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STRUCTURAL HEALTH MONITORING OF CIVIL INFRASTRUCTURE

Danish Zaman[1], Amir Ali[2], Ayush Singh[3]

[1,2,3]Department of Civil Engineering,

IIMT College of Engineering,Greater Noida,Uttar Pradesh, (India)

ABSTRACT

There is a phenomenal rise in construction activities in the field of civil engineering in the recent years. Major structures like buildings, bridges, dams are subjected to severe loading and their performance is likely to change with time.It is therefore, necessary to check the performance of a structure through continuous monitoring by help of structural health monitoring.. Reduction of inspection costs, research, with the possibility to better understand the behavior of structures under dynamic loads, seismic protection, observation, in real or near real-time, of the structural response and of evolution of damage, so that it is possible to produce post-earthquake scenarios and support rescue operations, are the main advantages related to the implementation of such techniques.

Keywords: Structural Health Monitoring, Seismic Monitoring Network

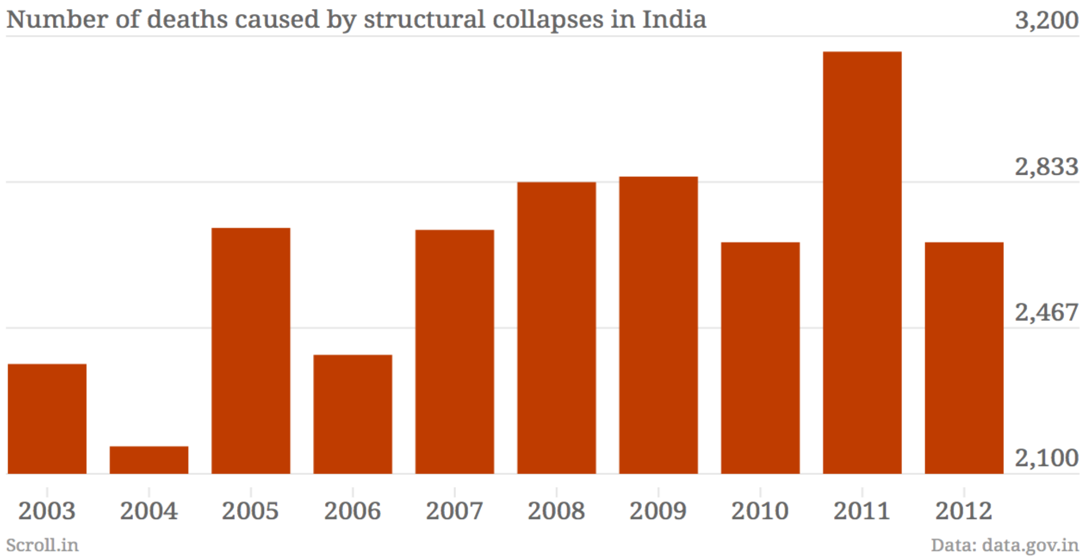
I. INTRODUCTION

Civil infrastructures including bridges and buildings, begin to deteriorate once they are built and used. Maintaining safe and reliable civil infrastructures for daily use is important to the well being of all of us. Knowing the integrity of the structure in terms of its age and usage, and its level of safety to withstand infrequent but high forces such as overweight loads, earthquakes, and fatigue is important and necessary. The process of determining and tracking structural integrity and assessing the nature of damage in a structure is often referred to as health monitoring.

