Study of Bond Strength Failure of R.C.C. Using Structural Health Monitoring

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ABSTRACT

At present active Structural Health Monitoring (SHM) techniques has been exceptionally feasible in keeping up performance and precisely evaluating damage parameters of the steel structure yet SHM have turned out to be less proficient for Reinforced Concrete structures (RCC) because of non-homogeneity of RCC structures. In this research work an innovative structural health monitoring technique was studied through tests performed on flexural reinforced beam. The experimental and EMI technique based analysis has been done a flexural beam to studying the behaviour of bond failure due to flexural load using Piezoelectric (PZT) which was based Electro Mechanical Impedance (EMI) technique, beam specimen had been monitored to extract its admittance signature. Afterwards obtained admittance signature is compared with available undamaged structural system admittance signature and consequently distinguishing the sort of structural system with the assistance of Hixson's table. Stiffness coefficient value is calculated based on the equations given by identified structural system using Hixson's table. Experimental damage parameter and Formulated damage parameters as given by Hixson's table were contrasted finally with discovering the coefficient of distinction. It had been found that there isa change in the admittance pattern in the analysis showing that the admittance increases from healthy to moderate damage state and subsequently decreases when severe damage is attained under flexural loading. And, finally quantification of damage was done through statistical indices method.

Keywords: Structural Engineering, Workability, Compressive strength, Flexural strength, Health Monitoring.

1. Introduction

Construction industry is one of the pounding industries of today's world that has great impact on the economy of any country. Construction is an important sector that comes up with great infrastructure development for the country. As these infrastructure is an important long term investment which needed to be monitor properly for their performance and all-inclusive condition. And there are some critical structure such as thermal power plants, dams, bridges, etc. which were needed to be monitor, so that some physical variation in the structure can be timely mend or restore with minimum loss of life and money. Therefore, instrumenting the structure at the commencement of its construction and its monitoring, subsequently provide useful information about its behavior at actual loading condition. Ironically, due to huge investment in construction of a structure engineers are rarely concerned about the post behavior of the structure. Several incidents of failure of reinforced concrete structures had drawn the attention of the researchers to explore the field of real-time based monitoring while improvising various technologies. Structural Health Monitoring (SHM) is one such technology being improvised or rather being used for monitoring and preventing catastrophic failures.

The utility of reinforced cement concrete which revolutionized construction materials is that reinforcing steel which is strong and ductile in tension with concrete being strong and relatively durable in compression. The binary action of carrying tension and compression being generated due direct tension or flexure and direct compression respectively made R.C.C. so popular that it cannot be replaced until a new material is introduced and verified for its serviceability and durability to an extent that concrete has been subjected. This means that to replace R.C.C. completely, a new material has to put a great effort against the utility of concrete and this would take time. Thus, for now we have to come up with both the merit and demerit of R.C.C. The binary action of R.C.C. as discussed above is very important and requires strain compatibility between both, surrounding concrete and reinforcing steel which is ensured by the bond developed between the two. The Bond developed which can be said as the adhesion between the surrounding concrete and reinforcing bars which were responsible for the effective transfer of the stress generated from concrete to the reinforcing bar. To avoid discontinuity or parting of the concrete and reinforcing bars under the applied load and subsequently destroying the composite action, the surrounding concrete and reinforcing bars must undergo same strain. Due to this strain compatibility, the building of the load-bearing flexural members such as beams, slabs with reinforced concrete as a composite material has been successful. Strain compatibility means, the strain at whichever point in the steel was equal to the strain in the adjacent concrete. Concrete being brittle material is supplemented by the tensile properties by the progress of this bond; this means that an R.C.C flexure member failing in tension would be preceded by large deformations produced by yielding of steel bar giving an ample warning before failure which would not be in the instance of member behaving completely as a brittle material. Tensile stresses in the R.C.C. member can occur either, directly through direct tension and also indirectly through shear. These tensile stresses cause tension along the diagonal planes. Therefore reinforcing bar must be provided at appropriate direction such that it cuts across the principal tensile plane preventing the possible tensile cracks.

