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# Nanomaterials in Building Materials for Seismic Resilience

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**Abstract :** In this paper I have discussed about the importance and application of nanomaterials used in building materials for seismic resilience. I have highlighted the salient features of nanomaterials which increase strength, stability and durability of the structure against seismic resilience, ageing and adverse environmental effects. Different types of building materials including concrete, cement, steel, glass, insulations and Nanosensors have studied and discussed. The key properties of these nanomaterials and associated changes in infrastructure's strength, stability and seismic resilience have been explained in detail. Many interesting phenomenon such as fillers and nano-sensors have thoroughly described and a systematic understanding has been developed. Moreover, this paper presents the advantages and benefits to nanomaterials in civil engineering to enhance the structural strength and seismic resilience.

## I. INTRODUCTION

Nanotechnology is the science and engineering of studying material properties at nanoscale and perform cutting edge research and technology development to not only understand but also control atomic/molecular level science perturbing the overall properties of material [1,2].It covers a wider spectrum of many disciplines and includes collaborative approaches via engineers, scientists, and researchers in order to secure sustainable development.Recent developments in nanotechnology from synthesis to characterization of building materials such as metal, cement, concrete, polymers, glass, plastics etc. has opened avenues for application of nanostructures in civil engineering [3,4]. Nanomodification of building materials is a great concept for 'bottom-up' engineering approach, whichstarts with inducing engineering molecular structure modifications to alter the bulk properties of intended building material. It is believed that addition of nanomaterials in building materials and structural technology provides a strong infrastructural stability to seismic activities. Nanoparticles improve the bulk properties via enhancing the strength of conventional concrete, acting as filler and refining the intersectional zone in cement, alteringthe cement matrix systemand assisting in elimination of faults associated with voids formation, porosity and alkali silica reaction [4].

It is reported that the resilience of the building infrastructure is investigated with reference to the damage and disruption generated by seismic events [5-7].It measures the ability of a structure to resist and recover functionality in an efficient manner when exposed to seismic or extreme events [8].The quality of building materials and effects of aging and environmental conditions can significantly change the seismic performance, functionality the resilience of the structure at the time of seismic event. In order to have a better explanation, Figure 1 shows the system functionality and definition of resilience of a structure [9].

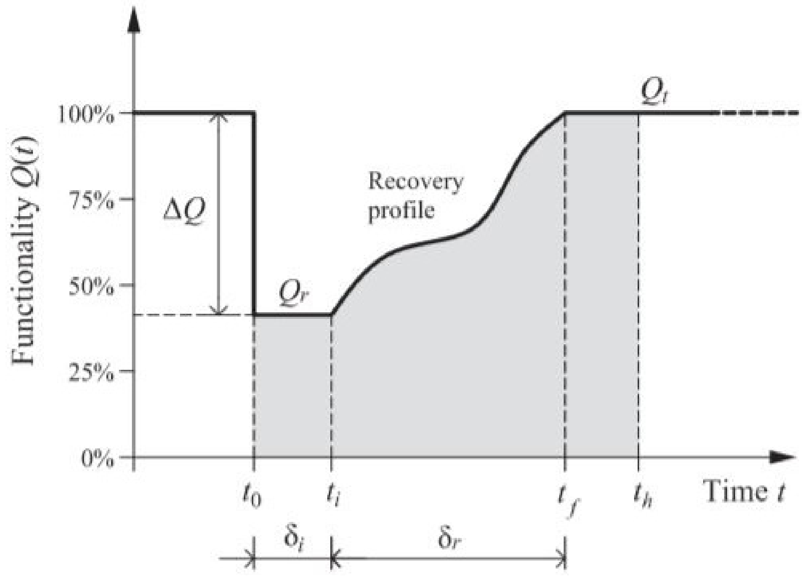


***Figure 1: Resilience of structure undera seismic event***
*(Image Reprint: Earthquake Engg. Struct. Dyn. 44, 2445, (2015))*

Here, Q = Q(t) is the time-variant functionality indicator from 0 to 1, ΔQ is the loss, $t_0$and $t_0$ are start and finish time of event, $\delta_r$= $t_f$ - $t_i$ is the recovery time interval and $\delta_i$ is the idle time.

