Using Smart Phone Sensors to Undergo Structural Health Monitoring in RCC Structures

Swapnil Deshbhratar and Vikas Varekar

June 2, 2020

USING SMART PHONE SENSORS TO UNDERGO STRUCTURAL HEALTH MONITORING IN RCC STRUCTURES

[1]Swapnil Shekhar Deshbhratar, Department of Civil and Environment Engineering, Veermata Jijabai Technological Institute, Mumbai 400019, India
[2] Dr. Vikas Balasaheb Varekar, Assistant Professor, Department of Civil and Environment Engineering, Veermata Jijabai Technological Institute, Mumbai 400019, India
Email: swapnildeshbhratar@gmail.com, vbvarekar@ci.vjti.ac.in

ABSTRACT

The engineering structures may fail due to the damage in material or change in their geometric properties. Thus the main aim of Structural Health Monitoring is to perform as an alert system or alarm at the time of initial stages of damages and avoid further propagation of failure inside the structure. To determine the health of an infrastructure, structural auditing is done by standard non-destructive and destructive tests which are in-situ, are instantaneous and are relied by the engineers. Due its instantaneous nature, this method maybe laborious when it is tested for determining the service life of a structure or its member (as the use of structure is continuous). The auditing done by the standard NDTs and destructive test in frequent and continuous fashion could be labour and cost intensive. Henceforth, a continuous monitoring system is to be used which can have capacity to record continuous data in very short time frequency, over long time span with high accuracy. For this, accelerometer sensor from the smart phone is used and data is recorded and stored in memory device of the smart phone. To record the data, a residential building which was reported weakening of slab member is taken as a case study and smart phone is placed over a slab surface. Sensor is recorded to its maximum sensitivity and then levelled before using it. Then the data is collected from the memory storage in the form of accelerations (m/s^2) and statistical data is compiled from it. In general when accelerometer levelled it reads as (1,0,0), (0,1,0), (0,0,1) towards x, y, z axis respectively. When the sensor moves, it changes it acceleration towards three different axis and the resultant acceleration is calculated. Standard deviation of the sensor data came out to be 0.004 and member was deflecting with 0.006 m/s^2 which is very low, thus it was concluded that the member is safe in service condition. As smart phone can improve great mobility, better accessibility, high memory storage capacity, ease of use, low in cost and highly sensitive to the movement. Hence, it is an ideal choice to use smart phone as a sensor for structural health monitoring of RCC structure.

Keywords: *Structural Health Monitoring (SHM), Reinforced Concrete Structures (RCC), Accelerometer, Standard Deviation*

1. INTRODUCTION

Life of a structure in India is predicted and designed to perform 50 years without failure of any member of the structure. Sometimes there are some unforeseen circumstances which couldn't be controlled like environment, earth quakes and extreme wind loads etc. Most of the failures are caused by the overloading of the members over long period of time. Although this failure could be detected by the Structural Health Monitoring (SHM) sensors on the real time basis. Conventional Non Destructive Tests (NDT) are slow and inefficient as compared to SHM.

Bastien (2018), explained the use of SHM system in the field of repairs and rehabilitation and identified the use of sensors, but it failed to explain the working of sensors used and its design. Thus SHM considers to replace the conventional methods in terms of mechanisms used to modify responses in changed circumstances resulting in increase in reliability, utility and minimization of maintenance work. There are other benefits such as life extension of ageing structures, integration of design of structure including its complete management, damage identification of structure, changing the older inspection to condition-based maintenance, which helps to use the talents of engineers to look ahead to public safety.