The essential hypothesis of the principle for flexure that the plane section before bending stay plane even after bending only valid when the bond developed amongst the reinforcing steel and the concrete acts efficiently. Bond strength is a result of the mixture of various criteria such as the mutual chemical adhesion, frictional resistance, mechanical interlock and shear along the cylindrical concrete surface between adjacent ribs. If this bond developed is insufficient or inadequate the composite action would break and relative slipping of the reinforcing bar would take place. Failure of this bond could lead to the damage of the structural component and ultimately leading to the failure of the complete structure.

Thus the detection of the bond failure is necessary so that adequate repair can be done timely. Conventionally to assess the nature of the bond strength destructive measurement by push-in, pull-out is performed. Non-destructive testing of the bond strength is beneficial in the field as the limiting failure conditions can be identified and subsequently monitored for other cases as well. The two popular NDT methods are acoustic method and electrical method. In Acoustic method of analysis the relative displacements and acoustic emission are at the same time recorded on pull out specimens subjected to monotonic, cyclic and long haul loads and subsequently based on Fourier transforms of the signals, the coherence spectrum analysis is performed and acoustic emission signal pattern are compared.

2. WORKING PROCESS

2.1 Design of Beam and Load calculation

Beam specimen was calculated by Limit State Method using IS 456:2007 for flexural design. The area of the beam was taken as 150× 150 mm. By Limit state design method limiting moment is calculated using the equation,

$$M_{ulim} = 0.1389 f_{ck} b d^2 \tag{3.1}$$

Where for M25, f_{ck} =25N/mm^2, cover = 30mm.

Therefore,

M_{ulim} = 0.1389 × 25 × 150 × (150-30)^2 = 7.5 kN-m

For the moment calculated above the area of reinforcement can be planned using the formula,

$$A_{streq} = \frac{0.5\, f_{ck}}{f_y} \times \left[1 - \sqrt{1 - \frac{4.598 M_u}{bd^2 f_{ck}}}\right] \times bd \qquad (3.2)$$

Using the above formula Ast_{req} computes to = 216.26 mm^2. Minimum A_{st} required is given by the formula,

$$\frac{A_{st}}{bd} = \frac{0.85}{f_y} \qquad (3.3)$$

The overhead equation provides the value of A_{st} required as 36.8674 mm^2. The beam is designed as under-reinforced beam so that flexural tension generates in the rebars and we can study the debonding phenomenon. Therefore 2 bars of 10 mm Ø are provided (Ast= 157.07 mm^2).

2.2 Load Calculations

For specimen to be subjected to flexural loading its load calculations are done for four-point loading.

Dead load of the beam= 0.150×0.150×25=0.5625 kN/m

The assessment of the load that can be carried by the section is developed by generating the BMD of the flexural beam. Figure 6 gives the BMD and SFD of the specimen. From BMD subsequent equation can be used for the calculation of load, M_u is equal to

$$M_u = 1.5 \times \left(\frac{M_D L^2}{8} + \frac{PL}{6}\right) \qquad (3.4)$$

The overhead equation provides the value of failure load as 49.74 kN.

2.3 Design for Shear

The value of shear stress τ_v can be calculated using given equation,

$$\tau_v = \frac{V_u}{bd} = \frac{49.74 \times 1.5 \times 1000}{2 \times 150 \times (150-30)} = 2.0725\ \mathrm{N/mm^2} \qquad (3.5)$$

For τ_c, A_{st}provided = 157 mm^2 (% steel = 0.87%).

Therefore τ_c= 0.6036 N/mm^2 and τ_{cMax}= 3.1 N/mm^2 (For M25 grade).

Now, we see that $\boldsymbol{\tau_{cMax}} > \boldsymbol{\tau_c} > \boldsymbol{\tau_v}$. So, designing for shear stress $\boldsymbol{\tau_v - \tau_c}$,

Design shear = $\tau_v - \tau_c$= 2.0725-0.6036= 1.4689 N/mm^2

The shear reinforcement for the above stress was provided in the form of perpendicular stirrups, the space of which can be calculated using the formula,

$$V_{us} = \frac{0.87\, f_y\, A_{sv} d}{S_v} \qquad (3.6)$$

Where V_{us}=1.4689×150×120 = 26.44kN, f_y =250 N/mm^2, d=120 mm, A_{sv}=100.53 mm^2

From the above formula S_V is calculated to 99.23mm. Therefore 90mm spacing provided for 4 numbers of 2-legged 10mm diameter stirrups.

