Journal of Manufacturing Engineering, March 2023, Vol. 18, Issue. 1, pp 020-025

A REVIEW OF NANOTECHNOLOGY FOR SEISMIC SAFETY IN STRUCTURES

***Nishtha Sahu[1] and Shahrukh Ali[2]**

[1]Department of Civil Engineering, Kashi Institute of Technology, Varanasi, Uttar Pradesh-221311, India
[2]Department of Civil Engineering, Ashoka Institute of technology and management, Varanasi, Uttar Pradesh- 221007, India

ABSTRACT

Many earthquakes have occurred worldwide in recent decades, resulting in massive destruction and structure collapse due to poor seismic design. The goal is to design structures so that damage to them is minimized and to construct structures that are safe, sustainable, and durable for future generations. Nanotechnology is one of the most promising technologies of the twenty-first century, and it is gaining traction in the building industry. The main goals of this work are to provide a quick review of the possible benefits of nanotechnology before discussing nanotechnology innovation for structural seismic safety. Several studies and analyses have shown that using nanotechnology could improve traditional construction materials like concrete and steel performance and properties. During the review, it was discovered that nanotechnology has the potential to revolutionize the traditional engineering business and aid in meeting the demand for sustainable development.

***Keywords**: Nanotechnology; sustainability; Seismic safety; damage control*

1. Introduction

The word “nano” means “dwarf” in ancient Greek. It is a billionth of a metre in length. Nanoparticles have a size range of 1 to 100 nanometers [1]. Nanoparticles and structures have extraordinary properties due to this dimensional range, and nanotechnology deals with studying and analyzing these features. The physical and chemical properties of molecular-scale structures are studied in nanotechnology, and they can be combined to build bigger structures for human use. The arrangement of the atoms and molecules influences the material’s qualities. Nanotechnology is a multidisciplinary branch of science and engineering that enables the atomic or molecular operation of functional materials, devices, and systems [2]. In many fields of the twenty-first century, such as medicine, energy, climate change, building, and so on, this is the most promising technology. In terms of the construction business, nanotechnology offers an intriguingly large quantity of improvement [4]. The nanotechnology-created items have extraordinary capabilities, and they have the potential to completely resolve current construction challenges, as well as alter the necessity and association of the construction process. After seeing nanotechnology’s tremendous potential and significance in the construction industry, the European Commission approved funding for the Growth project GMA1-2002-72160 “NANOCONEX” in 2002[5]. The main goal was to raise awareness and examine nanotechnology’s existing state and future capabilities in the building industry.

Nanotechnology has become a more efficient, long-lasting, and environmentally friendly alternative to traditional construction materials [6]. Nanotechnology has various potential applications in the building industry, including improving cement-based materials, noise reduction, surface coating, fire prevention, and thermal insulation [7]. Issues like material evaluation and degradation control are being focused on improving structural performance and durability. Recent research has concentrated on the seismic safety of structures and monitoring their performance when subjected to seismic activity.

2. Scope of Nanotechnology in India

Nanotechnology has immense potential for India, and a multi-pronged strategy will allow it to be fully realized. The Indian government has been a pioneer in fostering nanotechnology research and development since the early 2000s. The DST announced a Nano Mission on Nano Science and Technology on May 3, 2007, with the goal of assisting, encouraging,

**Corresponding Author - E- mail: sahunishtha0103@gmail.com*

and evolving all aspects of nanoscience and nanotechnology that can benefit the country [8]. Infrastructure Development for Nano Science and Technology Research, Human Resource Development, International Collaborations, Public-Private Partnerships, Nano Applications and Technology Development Centers, and Academia-Industry Partnerships are among the objectives of the Nano Mission (DST 2008). Nano Mission Phase II (2012-2017) focuses on product advancement and commercialization for markets and customers at a cost of Rs. 650 crores. In India, the advancement of nanoscience and technology has the potential to help the country address societal concerns such as water supply and healthcare and achieve economic gains through the growth of the nanotechnology-based industrial sector [10]. Long-term funding that can help incoherent research initiatives with high-impact outcomes is needed. Various research centres across India must collaborate in collective efforts to improve results. India can aim to become a global leader in nanotechnology because nanotechnology is a new technology, and India has a large skilled workforce.