Islam et al. (2010), studied the use of sensors used in SHM and applied in a bridge in Youngstown, Ohio. SHM is used for inspecting old buildings and bridges regarding the faltering strength, to study the different environmental factors that may have been skipped during building process, looking for safety concerns, focusing not only on industry purposes but also on public safety. Xuefeng et al. (2015), used cloud based structural health monitoring using smartphones in the large span bridges using smartphone applications using accelerometer sensor which helped to record the data which is then transferred to the cloud which helped to process the data. These sensors are the accelerometer chips which measure proper acceleration. Proper acceleration, being the acceleration of a body in its own instantaneous rest frame which is not same as coordinate acceleration but being the acceleration in a fixed coordinate system. Scuro et al. (2018), introduced use of Internet of Things in the field of SHM and co-related the use of SHM in public safety and development of smart cities. Hence with these sensors which are placed over different points of the members, deflection is measured for a whole day and readings are recorded in the database. User can access this database using Ethernet and can set a cut-off points over the reading. If any reading exceeds the cut-off, it will warn the user with means of notification on their desktop or cellular device. This sensors are placed in such way that they will detect any deflection in members.

The objective is to find out deflections in a member in the form of accelerations. Hence it is possible to use such type of sensor with use of accelerometer in the smartphone to determine the deflection by structural member. It is also focused in making this use of sensors and SHM financially economical by using these cheap accelerometer chipsets and placing sensors at critical points throughout the span to measure deflections in the structure.

2. MATERIALS AND METHODOLOGY

Smart phone is being used as a sensor for Structural Health Monitoring. In this, accelerometer chip of the cell phone has being used to determine any deflections made by RCC member. Readings from this comes in accelerations made against gravity i.e. G-force. In this, I2C 3-axis accelerometer sensors of smart phone are being used to carry out structural health monitoring of a structural member. To read accelerometer data an android application had been installed named as Physics Tool Box Pro Version 1.9.4.5. It has been developed by Vieyra Software which provide low cost data analysis tools open to public use based on Washington DC, USA.

Firstly calibrate the sensor by tapping gear icon and then tap Calibrate the g-Force Meter option in the lowest most option in the menu. After calibration tap again gear icon and tick mark the graph option, g-Force, show X, show Y, show Z and clock time. To set the sensitivity of sensor there is an option High, Low and Custom. Accelerometer measure the data by the frequency, suppose sensitivity set 20 Hz i.e. in one second it will record data up to 20 times. Maximum frequency varies from low end sensors to high end sensors. For measurement tap to "+" with red background fill icon and when data collection time is done then tap to square with red background fill that will stop the data collection. Name the file required and it will saved automatically on the cell phone's memory. SHM is done by using smart-phone as sensor which measures the acceleration data for any sudden deflections or vibrations made by the structural member. These deflections readings are recorded by the sensor and file is compiled by using .csv format of Microsoft Excel. From these files, data is extracted for measures of central tendencies, standard deviations and plotting the relevant graphs and the results are made. To determine peak deflection from the sensor, concrete cube of M-25 grade is to be casted and tested as per IS code 516. Cubes are made from cube molds of dimension 150mmX150mmX150mm which are machine mixed, tamped into 3 layers with tamping rod 35 times.

These cubes are then cured in curing pond at temperature maintained at 27°C for 7 days and 28 days. The standard peak deflection after failure of concrete cubes is found out by lab tests. On the basis of standard peak deflections by the testing cubes, in-situ RCC member deflections are correlated and the conclusions are made.

Quantity of material per m^3
Cement = 450 kg
Water = 213.9 kg
20mm Coarse Aggregate = 589.12 kg
10mm Coarse Aggregate = 522.80 kg
Fine Aggregate = 578.94 kg

As per above mix, concrete cubes are casted and tested on compression testing machine. The smart phone should be placed in such way that,

(i) It should not tamper the testing process.
(ii) It should stick on concrete surface firmly.
(iii) It should not come in contact with the surface of testing machine.

2.1 Lab test for SHM using concrete cube as sample

2.1.1 Case 1
Age of cube = 7 days
Weight of sample = 8.159 Kg
Crushing load = 248.5 KN
Compression strength = 11.04 N/mm^2

Table 1. Statistical data collected from sensor generated by application package of smart phone.