Nanomaterials can contribute a lot in this endeavor to not only offer higher strength to the building structure but also reduce the adverse effects caused via environmental factors and ageing effects. The lighter and stronger structural composites i.e. concretes, enhanced properties of cementitious materials, low maintenance polymer coatings can reduce thermal transfer rate of fire retardant and other insulation material could provide stability to the infrastructureunder seismic events with speedy recovery. It will also lead to significant reductions in $CO_2$pollution and the high performance thermal insulators will result in efficient use of energy [10].Nanomaterials can also provide a shield for external environmental moisture and water absorption and to increase the lifespan of pavements leading to higher structural durability. For comparison, a carbon nanotube (CNT) has a Young's modulus of 1054 GPa, tensile strength of 150 GPa and a density of 1.4 g-cm$^{-3}$ indicating that a CNT has 150 times more strength than steel and is also 6 time more lighter.Therefore, in the presented article, we explore and demonstrate the potential of nanotechnology and numerous nanomaterials offering higher aspect (surface to volume ratio) for target oriented technical utilization in building materialsin civil engineering whichultimately leads higherstrength, stability and durability of the structure against seismic resilience and environmental and ageing effects.

## II. MATERIALS AND METHODOLOGY

Nanomaterials are the materials having a mean diameter ranging between 1 - 1,000 nm (where 1 nm = $10^{-9}$ m). These materials can generate a variety of products with unique characteristics (depending upon particle size)that can significantly improve the properties of construction materials. Nanomaterials can offer high strength concrete, lighter & stronger structural composites, greatly cementitious materials, reliable and waterresistant coatings, better fire retardant & insulation, highly reflecting glasses and sound absorbing acoustic barriers [11]. The variability in these material along with geometrical properties and physical quantitiesgoverns the strength, reliability and deterioration process which leads to seismic resilience of the building infrastructure [9,12-14]. Thereby, considering their utmost importance, the different types of nanomaterials and their applications has been discussed in the following section.

**NanoConcrete:** Nano concrete utilizes nano materials or a concrete with in which the size of the nano particles remains under 500 nm. Nano particle in concrete improves the bulk properties (packing model structure), and act like a filler by refining the intersectional zone in cement producing more density. In this way, their manipulation in the cement matrix system provides complete elimination of micro void, porosity and deterioration associated with alkali silica reaction. Nano materials start to evolve and become a binding agent which is much smaller than the cement particles, thus improving the structure of hydration gel and strong resilience to seismic activity [15]. Comparing the properties of nano concrete with other materials, the results are very surprising as shown in Table 1 [4].

*Table 1: Comparison of concrete properties*

| | Compressive strength (MPa) | Flexural strength (MPa) | Porosity (%) | Water absorption (%) |
|---|---|---|---|---|
| Normal concrete | 10–40 | 1–10 | <30 | <30 |
| High performance concrete (HPC) | 41–100 | 11–20 | 12–25 | 12–25 |
| Ultra high performance concrete (UHPC) | 100 | 20–30 | <10 | <12 |
| Nano concrete | 70 | 12–20 | <10 | <12 |

**Carbon Nanotube:** Carbon nanotube (CNT) is cylindrical tube-shaped allotropes of carbon having a diameter in the nanometer scale and a length-to diameter ratio of up to 132,000,000:1 [4, 16] which is significantly larger than any other material. Typically, CNTs have diameters ranging from <1 nm to 50 nm when stacked in a group depending on their structure and layers.CNT are categorized as single-walled nanotube (SWNT), double-walled nanotube (DWNT) and multi-walled nanotube (MWNT) depending upon the number of ‘‘ropes” held together by van der Waals forces or pi-stacking [17]. The superior mechanical and transport properties of CNT stands out as an ultimate carbon fibers comparison to other engineering materials. Also, CNT offer a unique combination of stiffness, strength, and tenacity along with high thermal and electrical conductivity in comparison to other materialsas shown in table 2.