3. Nanotechnology and structural seismic safety

3.1 Nanosensors

Over the last few decades, the globe has witnessed countless earthquake drills resulting in massive destruction and infrastructure collapse due to an inadequate response to seismic activity. As a result, such assessments' results are crucial to maintaining or reconstructing the destroyed building. Different methodologies for detecting structural damage have been developed. According to research, nanosensors might be installed in structures to provide early warning of seismic problems. Carbon nanotube sensors and micro-electromechanical systems (MEMS) are mostly used in beams and concrete blocks. Sensor made of carbon nanotubes MEMS is utilized to monitor the moisture and internal temperature of the concrete during various stress conditions [11]. A visual study of fracture widths or regions of concrete spalling is the most well-acknowledged reasonable technique. FBG (fibre Bragg grating) technology and BOFDA (Brillouin optical frequency-domain analysis) are the sensing systems that have been proposed [12] to detect and estimate the surface crack width, position, and time in reinforced concrete structures.

3.2 The carbon nanotubes

Carbon nanotubes, or CNTs, are single-layer carbon atoms or graphene tubes that are cylindrical in shape. It is both single-walled (less than 1 nanometer in diameter) and multi-walled (diameters reaching more than 100 nm) [13]. Because carbon nanotubes modify the electrical characteristics of cement mortar and enhance their compressive strength, they can be utilized to identify structural degradation as well as for structural health monitoring [14]. The addition of a 1% carbon nanotube can improve the mechanical characteristics of Portland cement and water [15]. The fire resistance of steel structures is frequently provided with a coating created by a spray-on cementitious technique [15]. Nano-cement (made up of nano-sized particles) has the potential to provide long-lasting, high-temperature, and resistant coverings. This is accomplished by mixing carbon nanotubes with cementitious materials to create fibre composites that can mimic some of the nanotubes' amazing capabilities [16]. Carbon nanotubes can improve some qualities, like durability, when used as a replacement for polymeric substance admixtures.

Carbon nanotubes and nanofibers have excellent electrical and thermal conductivity properties, with tensile strengths in the GPa range and moduli of elasticity in the TPa range [17]. They also have distinct electrical and chemical properties [18]. As a result, adding nanoparticles to these construction materials can improve their electromechanical properties [17]. The composites as mentioned above show promise in construction for crack propagation with properties such as electromagnetic shielding and sensing and improved mechanical properties [18]. Multi walls are made up of numerous concentric graphene cylinders coaxially planned around a hollow core, while single walls are made up of single graphene chambers. In comparison to single-wall CNTs, CNFs have a reduced production cost [18].

3.3 Nanotechnology in concrete

Concrete is a nanostructured material that matures with the passage of time. Amorphous phase, nanometer to micrometer-sized crystals, and water make up this mixture [19]. The durability of concrete can be increased by adding nanoparticles through chemical and physical interactions, such as pore filling. The concrete is held together in the amorphous phase by a nanomaterial called calcium–silicate–hydrate (C–S–H), which acts like glue [20]. Nanoscience and nanotechnology, sometimes known as nanomodification, are phrases that are commonly used to describe two main paths of nanotechnology application study [21]. Nano-designing encompasses methods for controlling structure at the nanometer scale in order to create a new era of customized, multifunctional cementitious composites with superior mechanical performance and durability, as well as a variety of novel properties such as self-sensing, low electrical resistivity, crack propagation control, self-cleaning, and self-healing [22]. Cement can be nanoengineered by combining nanoscale building blocks to control material behaviour and add new qualities or by gluing atoms to concrete particles, additives, and aggregates to create surface usefulness that can be modified based on explicit interfacial relationships. In a study, two tests were carried out on concrete columns to assess structural health using piezoceramic-based sensors. The first test was performed on a shake table with an RC column in which piezoceramic-based sensors were installed in earthquake-prone columns. The second test involved earthquake loads on the RC pier of the Niu-Dou Bridge in Taiwan. As a result of the wave response analysis, the degree of destruction and the presence of a crack can be determined [23].

