IITB-Monash Research Academy

Indian Institute of Technology Bombay | MONASH University

An Indian-Australian research partnership

Project Title:	**Development of Smart FRP Rebars for Health Monitoring of Concrete Structures**
Project Number	**IMURA1155**
Monash Main Supervisor (Name, Email Id, Phone)	A/Prof. Ye Lu — *Full name, Email*
Monash Co-supervisor(s) (Name, Email Id, Phone)	
Monash Head of Dept/Centre (Name,Email)	A/Prof. Ha Bui, ha.bui@monash.edu — *Full name, email*
Monash Department:	Department of Civil Engineering
Monash ADGR (Name,Email)	A/Professor Timothy Scott, timothy.scott@monash.edu — *Full name, email*
IITB Main Supervisor (Name, Email Id, Phone)	Prof. Arghadeep Laskar — *Full name, Email*
IITB Co-supervisor(s) (Name, Email Id, Phone)	Prof. Sauvik Banerjee — *Full name, Email*
IITB Head of Dept (Name, Email, Phone)	Prof. Deepankar Choudhury — *Full name, email*
IITB Department:	Civil Engineering

Research Clusters:

Research Themes:

Highlight which of the Academy's CLUSTERS this project will address? *(Please nominate JUST **one.** For more information, see www.iitbmonash.org)*		**Highlight which of the Academy's Theme(s) this project will address?** *(Feel free to nominate more than one. For more information, see www.iitbmonash.org)*	
1	*Material Science/Engineering (including Nano, Metallurgy)*	***1***	*Artificial Intelligence and Advanced Computational Modelling*
2	*Energy, Green Chem, Chemistry, Catalysis, Reaction Eng*	2	*Circular Economy*
3	*Math, CFD, Modelling, Manufacturing*	3	*Clean Energy*
4	*CSE, IT, Optimisation, Data, Sensors, Systems, Signal Processing, Control*	4	*Health Sciences*
5	*Earth Sciences and Civil Engineering (Geo, Water, Climate)*	5	*Smart Materials*
6	*Bio, Stem Cells, Bio Chem, Pharma, Food*	6	*Sustainable Societies*
7	*Semi-Conductors, Optics, Photonics, Networks, Telecomm, Power Eng*		
8	*HSS, Design, Management*		

The research problem

Indian Standard (IS) on Plain and Reinforced Concrete Code of Practice [1] considers a design life for reinforced concrete structures as 50 years, while the Canadian Highway Bridge Design Code [2] considers a service life of 75 years for newly constructed bridges. During the service life of a structure, the concrete is quite often exposed to aggressive environment that causes its deterioration. This results in a significant reduction in its service life, and in few cases, may result in catastrophic damage and fatalities to property and lives. The National Crime Records Bureau [3] statistics reported that a total of 13,178 people lost their lives in India between 2010 and 2014 in accidents where buildings, flyovers or other structures have failed/collapsed. The study further reported that the collapse of residential buildings caused 4,914 fatalities between 2010 and 2014, which accounts for about 37.3 per cent of the total number of deaths. Another major reason for collapse of structures before their design life is the unrealistic loading conditions assumed at design stage. A study published in MEICON [4] points out the ludicrous magnitude of imposed loads that exist in commercial buildings and the inadequate interpretation of the imposed-loads acting on the structure that could cause unexpected catastrophic failures.

The proposed research will be focused upon analysing the monitoring capabilities of smart fiber reinforced polymer (FRP) bars with embedded Fiber Bragg Grating (FBG) sensors and piezoelectric wafer transducers (PWTs). These smart FRP bars can be either installed in concrete during maintenance and conservation or embedded in concrete during casting of concrete structural members. Both Fiber Optic Sensing (FOS) and acousto-ultrasonic (AU) techniques will be utilized to detect the various modes of material failure in reinforced concrete structure. It is expected that the proposed research will lead to the progressive accomplishment of further phases of the research.

REFERENCES

[1] Bureau of Indian Standards, "IS 456, Indian Standard Plain and Reinforced Concrete Code of Practice," 2000.

[2] CSA, "Canadian Highway Bridge Design Code," Ontario, Canada, 2006.

[3] Rakesh Dubuddu, "Between 2001 & 2015, an average of 7 people died per day in Collapse of Structures including Buildings," *National Crime Records Bureau, Factly*, pp. 1–8, 2019.