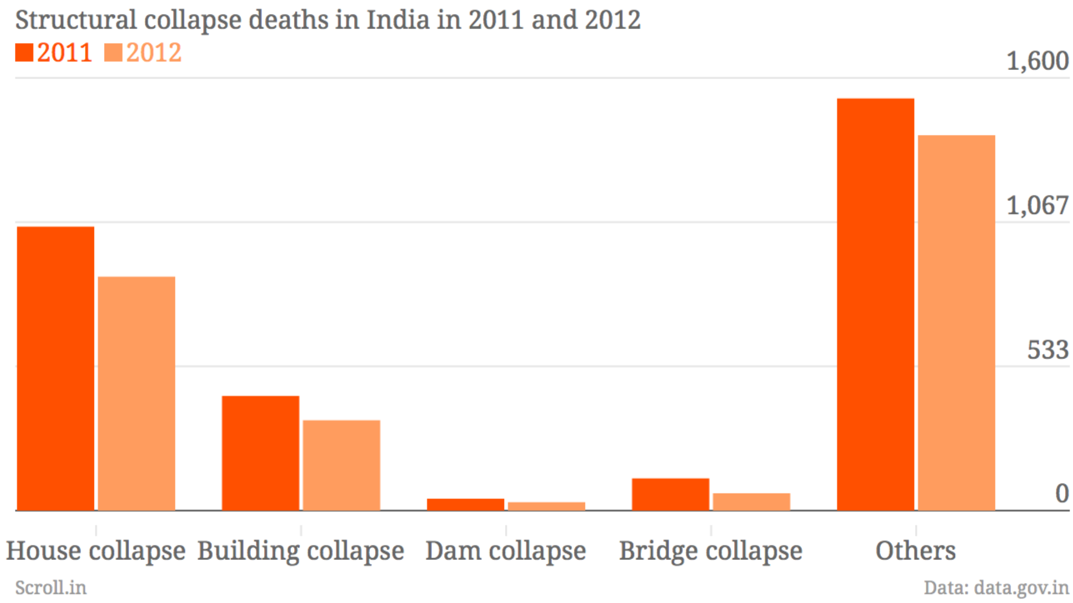
Structural health monitoring and damage identification are assuming larger and larger importance in civil engineering. Structural Health Monitoring (SHM) is defined as the use of in-situ, non-destructive sensing and analysis of structural characteristics in order to identify if a damage has occurred, define its location and estimate its severity, evaluate its consequences on the residual life of the structure [1]. Even if SHM is a relatively new paradigm in civil engineering, the assessment of the health state of a structure by tests and measurements is a common practice, so that evaluation and inspection guidelines are available since a long time [2]. SHM objectives are consistent with this practice but it takes advantage of the new technologies in sensing, instrumentation, communication and modeling in order to integrate them into an intelligent system.Information obtained from such systems could be useful for maintenance or structural safety evaluation of existing structures, rapid evaluation of conditions of damaged structures after an earthquake, estimation of residual life of structures, repair and retrofitting of structures, maintenance, management or rehabilitation of historical structures.

II. PREVAILING CONDITION IN INDIA

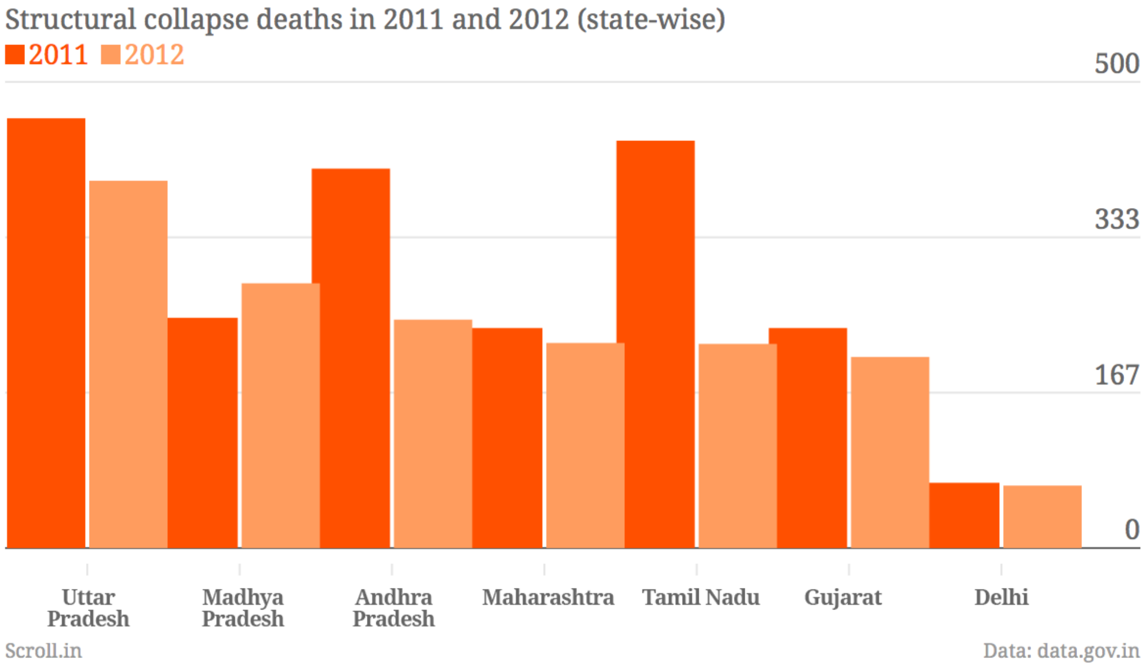
Every year, India loses an average of 2,658 people to different kinds of structural collapses[3]; that is around 7 deaths a day. 2011 saw the highest fatalities in ten years, 3161 deaths.Every year, India loses an average of 2,658 people to different kinds of structural collapses; that is around 7 deaths a day. 2011 saw the highest fatalities in ten years,3161 deaths.