3. RESULTS AND DISCUSSION

3.1 Experimental Results of Materials Used

- **Cement**

Specific gravity of cement – 3.13
Consistency of cement – 0.43

- **Aggregate**

Specific gravity of aggregate – 2.64
Finesses modulus for coarse aggregate– 2.68; Fine aggregates belongs from zone - II
Fineness modulus for fine aggregate – 7.20

- **Workability of concrete**

Slump value – 75mm, it verified that the degree of workability of concrete is medium and its compaction factor value is 0.92.

- **Compressive strength of cubes**

Table 4.1 Compressive Strength of cubes

S.No.	Cube – 1 (N/mm^2)	Cube – 2 (N/mm^2)	Cube – 3 (N/mm^2)	Average Compressive Strength (N/mm^2)
Day – 7	20.86	19.22	20.72	18.94
Day – 28	31.54	31.21	32.54	31.76

From the above result, it was easily conclude that the compressive strength of a cube specimen was 31.76 N/mm^2 and the result obtained verified that, the beam specimen casted earlier would resemble required strength and stiffness.

3.2 Experimental Result of a Beam Specimen

The surface deformations were visualized at the time of testing the specimen in four-point loading. The surface deformations for healthy state. The deformation for the healthy state was very negligible but present due to the excitation of the piezoelectric patch surface bonded in the rebar at a terminal voltage of 1 V that generated vibrations which travelled in beam specimen through the rebar. These deformation noted was very negligible and of order 0.02818mm. The deformations under moderate damage condition produced by 4-point loading of 30 kN. The deformation in moderate damage condition was increased and resulted to be of order 0.0845mm. In last stage, i.e. the final damage condition (severe state) a load of 200 kN was applied through 4-point loading setup, the surface damages that increased from the previous two damage states and deformation was noted as 0.564mm. These deformations was obtained from strain gauge through experimental analysis.

The value of stiffness can be easily calculated, from the above loading condition and deformation obtained. From the values of stiffness it was concluded that, the percentage change in stiffness from healthy state to moderate state was equal to 0.030%. Similarly, the percentage change stiffness from moderate state to sever state was equal to 0.042%.

4. CONCLUSION

4.1 Combined Conclusion

The main aim of this research work was to know the behavior of bond failure of reinforcing bar in flexural member using Electromechnical Impedance Technique of Structural health monitoring by experimental. In this of the damage detection method, it has been demonstrated and verified by experimental test results that bond failure of reinforced structures can be detected using embedded piezoelectric actuators and sensors built in the reinforced structures. Thus, it would help SHM to closely monitor the bond failure phenomenon in various structures in real-time.

Following conclusions can be drawn from this research work:

- Material that were used while casting has reliable property as per IS code specification and compressive strength of cube has an average value 31.76 N/mm^2 for M25 mix design , which verified that the beam specimen that was casted would resemble same property.
- Special attention has to been given in the selection of the frequencies. It has been seen that damage detection potential greatly depends on the frequency selection rather than on the level of the loading. This observation demonstrates that excitation loading sequence can have a level low enough that this technique may be considered as applicable and effective for real structures.
- The sensitivity for damage detection through EMI technique is closely associated to the frequency band selected. Thus, PZT sensors are scanned over a wide frequency range of 20-240 kHz in order to select a suitable frequency for acquiring the optimum signature.
- In this case study, EMI technique is beneficial in the range of 64 kHz – 68 kHz.
- The structural combination obtained from comparing the real part (x) and imaginary part (y) with the Hixon's table inferred that stiffness coefficient is the parameter that can be utilized to study the behavior of rebar bond failure.
- From experimental analysis, the load and deformation value gives the stiffness value in all three conditions and it was concluded that the change in stiffness in first stage 0.034% and in second stage the percentage change is 0.042%.
- The effect of the bond failure can be recognized on the basis of the percentage change in the stiffness of specimen in the three different stages obtained from the EMI technique analysis. As the flexural damage with subsequent bond failure progresses, in the first stage (i.e. Healthy to Moderate) stiffness decreases with a percentage decrease of 0.036% and in second stage (i.e. Moderate to Severe), the stiffness decreases with percentage change of 0.048%.
- From the above two conclusion, it was seen that in both experimental and EMI based method the value change in stiffness in both the stages is approximately same. So, based on this result it can be inferred, that the EMI based technique was reliable for bond failure analysis.
- The quantification of bond failure was done with the following damage indices technique Root Mean Square Deviation (RSMD) indices, Mean Absolute Percentage Deviation (MAPD) indices, Correlation Coefficient Deviation (CCD) indices.
- The known RMSD and MAPD indices provided a quantitative assessment of the examined flexural damage states (cracking and yielding) in time domain analyses