Statistical Data from sensor	
Mean	0.998803
Median	1
Mode	1
Minimum	0.95
Maximum	1.37
Standard Deviation	0.00406
Variance	1.65E-05

Testing start time: 10:18:46 AM
Testing failure time: 10:21:01 AM
Testing end time: 10:21:01 AM

2.1.2 Case 2
Age of cube = 7 days
Weight of sample = 8.353 Kg
Crushing load = 289.4 KN
Compression strength = 12.86 N/mm^2

Statistical Data from sensor	
Mean	1.001292
Median	1
Mode	1
Minimum	0.73
Maximum	1.46
Standard Deviation	0.010087
Variance	0.000102

Testing start time: 10:24:51 AM
Testing failure time: 10:25:02 AM (0.73) & 10:25:06 AM (1.46)
Testing end time: 10:27:07 AM

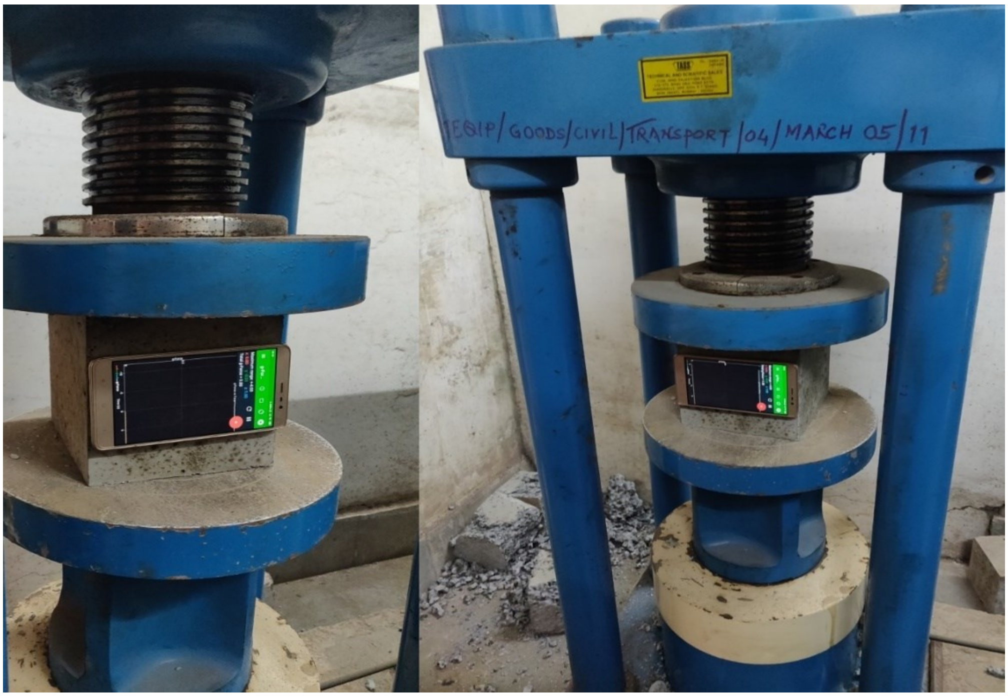

Figure 3. Testing of concrete cubes in which smart phone used as sensor for SHM

2.2 In-situ test for SHM in RCC structures

Site visit is done on a residential cum commercial structure. On the ground floor and first floor there is a hospital mean-while from the second floor residential complex starts. First two floors of hospital have basic medical equipment including sonography machines. Meanwhile 6 months back there was fire outbreak in the first floor of the building. This resulted in weakening of members especially on slabs. Readings from this comes in accelerations made against gravity i.e. G-force. During testing building is being continuously used by residents and made sure no tampering was done to the device and to the readings. Thus cell phone is placed on slab of first floor and readings are taken for a time span of 13 minutes.