The structural collapses recorded in the official data include broken houses, buildings, bridges and even dams, among others. Of these, most are houses and buildings, accounting for an average of 1,260 deaths a year.



In the case of buildings and houses, most accidents tend to occur in populated cities and towns, where dense living conditions result in higher fatalities whenever a mishap occurs. In Mumbai alone, there are reports of a major building collapse every few weeks. Nationally, Uttar Pradesh, Tamil Nadu, Madhya Pradesh, Maharashtra, Andhra Pradesh and Gujarat have been reporting more than 150 deaths each year.Builders and residents of structures are often careless about the quality of construction material and the subsequent maintenance of a finished building [4].



III. STRUCTURAL HEALTH MONITORING

Structural health monitoring (SHM) is a process in which certain strategies are implemented for determining the presence, location and severity of damages and the remaining life of structure after the occurrence of damage. This term is usually referred to aerospace, civil and mechanical engineering infrastructure. It is the continuous measurement of the loading environment and the critical responses of a structural system or its components. Health monitoring is typically used to track and evaluate the performance, symptoms of operational incidents and anomalies due to deterioration or damage as well as health during and after extreme events. Damage identification is the basic objective of SHM.

There are mainly four levels in damage identification [5]:

Level 1: Determination that damage is present in the structure

Level 2: Level 1 plus determination of the geometric location of the damage.

Level 3: Level 2 plus quantification of the severity of the damage

Level 4: Level 3 plus prediction of the remaining service life of the structure.

SHM involves the observation of a system over time using periodically sampled dynamic response measurements from an array of sensors, the extraction of damage-sensitive features from these measurements, and the statistical analysis of these features to determine the current state of the system health. For long term SHM, the output of this process is periodically updated to provide information regarding the ability of the structure to perform its intended function in light of the inevitable aging and degradation resulting from operational environments. After extreme events, such as earthquakes or blast loading, SHM is used for quick condition screening and aims to provide, in near real time, reliable information regarding the integrity of the structure.

Health monitoring has gained considerable attention in the civil engineering community over the last two decades. Although health monitoring is a maturing concept in the manufacturing, automotive and aerospace industries, there are a number of challenges for effective applications of the concept on civil infrastructure systems. While successful real-life studies on new or existing structures are necessary for transforming health monitoring from research to practice, laboratory benchmark studies are also essential for addressing issues related to the main needs and challenges of SHM. Although it is still mainly a research area in civil infrastructures, it would be possible to develop successful real-life health monitoring systems if all components of a complete health design are recognized and integrated. Hence, SHM offers great promise for civil infrastructure implementations.