[4] MEICON (s.d.), "Mythbusters [online]," *Avaiable at www.meicon.net/mythbusters*.[5]

Project aims

The over-reaching goals of the proposed project are as follows:

- To document past and present research available on state-of-the-art structural health monitoring (SHM) for various infrastructure systems based on Fiber Bragg Grating (FBG) based FOS technology and acousto-ultrasonic (AU) techniques
- To experimentally examine the efficacy of smart FRP bars with embedded FBGs and PWTs in evaluating the performance of concrete members under loading.
- To experimentally evaluate the degradation of bond characteristics at the interface of FRP bars and concrete using guided wave based SHM with embedded PWTs.
- To further evaluate the capabilities of embedded PWTs to acquire the acoustic emission waveforms generated due to micro-cracking for damage assessment of concrete members.
- To develop a custom-built SHM system using a combination of FOS, AU, optical interrogator, 5G network using the data retrieved during the laboratory experiments.
- To subsequently present/publish the research findings in conferences/journals.

What is expected of the student when at IITB and when at Monash?

Highlight how the project will gain from the students stay at IITB and at Monash

1. Portion of Research to be conducted at IIT Bombay:

A. Research Planning

- **Systematic Review of Research Work:** A systematic review of FOS and AU technologies and their applications in SHM of bridges and buildings will be performed, by keeping track of latest research. This will be done by studying the related articles published in reputable peer-reviewed journals and preparing a review report on the up to date developments in the area of the proposed research.

- **Identification of Areas of Improvement**: The issues related to SHM of infrastructure system particularly in the use of FOS, AU and Smart Bar technology which needs to be tackled, and further research will be explored through extensive literature survey.

- **Identifying Beam Specimens:** As per the dimension of the available testing frame, steel reinforced concrete beams (new and selectively weakened) will be identified and casted. Further, reinforced concrete beam specimens with smart FRP bars will also be designed and casted.

- **Identifying FOS Arrays:** The FOS arrays (location, number and Bragg wavelengths of the FBG sensors) to be embedded inside the FRP bar will be identified.

- **Identifying PWT Arrangement:** The PWT arrangement (location, number and configuration of the PWTs) to be instrumented on the embedded FRPs and concrete specimens will be identified.

B. Experimental Investigation

- **Procurement of Optical Interrogator, FOS and PWTs:** The FBG arrays to be embedded in FRP bars and PWT patches to be applied on the embedded FRP bars and the concrete specimens, as finalized during the research planning stage will be procured and applied at respective application locations.

- **Calibration of FOS and PWTs:** Appropriate calibration tests will be performed to determine the strain sensitivity coefficient for the FBG sensors and calibrate the AE signals for various modes of material failure in FRP reinforced concrete members under laboratory-controlled conditions.

- **Smart Bar Production:** The smart-bars will be manufactured by embedding FBG sensors into FRP bars at an FRP manufacturing plant.

- **Supplementary Products:** Certain supplementary fixtures (e.g., end connectors) are required along with smart-bars to protect the ingress and egress points of the sensor into the FRP bar.

- **Experiment:** The long-term monitoring capabilities of smart-bars will be evaluated under laboratory-controlled environment. The degradation of the bonding properties at the interface of FRP bars and concrete using guided waves from embedded PWTs will also be evaluated. Further, acoustic emission waveforms acquired by the embedded PWTs shall be used for damage assessment of concrete members.

- **Conclusion:** The data gathered through all sensors can be utilized for the development of damage index matrix that can identify and predict emerging failure modes.

- **Report Generation:** A research report will be prepared on the basis of the research work undertaken. The work being proposed and the results of the research will be published.

2. Portion of Research to be conducted at Monash University

C. Finite Element Simulation and Development of IOT Platform

- **Finite Element Simulations:** Appropriate FE simulations will be conducted on the beam specimens to predict the failure stress, strain and cracking pattern before the final experiment.

- **Development of Cloud Based Wireless Technology:** The study will focus on developing an IOT platform for remote monitoring techniques and remote data collection and processing so that a researcher or maintenance engineer can remotely collect relevant data without going for site visit. With the use of wireless technology, structural condition can be monitored in a remote office by means of a desktop computer or a mobile application.

- **Use of Information Retrieval Methods:** The algorithms for data retrieval and data interpretation from the information received from the logging system may be refined and would be applied to improve upon its effectiveness.

- **Assessment of the Proposed Methods:** The proposed methods would be evaluated upon various criteria.