4.2 Future Scope and Recommendations

- The structural combination present in the Hixon's table gives equations for example, $x=c$ and $y=m\omega$, these equations does not contain stiffness parameter which should be present, as a concrete specimen always has stiffness. Thus Hixon's table needs to be updated for more precise results.
- Wireless smart sensors can be used for real time structural health monitoring, in order to avoid too much congestion of wires.
- As seen above, that PZT – patch was a highly sensitive material, even a small pressure will lead crack in it. So, properties of PZT can be improved for further investigation.
- Slight changes should be made in the reinforcement bar in reality, so that the PZT can be bonded to it without changing the properties of PZT.

5. References:

[1] M Balamurugan & R Santhosh (2017), "Influence of Egg shell Ash on the Properties of Cement", Imperial Journal of Interdisciplinary Research, 2017.

[2] D.Gowsika, S.Sarankokila, K.Sargunan (2014), Experimental Investigation of Egg Shell Powder as Partial Replacement with Cement in Concrete" International Journal of Engineering Trends and Technology (IJETT) –Volume14 Number 2–Aug2014.

[3] N. Parthasarathi, M. Prakash ,K. S. Satyanarayanan, "Experimental study on partial replacement of cement with egg shell powder & silica fume", Rasayan J. Chem., 10(2), 442 - 449(2017)

[4] IS 10262:2009, Bureau of Indian Standards, New Delhi, India.

[5] IS 456:2000 ,Bureau of Indian Standards, New Delhi, India.

[6] Bureau of Indian Standards, IS 4031 : 1968, For Determining the properties of Cement.

[7] Mohamed Ansari M, Dinesh Kumar M, Milan Charles J, Dr.Vani G, "Replacement of Cement using Eggshell Powder" SSRG International Journal of Civil Engineering (SSRG–IJCE) –Volume3 Issue3–March2016.

[8] Dr.Amarnath Yerramala "Properties of concrete with eggshell powder as cement replacement". The Indian concrete journal october 2014.

[9] DivyaB, Vasanthavalli K, Ambalavanan R, "Investigation on Cement Concrete at Mixed With Egg Shell Powder "International Journal of Innovative Research in Science, Engineering and Technology Vol. 6, Issue 3, March 2017.

[11] Aktan, A.E., Catbas, F.N., Grimmelsman, K.A. and Tsikos, C.J. (2000). "Issues in Infrastructure Health Monitoring for Management", Journal of Engineering Mechanics, 126(7): 711-724.

[12] Adams, R.D., Cawley, P., Pye, C.J. and Stone, B.J. (1978). "A Vibration Technique for Non-Destructively Assessing the Integrity of Structures", Journal of Mechanical Engineering Science, 20: 93-100.

[13] B. Savet Divsholi, and Y. Yang, "Application of PZT Sensors for Detection of Damage Severity and Location in Concrete", Proc. of the SPIE, The International Society for Optical Engineering, vol. 7268, art.no. 726813, 2008.

[14] Bing Chen, J. L. (November 2008). Damage in carbon fiber-reinforced concrete, monitored by both electrical resistance measurement and acoustic emission analysis. Construction and Building Materials , 2196–2201.