IV. NEED OF SHM

Appropriate maintenance prolongs the life span of a structure and can be used to prevent catastrophic failure. Higher operational loads, complexity of design and longer life time periods imposed to civil structure make it increasingly important to monitor the health of these structures. Economy of a country depends on the transportation infrastructures like bridges, railways, roads etc. Any structural failure of these causes severe damage to the life and economy of the nation. Every nation is spending millions of Dollars every year for the rehabilitation and maintenance of civil engineering structures. Failure of civil infrastructure to perform at optimum level may effect the gross domestic production of the country. Strength of structures decreases due to continuous loading and impact of environment. Hence, it should be evaluated if the performance of the structure is satisfactorily or not after such deterioration. If structural strength falls down below a certain threshold level, sudden failure is possible which might result in accident and affect the serviceability of the structure. Early detection of damage is of special concern for civil structures. If not identified in time, damage may have serious consequences for safety of occupants. There are several natural events which may affect the strength of structure. It should be ensured that the structure is safe after such natural events. If structures are monitored periodically or continuously, better understanding will be achieved about the behaviour of the structure. It will be very useful for design improvement. By proper SHM, the number of catastrophic events can be decreased, which will be helpful for economy of the country and also for psychology of human beings. If damage/ cracks developed before failure, are detected at an early stage, proper measures can be taken. Collapse of bridges, tall buildings and other important structures hamper the economic growth of the country and also results in the loss of human resources. Structures are designed for a certain life span, and it is assumed that during this period the structure is maintained properly. By proper monitoring, it may be possible that the life of the structure be increased and serviceability enhanced, resulting in huge savings. Fatigue assessment can be determined, if continuous monitoring is done. It may possible that a new constructed structure may not be performing well with respect to design parameters, either due to inferior material or faulty construction. This can be ensured by proper health monitoring.A successful health monitoring design requires the recognition and integration of several components. Identification of health and performance metric is the first component which is a fundamental knowledge need and should dictate the technology involved. These facts underline the importance of an automated health monitoring system, which can not only prevent an incipient damage included collapse, but also make the assessment of structural health, as and when desired, at a short notice. These automated systems hold the promise for improving the performance of the structure with an excellent benefit/ cost ratio, keeping in view the long term benefits.

V. SHM TECHNIQUES

Until very recently and to great extent even today, visual inspection by trained personnel had been the most common tool to identify the external signs of damage in buildings,bridge and industrial structures. Once gross assessment of the damage location is made,localized techniques such as acoustic, ultrasonic, radiography, eddy currents, thermal, magnetic field or electro-magnetic impedance can be used for a more refined assessment of the damage location and severity. If necessary, test samples may be extracted from the structure and examined in the laboratory. One essential requirement of this approach is the accessibility of the location to be inspected. In several cases, critical parts of the structure may not be accessible or may need removal of finishes. This procedure of health monitoring can therefore be very tedious and expensive. Also, the reliability of the visual inspection is dependent, to large extent, on the experience of the inspector.

Over the last three decades, a number of studies have been reported which strive to replace the visual inspection by some sort of automated method, which enable more reliable and quicker assessment of the health of the structure. The idea of smart structures was thought to be an alternative to the visual inspection methods. Because of their inherent 'smartness', the smart materials (such as piezoelectric material, shape memory alloys, fibre optic materials) exhibit high sensitivity to any change in environment.

VI. SENSORS FOR HEALTH MONITORING

As new sensors become available, the possibility for application of improved structural health monitoring techniques are increasingly feasible. These new sensors include Micro-electromechanical System (MEMS) devices for accelerometers and other applications, nuclear magnetic resonance (NMR) capsules to detect chloride ions, shearography to detect out-of-plane displacements caused by delamination, LIDAR to capture 3D position of objects, infrared thermography to detect debonding, and others. These new sensors typically target the monitoring of one specific type of damage; for example, concrete cracking, cable breakage, steel reinforcement corrosion, and delamination or debonding. Although everyone of these measurement is important, it is important to realize that any particular one of these methods do not, in general, give the picture of the overall health of the structure. Acoustic approaches such as acoustic emissions, ultrasonic measurement, impact-echo and tap tests are well proven technologies that are used to evaluate local conditions of the infrastructure. Innovations in this area such as the use of air-coupled devices have made application of these approaches significantly easier. Some of these techniques such as the tap test are very robust and inexpensive; consequently, they are often used in spite of being labor intensive. Another robust technique is the use of X-ray and Gamma ray to get visual images of the interior of structures such as steel cables and slabs. This method is easy to understand, and has a wide base of acceptance. Its major detraction is that the size of the equipment makes it difficult to reach locations with difficult access such as the bottom of the deck of a tall bridge or the steel tower of an off-shore structure. Another problem, also associated with access, is the need to have access to both sides of a structure when often even access to one side is difficult. Recent research using back-scattered signals has mitigated this problem. Radar technology has recently seen many new innovations in the area of