Statistical Data	
Range	0.448
Minimum	0.798
Maximum	1.246
Average	0.994568438
Median	0.995
Mode	0.994
Standard Deviation	0.004850909
Variance	2.35313E-05

Start time: 21:22:14 PM
End time: 21:35:20 PM

Figure 4. Testing site for SHM using smart phone as sensor

3. RESULT AND DISCUSSION

Laboratory test results

For Case 1

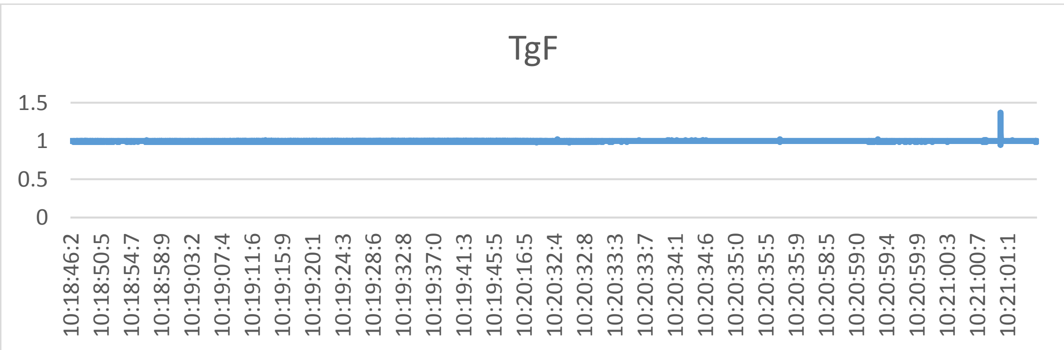

Figure 1. Graphical representation of sensor deflection over the time of testing

Interpretation from above data

The concrete sample fails at crushing load of 248.5 KN by Compression Testing Machine with the sample cured for 7 days at curing pond. As the weight of ideal concrete sample should be ranging from 8.1 Kg to 8.5 Kg and weight of the sample comes out to be 8.159 Kg, thus the readings from the sample should be accepted. From the sensor data acquired, deflection was up to 0.95 and 1.37 accelerations which means the sample is failed at that time. The graph is plotted between the deflection vs time, on X-axis of graph shows the time of data collection by sensor meanwhile on Y-axis of graph shows the resultant deflection made by the test subject which is ranging from (0 to 1.6)