Cracks are quite common in concrete because of its poor tensile strength [24]. These fissures reduce the durability of concrete by providing an easy path for the passage of fluids and gases that may contain harmful compounds. The micro-cracks that have formed will degrade the reinforcement as well as destroy the concrete. As a result, it is critical to mend the fracture and examine the crack width as soon as possible. Because the expense of concrete repair and maintenance is typically significant, self-healing concrete has evolved. The development of nanotechnology has boosted the plan and manufacture of self-healing materials. As a result, self-healing fissures will improve the durability, sustainability, and service life of concrete structures [25].

3.4 Nanoclay

The clay component of soil contains nanoclays, the most important of which are allophane and montmorillonite [26]. Nanoclay provides lubrication at seismic faults, according to studies. Smectite clays are the predominant constituent found in the decollection zone of landslides and in slipping zones. Smectite clays can control slip during landslides and earthquakes, as well as mechanical behaviour from gradual creep to high accelerations [27].

As an encouraging additive, nanoclay materials can be employed to guard against chloride infiltration, reduce shrinkage and penetrability, and improve mechanical performance [28]. The substance is montmorillonite, which is naturally hydrophilic. Clay-based nanocomposites have improved their overall performance, making them a viable contender for cementitious structural grids [29].

3.5 Nanotechnology in Cementitious based materials

Using atomistic or sub-atomic level modelling and propelled characterization methods, nanoscience and nanotechnology manage the designing and estimation of the nano and microscale structure of based materials to all the more likely see how this structure influences macroscale properties and execution [30]. Nano-designing entails controlling the structure at the nanometer scale to create multifunctional, new-generation cementitious composites with unrivalled mechanical execution and toughness, as well as a variety of novel properties such as self-cleaning, low electrical resistivity, self-healing, self-control of cracks, self-sensing capabilities, and high ductility [31].

Bulk cement components are reduced to a nano range of around 1–100 nm using a top-down approach and nanofillers such as nano alumina, nanosilica, and nanotitania. We note the separation of nanosilica and nanotitania from Sri Lankan quartz stores and mineral sands for use as additional substances in cement items to increase execution and reduce the cost and volume of cement production, as well as the resulting ecological impacts [32]. The evolution of today's cement business searches for ways to improve the materials by increasing the required amount of nano-based structure or nanoparticles in cement products. Nanoclay, nanosilica, and carbon nanotubes are frequently used nanoparticles [33].

3.6 Silicon Dioxide Nanoparticles (SiO_2)

When compared to microsilica or silica flume, silicon dioxide nanoparticles have been proven to improve the strength and workability of concrete, increase water resistance, and reduce motar setting time. Microsilica is used to replace the cement in concrete. Microsilica can be replaced with concrete due to the pozzolanic reaction, however the strength is unaffected [34]. As a result, substituting microsilica for concrete should reduce cement's CO_2 footprint dramatically. This is relevant in view of the fact that the cement sector is one of the modern industries that emits a lot of CO_2, accounting for 8% of global CO_2 emissions[35]. Colloidal silica is the most widely used and least expensive nanomaterial for soil treatment. Colloidal silica has been proposed for ground improvement and liquefaction mitigation. It has the ability to decrease pore pressure development during seismic activities by employing innovative stabilization techniques. [36]

Although nanosilica isn't widely used in concrete, silica fume, which is considered a microsilica, has only been used in concrete for a few years to generate high-performance concrete. Nanosilica has been shown to expedite hydration at young ages [37], improve mechanical characteristics even at low degrees of substitution [38], and refine pore structure [39] due to its amazingly tiny particle size. Furthermore, nanosilica has a large specific surface area and ideal pozzolanic action due to its amorphous nature [40], which forms additional C-S-H gel when it reacts with calcium hydroxide, resulting in a denser matrix [41]. When compared to microsilica, Nano-SiO2 reduces the setting time of mortar, reduces water depletion, improves strong usefulness and quality, constructs water invasion insurance, improves the quality and usefulness, confinement by improving the cohesiveness, and helps control the separating of calcium, which is inextricably linked to various types of deterioration. [42]