[15] Cao Jingyao, Chung D.D.L. "Degradation of the bond between concrete and steel undercyclic shear loading, monitored by contact electrical resistance measurement" Composite Materials Research Laboratory, State University of New York at Buffalo, Buffalo, NY 14260-4400, USA

[16] C. Lee, and S. Park, "De-Bonding Detection on a CFRP Laminated Concrete Beam Using Self Sensing-Based Multi-Scale Actuated Sensing with Statistical Pattern Recognition", Advances in Structural Engineering, vol. 15(6), pp. 919-927, 2012.

[17] C. P. Providakis, D.-P. N. Kontoni, M. E. Voutetaki, and M. E. Stavroulaki, "Comparisons of Smart Damping Treatments Based On FEM Modeling of Electromechanical Impedance", Smart Structures and Systems, vol. 4(1), pp. 35-46, 2008.

[18] C.P. Providakis, and E. Liarakos, "T-WiEYE: An Early-Age Concrete Strength Development Monitoring and Miniaturized Wireless Impedance Sensing System", Procedia Engineering, vol.10, pp. 484- 489, 2011.

[19] C.P. Providakis, and M. E. Voutetaki, "Electro-mechanical Admittance Based Damage Identification Using Box-Behnken Design of Experiments", Structural Durability and Health Monitoring, vol.3 (4), pp. 211-227, 2007.

[20] El-Borgi, S., Choura, S., Ventura, C., Baccouch, M. and Cherif, F. (2005). "Modal Identification and Model Updating of a Reinforced Concrete Bridge", Smart Structures and Systems, 1: 83-101.

[21] Esteban, J. (1996). "Analysis of the Sensing Region of a PZT Actuator-Sensor", Ph.D. Dissertation, Virginia Polytechnic Institute and State University, Blacksburg, VA.

Fairweather, J.A. (1998). "Designing with Active Materials: An Impedance Based Approach", Ph.D. Thesis. Rensselaer Polytechnic Institute, New York.

[22] Farrar, C.R. and Jauregui, D.A. (1998). "Comparative Study of Damage Identification Algorithms Applied to a Bridge: I. Experiment", Smart Materials and Structures, 7(5): 704-719.

[23] Giurgiutiu, V. and Zagrai, A.N. (2002). "Embedded Self-Sensing Piezoelectric Active Sensors for On-Line Structural Identification", Journal of Vibration and Acoustics, ASME, 124: 116-125.

[24] Giurgiutiu, V., Redmond, J., Roach, D. and Rackow, K. (2000). "Active Sensors for Health Monitoring of Ageing Aerospace Structures", Proceedings of the SPIE Conference on Smart Structures and Integrated Systems, SPIE 3985: 294-305.

[25] J. Wolf, S. P. (2015). Detection of crack propagation in concrete with embedded ultrasonic sensors. fracture mechanics .

[26] Kabir Md. Rashedul, Islam Md. Mashfiqul September 2014 “Bond stress behavior between concrete and steel rebar: Critical investigation of pull-out test via Finite Element Modeling” International Journal for Computational Civil and Structural Engineering.

[27] Kamada, T., Fujita, T., Hatayama, T., Arikabe, T., Murai, N., Aizawa, S. and Tohyama, K. (1997). “Active Vibration Control of Frame Structures with Smart Structures Using Piezoelectric Actuators (Vibration Control by Control of Bending Moments of Columns)”, Smart Materials and Structures, 6: 448-456.

[28] Kumar, S. (1991). “Smart Materials for Accoustic or Vibration Control”, Ph.D. Dissertation. Pennsylvania State University, USA.

[29] Lee C, Park S; De-bonding detection on a CFRP laminated concrete beam use self-sensing based multi-scale actuated sensing with statistical pattern recognition. Advances in Structural Engineering. 2012;15(6):919-927.

[30] Lynch, J.P., Partridge, A., Law, K.H., Kenny, T.W., Kiremidjian, A.S. and Carryer, E. (2003). “Design of Piezoresistive MEMS-Based Accelerometer for Integration with Wireless Sensing Unit for Structural Monitoring”, Journal of Aerospace Engineering, 16(3): 108-114.