For Case 2

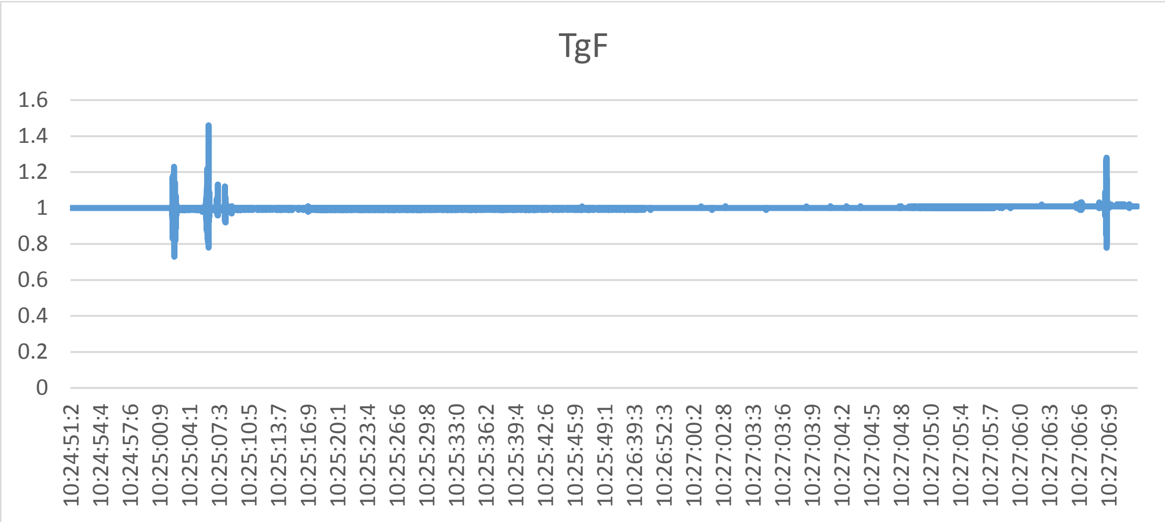

Figure 2. Graphical representation of sensor deflection over the time of testing

Interpretation from above data

The concrete sample fails at crushing load of 289.4 KN by Compression Testing Machine with the sample cured for 7 days at curing pond. As the weight of ideal concrete sample should be ranging from 8.1 Kg to 8.5 Kg and weight of the sample comes out to be 8.353 Kg, thus the readings from the sample should be accepted. From the sensor data acquired, deflection was up to 0.73 and 1.46 accelerations which means the sample is failed at that time. This also gives an implication that the test subject started to fail just before its critical failure point at the time of 10:25:02 AM. The test subject although failed in compression testing machine at the time of 10:27:06 AM. The graph is plotted between the deflection vs time, on X-axis of graph shows the time of data collection by sensor meanwhile on Y-axis of graph shows the resultant deflection made by the test subject which is ranging from (0 to 1.6). The start and end point of graph signifies the starting and ending of testing.

For in-situ test

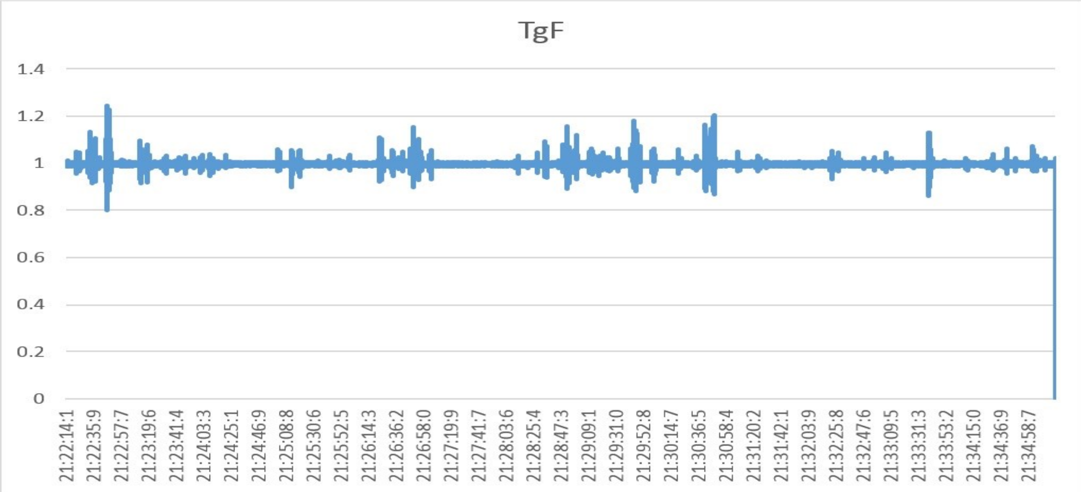

Figure 4. Testing of RCC structure in which smart phone used as sensor for SHM

Interpretation from above data

As structural member is deflecting at normal range at 0.006 m/s^2 although extreme readings may be due to slight sudden movement of sensor or any physical unknown factors. When the sensor data shows G-force 1 then it means that there is no sudden deflection in the member. As per measure of central tendency 0.994 is most recurring and the readings from the sensor lie mostly near the mean of readings because of low standard deviation. At its normal service life and there no threat to its entire structural integrity till now. The graph is plotted between the deflection vs time, on X-axis of graph shows the time of data collection by sensor meanwhile on Y-axis of graph shows the resultant deflection made by the test subject which is ranging from (0 to 1.4). The start and end point of graph signifies the starting and ending of testing.