- **Report Generation:** A research report will be prepared on the basis of the research work undertaken. The proposed work and the results of the research will be published.

Expected outcomes

The outcomes from the present research will result in a framework for integrating the information collected from FRP smart-bars (with embedded FBGs and PWTs) installed within the structure for damage assessment in concrete using FOS and AU techniques. Subsequently, the research will utilize IOT to create a conducive environment to implement real-time SHM system and make it comprehensible to the end-user, visible in their mobile application with the data presentation in the form of simple holograms and charts. This level of preparedness is paramount for real-time field applications of SHM systems which will replace the old and obsolete methods of inspection and monitoring and also protect the integrity of our old and heritage structures.

How will the project address the Goals of the above Themes?

It is quite common nowadays to hear about smart-watches or health-tracking devices that can detect the human health condition on a real time basis and intimate the users regarding their health condition and if they need to see a doctor. A similar concept of a health monitoring system for **sustainable smart infrastructural societies** can be imagined which consists of a basic set of digital transducers (sensors) which are applied on infrastructures such as bridges and buildings. These sensors can be embedded/mounted on structural elements to be monitored. An optical interrogator/data acquisition (DAQ) system can be installed close to or within the structure for the collection of optical & acousto-ultrasonic signals. The interrogator/DAQ can be placed inside a leak-proof casing and used for data transmission to the operator of the system. The next most important component part of the system is the visual interface to process the accumulated raw data and to convert it into simple hologram and charts comprehensible to the end user. This integrated self-sensing system can allow the user to track the health status of the infrastructure through their smartwatches or mobile phones.

The proposed research enables a system for data-interpretation in real-time which will be visible to all the users in a smart-screen installed near the structure. Based on the inbuilt algorithms, the system will detect the levels of damages incurred within the infrastructure and send warnings to the user if the conditions of the structure become unserviceable; thereby making the infrastructure smart and sustainable.

The excellent sensing characteristics of the smart FRP bar and the ease of implementation of the developed novel embedment technique indicates that the novel smart FRP bar manufactured using the developed technique has a great potential to build a smart infrastructural society. Timely maintenance or rehabilitation of the infrastructures is possible with these smart bars resulting in a considerable long-term saving in life and economy.

The above vision of building a smart infrastructural society can be achieved through a two-fold process. Firstly, the ease of producing smart materials needs to be addressed efficiently to convince the manufacturers to adopt this technology in their production plants. The past study has unequivocally solved the first-fold of the problem by disclosing the technique to the manufacturer of normal FRP bar using a simple yet sophisticated model to convert any production line into a smart production line. Currently, there are no strict guidelines to monitor the health of a structure over its life-span. SHM of engineering structures should be a mandatory regulation for every construction to ensure the safety of the end-users. Thus, as a second step towards the development of a smart infrastructure society, it is crucial to introduce guidelines to use these smart materials as a built-in real-time data monitoring device for medium and large-scale infrastructural projects. This above-mentioned objective can be achieved by building a prototype smart-colony which would serve as an exemplar for the construction industry and provide sufficient data to include smart bars in the upcoming design codes and guidelines.

Potential RPCs from IITB and Monash

IITB:
Prof. Ravi Sinha
Prof. Jayadipta Ghosh

Monash:
A/Prof. Colin Caprani
Prof. Wenhui Duan

Capabilities and Degrees Required

Master's degree in Civil Engineering with Specialization in Structural Engineering.
Prior experience in the areas of large-scale structural testing/structural health monitoring/Fiber Optic Sensor/Wireless Sensors and IoT.

Necessary Courses

Students should have adequate exposure to the following courses:
Structural Dynamics
Finite Element Methods
Concrete Structures

Additionally, selected students would be required to take following courses during PhD program
Non-Destructive Testing of Materials
Fiber Optic Communications
Signal Processing and its Applications

Potential Collaborators

Prof. Siddharth Tallur, Department of Electrical Engineering, IIT Bombay
Prof. Asim Tewari, Department of Mechanical Engineering, IIT Bombay
Prof. W.K. Chiu, Department of Mechanical and Aerospace Engineering, Monash University

Select up to **(4)** keywords from the Academy's approved keyword list **(available at http://www.iitbmonash.org/becoming-a-research-supervisor/)** relating to this project to make it easier for the students to apply.

Cloud Computing
Sensor and Sensor Networks
Next Generation Infrastructure
Modelling and Simulation