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sensing. Major innovations include the development in ground penetrating radar and broadband radar. Application of these radar techniques in conjunction with improved signal processing have made it possible to obtain three dimensional views of reinforcing steel in concrete slabs while traveling at highway speeds. Recent developments of fiber optic sensors have made distributed sensing possible. New fiber optic sensor capabilities include measurements of cracks in concrete and vehicle counting. The uses of chemical coatings have further increased their use to detect the presence of chloride ions, and by extension corrosion of reinforcing steel in concrete. Although fiber optics can theoretically multiplex for infinite number of sensors, the usable frequency range and the dynamic range of the sensors limit the number of sensors on each cable to as few as four sensors. Other disadvantages of fiber-optic sensors include the need for installation during construction, the need for skilled labor to install the sensors, and the relatively high cost associated with the data acquisition equipment. A similar method that avoids some of the disadvantages of fiber optics is the use of coaxial cable as sensors [6]. These cables are more robust, and they require less expensive and specialized equipment to obtain the signals. Sensors are being deployed in civil infrastructures. However, the recorded data for long term monitoring are extensive. Much of such data are being collected but not used because processing of the data is too costly. One way to get around this problem is to develop new sensors that are capable of processing the data before the output is recorded. Such smart sensors would reduce the amount of data that need to be collected and would distribute the computing effort. Another class of smart sensors consists of those sensors that can communicate with each other. The concept of nano-dust is a network of small sensors that are capable of communicating among themselves. When they are combined with other sensors, the result can be a powerful network of sensors that can both use neighboring sensors' data, and communicate the sensed data wirelessly by hoping from one sensor to another. Wired sensors have limited application because they usually need to be installed during construction. The wiring can also be a problem as wires get in the way of the function of the structure and limit the number of sensors that can be deployed. Wireless sensors are meant to eliminate these problems. Wireless sensors used so far are mostly powered by batteries. The batteries may be supplied by solar power, which omits the need of being close to an AC source. Unfortunately, these applications require wires nevertheless. The claim to being wireless refers usually to the fact that the transmission of data from the sensor to the data acquisition device is done wirelessly. In the near future, wireless sensors should be tetherless. Fault detection methods have been used for health monitoring of aerospace and mechanical systems. These methods are based on the comparison of model output and sensed signals. When the sensed signals are significantly different from the predicted output from the model, it is likely that damage has occurred. Pattern recognition is then used to identify the damage location and level of damage. These methods rely on an accurate model to predict the output parameters. In civil infrastructures, these methods are generally classified as stiffness or flexibility identification methods, in which the measured data are compared to the model prediction. Differences between measured data and model prediction are used to adjust the model. The adjusted model is then compared to the original model to determine the possible location and level of damage. These methods depend on the accuracy of the analytic model. In civil infrastructures, the analytic model of the undamaged structure may not be sufficiently accurate to yield consistent results.

VII. CONCLUSION

Health monitoring of structures is becoming more and more important: its ultimate target is the ability to monitor the structure throughout its working life in order to reduce maintenance requirements and subsequent downtime. Currently, visual inspection is the standard method used for health assessment of structures, along with non-destructive evaluation techniques. However, most of these techniques require a lot of manual work and a significant downtime. Thus, currently an increasing interest in SHM is rising, because it can provide cost savings by reducing the number of manual inspections.Wireless sensing are becoming desirable features in SHM systems and there has been a large development of new sensors during the last years. However, optimized and autonomous SHM systems are still not so spread.

The most recent and innovative applications concern of possible interaction among earthquake early warning, structural health monitoring and structural control. However, unlike traditional seismic monitoring, an event driven monitoring system is not useful: continuous condition assessment and performance-based maintenance of civil infrastructures are necessary in order to assess the short-term impact due to earthquakes and the long-term deterioration process due to physical aging and routine operation.

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