readings in RC structural components of Plinth Beam, Column, Beam and Slab.

S. No	Location	Total samples	No. of defects	No. of defect free
1	Plinth Beam	36	2	34
2	Column	96	2	94
3	Beam	133	1	132
4	Slab	99	1	98
	Total	364	6	358

As per Table 4, the graphs of probability density function, normal distribution, survival function and hazard function graphs have been plotted with respect to a failure data using Mini Tab and shown in Fig. 5

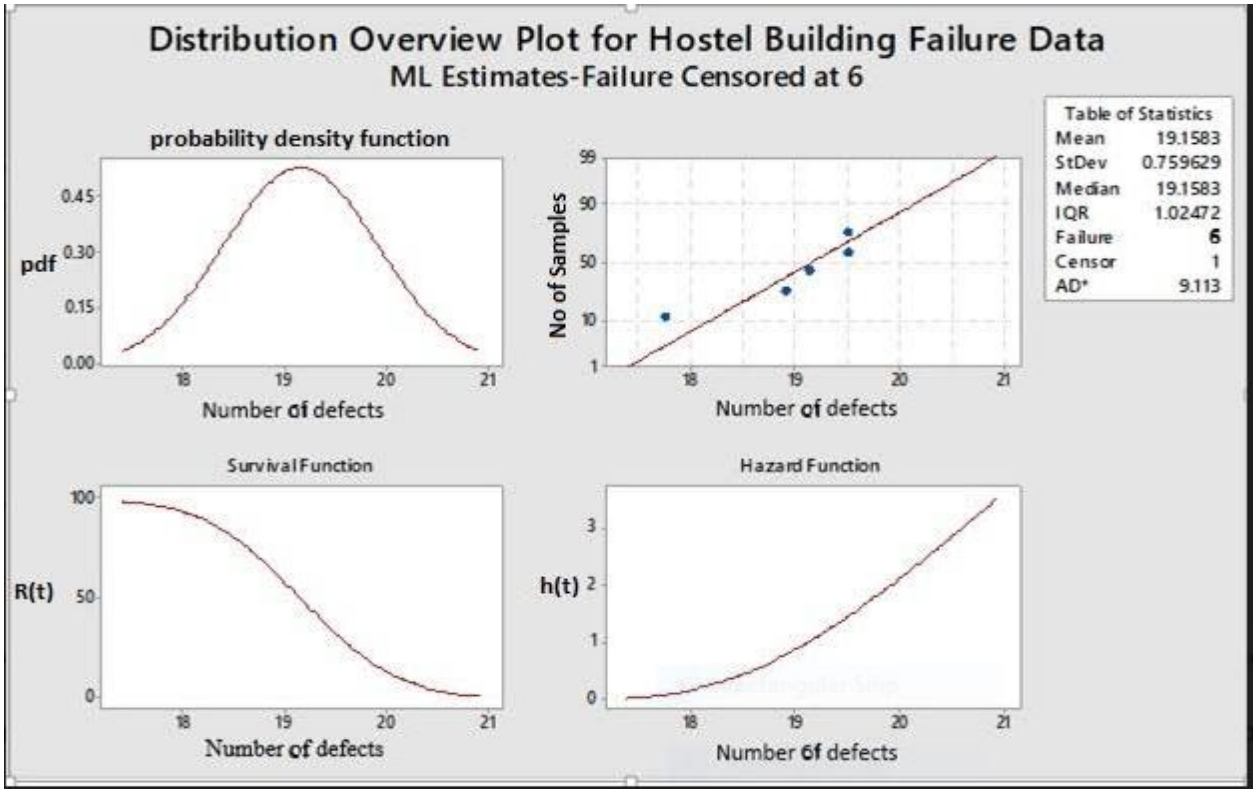

Fig. 5 Graph of reliability functions

MATLAB program has been developed for Six Sigma level using Y, DPMO.

7. Conclusions:

In this paper, six sigma concepts to assess the reliability of structure are implemented. Case study of college hostel building in JNTUCEA in this study NDT method to the strength values are arranged in ascending order using Excel software tool identified failure values as per table 1. By applying formulas of Y, DPMO and sigma level is to be calculate. When sigma level value is high structure is reliable sigma level value is less reliable. And also developed the MATLAB program to compare actual calculation results and MATLAB results are same.

This case study using SRH test NDT method is used to calculate sigma level value and obtained as is 3.63, as per Fig 4 and calculated percentage of acceptance is 99.8619%.

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