As the traditional Non Destructive Tests are instantaneous, slow, tedious and costly thus a use of Structural Health Monitoring is implemented on site. SHM sensors are costly, complicated and more research is to be conducted so as to be implemented by the engineers on site. Hence one of the most cheapest, readily available and low maintenance sensor used is the accelerometer which can be found in every smart phones of this decade. The use of this sensor could help any engineer as in great mobility, better accessibility, high memory storage capacity, ease of use, low in cost and high sensitivity to the sudden movement. The lab tests and in-situ tests gives the overall idea about the use of sensors in the actual site with much more promising results and less complicated manner.

4. CONCLUSIONS

Movements are caused in structures by the sudden load implied and change in load on it. Thus to measure the magnitude of movements smart phone sensors are used. These smart phone sensors are used on lab made concrete cube samples and in-situ RCC structure. From the lab results there were two different cases in which failure of cube sample can occur. In the first case of lab test, measure of central tendencies shows that most of the time cube samples are not deflecting till the end. Standard deviation for the given samples are 0.00406, which is very low. The cube sample fails at the maximum deflection at 1.37 m/s^2. The graph plotted between the deflection vs time, gives the idea of failure and nature of cube samples in loading which is measured by the sensor.

In the second case of lab test, measure of central tendencies shows that the cube were not deflecting till the end of test. Although standard deviation which is 0.010087 of the above tests show it otherwise, as it is much higher than ordinary results. The graph was plotted between the deflection vs time, gives the idea that the cube sample started to fail in between the test with the highest recorded deflection of 1.46 m/s^2 at that time. Although cube sample failed at 1.31 m/s^2 at the end but sudden deflection made by the sample is questionable. This could mean anything like cracking on the surface, improper mix design and casting techniques or any other failure modes of concrete. Thus in the lab tests done on the concrete cubes samples maximum safe deflection is found out to be 1.30 m/s^2. Deflections above 1.30 m/s^2 in any RCC structures are deemed to be unsafe when measured by the smart phone sensor.

In the in-situ test a RCC building is tested by using the smart phone sensor. The measure of central tendencies came out to be 0.994 m/s^2 which means most of the time sensors are deflecting at 0.006 m/s^2. The standard deviation is 0.0048 which is favourable, as most of the deflections lie between 0.994 m/s^2 to 1 m/s^2. From the graph plotted between deflections vs time, it gives clear idea that at the service use the structure may deflect up to 1.246 m/s^2 which is ok. Although from the site visit it was clear that retrofitting is needed to cover up the reinforcement.

ACKNOWLEDGEMENT

It is great pleasure to acknowledge the assistance and contribution of our own effort. I had always been grateful for the support that we got from all my surroundings with respect knowledge and support. I sincerely acknowledge to my guide Dr. Vikas Varekar, whose continuous encouragement and support enabled to materialized and contributed to its success. I am also thankful to whole Civil and Environmental Engineering Department, Veermata Jijabai Technological Institute, Mumbai for their constant support and providing infrastructural facilities and testing equipment. Finally, I am thankful to all my family and friends for their constant inspiration, support and encouragement.

REFERENCES

AKM Anwarul Islam, Ph.D., P.E., Frank Li, Ph.D, Phaneendra K. Kolli, “Monitoring Structural Health of a Bridge using Wireless Sensor Network”, 2010 Structures Congress ASCE.

Bastien Chapuis, “Introduction to Structural Health Monitoring”, Springer International Publishing AG 2018.

Carmelo Scuro, Francesco Lamonaca, R.S. Olivito, Domenico Luca Carni, “ IoT for Structural Health Monitoring”, IEEE Instrumentation & Measurement Magazine 2018.

Xuefeng Zhao, Yan Yu, Mingchu Li, Jinping Ou, “Cloud-structural health monitoring based on smartphones”, JVE International Ltd. VIBROENGINEERING PROCEDIA SEP 2015, Volume 5 ISSN 2345-0533.