3.7 Nanotechnology in Dynamic foundation structure interaction

One of the most advanced techniques used in seismic zones is seismic isolation. By including dampers and seismic isolation in structures, it provides security to its occupants and structural safety. It can also be utilized for historical structure restoration. It decouples the structure from the ground movement caused by earthquakes [43]. As suggested by the nanotechnological mixture, seismic isolation technology involves advancing column isolation technology or jet grouting technology, adequately integrated and planned from the geometric and execution standpoint of mechanical-physical science. The studies have shown that integrating nanotechnological materials with physical and mechanical properties different from soil can weaken the propagation of shear waves [44]. According to numerous lab tests and numerical investigations, the vibration value is 20-30, attributable to the relationship between natural soil impedance and the material that causes vibration obstruction. A thin layer of material was added, reducing impedance compared to the surrounding soil. It is estimated that the benefit of using column protection, both in terms of life cycle cost and further boosting the overall performance of the structure, will save 30% of labour costs. When it comes to critical interest structures, it is possible to gain a significant cost reduction if we consider post-seismic tremor utilization.

4. Seismic Structural Health Monitoring

Seismic Structural Health Monitoring (SSHM) is an important aspect of the structure's preservation. It is very useful in the safety assessment of structural damage. Vibration-based monitoring, like the destruction tool triggered by ground movements, can help predict the dynamic behaviour of a structure during seismic activity. [45] As a result of this information, effective safety programmes can be determined and improved. Depending solely on a short visual inspection could result in serious harm being overlooked since it is hidden by fire protection and building finishes. Coloured tags are used for visual inspection to indicate potential threats to the residents. The green colour indicates that the building does not pose a threat to human health. The yellow indicates that the structure threatens life security yet allows for limited access to recover items. The colour red indicates that the structure is life-threatening. Sensor data recorded is a sign of execution, and execution is based on the amplitude of relative displacement of a structure's roofing display performance. [46] In the mid-2000s, an alternative to tagging allowed engineers to employ sensors to monitor a structure's ongoing reaction as a health monitoring tool. To obtain displacements, differential GPS [47] with high examining proportions is used. Traditional accelerometer-deployed structures [48] are set up to capture acceleration data and count displacement using double integration gradually. Sensor networks, wireless communications, smart structures, microprocessor technology, and smart sensors are finding a wider range of applications in detecting structural deterioration and monitoring structural health [49]. These methods are critical in building structures that can withstand the threats posed by seismic activity while also improving the coherence of structures and increasing the security of tenants.

5. Future of nanotechnology towards seismic safety

Nanotechnology will make significant contributions to engineering and research for future generations and fundamentally restructure many existing technologies. For future generations, extensive research is required so that nanotechnology can contribute to the construction sector. Organizations propose using these seismic security progressions in their regulations and rule manuals. New systematic instruments for recognizing, illustrating, evaluating, and assessing nanoscale amalgamation, nanoscale construction, and nanoscale assembly should be developed to manage nanomaterials. Nanotechnology's health and environmental effects on human existence must be recognized. As a result, studies are being conducted to establish how to dispose of debris following a structural collapse, the toxicity of nanomaterials, and security challenges that develop during construction. Real-time monitoring should be established to make the constructions safe.

6. Conclusion

Nanotechnology's advancement may provide a solution to future energy issues. To overcome the vulnerabilities of seismic activity, substantial research into the utilization of nanotechnology is being relied on. The goal is to arrange the user's comfort and safety, increase structural performance, maintain an ecologically friendly environment, and develop cost-effective structural system seismic security solutions. Nanotechnology advancements may add to the improvement and result in a more effective and efficient technique for producing and utilizing energy as a construction application. Nanotechnology has the potential to save the environment while also increasing sustainability. In this relatively new industry, no effective 'Regulatory Framework' has been established, and if this trend continues, nations may grow to dominate this field. For the advancement of Nanotechnology in all aspects of life, India needs organized schemes, coordinated policies, and institutions and industry participation

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