*Table 2: Comparison of mechanical, thermal and electrical properties of fibers*

| Fiber Material | Specific Density | Strength (GPa) | Strain at Break (%) | Thermal conductivity (w/m.k) | Electrical Conductivity |
|---|---|---|---|---|---|
| Carbon Nanotube | 1.3 - 2 | 10 – 60 | 10 | > 3000 | 106 - 107 |
| Carbon Fiber-PAN | 1.7 - 2 | 1.7 - 5 | 0.3 – 2.4 | 8 - 105 | $6.5 – 14 \times 10^6$ |
| Carbon Fiber - Pitch | 2 – 2.2 | 2.2 – 3.3 | 0.27 – 0.6 | 1000 | $2 – 8.5 \times 10^6$ |

**Nano Steel:** Due to its superior properties such as strength, weld ability and corrosion resistance, steel is a highly important material for the design and construction.With advancement in technology, it is now feasible to develop nano-sized low carbon and high performance steel (HPS). The HPS incorporates nanoparticles of copper, molybdenum and vanadium at the grain boundaries site to offers higher corrosion-resistance and weld ability. The copper nanoparticles suppresses surface unevenness which the density of stress risers and hence fatigue cracking, thereby leading to increased safety and low monitoring requirement. On the other hand, this new steel with vanadium and molybdenum nanoparticles improves the delayed fracture problems linked with high strength bolts by reducing the effects of hydrogen embrittlement and improving the micro-structure [18]. Besides, the nanoparticles of magnesium and calcium also increases the overall weld toughness of the nanosteel. Sandvik Nanoflex is new stainless steel developed by Sandvik NanoflexTM which offers ultra-high strength, good formability, great surface finish and high ductility in the final product. The chemical composition (nominal) of the same can are tabulated in Table 3.

**Table 3: Chemical Composition of Sandvik Nanoflex**

| Material | C | Si | Mn | P | S | Cr | Ni | Mo | Cu | Ti | Al |
|---|---|---|---|---|---|---|---|---|---|---|---|
| % age | <0.02 | <0.5 | <0.5 | <0.02 | <0.005 | 12 | 9 | 4 | 2.0 | 0.9 | 0.4 |

**Nano Coatings:** Now a days,one of the major contribution of nanotechnology in building materials lies in coating materials. Modern coatings include certain nanoparticles or nanolayers that have been designed and developed for a specific purpose. For example, $TiO_2$ nanoparticles coatingare commonly used to coat glazing due to its sterilizing and anti-fouling properties which breaks down and disintegrate organic dirt through catalytic reactions [19]. The hydrophilic nature of $TiO_2$ allows uniform water spreading over the surface and wash away previously broken dirt particles. Nanoparticles are also used in paints to assure the corrosion protection under insulation due to its hydrophobicity and water repelling properties in metal pipes to protect metal from salt water attack. Besides this, various other special coatings also have also been developed to be utilized as anti-fraffiti, energy sawing, thermal control and antireflection coating in the building construction.

**Nanomaterials for Thermal Insulation and Fire Protection:** Aerogel materials in their micro and nanoporous hydrophobic form are highly desirable for being utilized as a core materials in vacuum insulation panels. It is found that silica based aerogel products are used for transparent insulation leading to super-insulating windows. Also, these micro and nanoelectomechanical systems great monitoring and controlling the internal environment of buildings and ultimately saves energy costs. In terms of fire protection, the steel structures used for building constructions are often provided by a coating via a spray-on cementitious process. The cement based on nanoparticleshas the potential to create a tough, durable, high temperature coatings with great fire resistance [10]. Such type of cement materials are synthesized via mixing of CNTs with cementious material to fabricate fiber composites inheriting outstanding properties such as strength and durability.Also, polypropylene fibersbeing a cheaper alternative are also used to increase the fire resistancethan conventionalinsulation process.

**Nanosensors**: Sensors are the mandatory equipment in the construction to avoid any tragic or accidental events in future. Recently, Nano and micro-electrical mechanical systems (NEMS/MEMS) sensors have been developed and used to monitor and control the environmental conditions, seismic resilience and the materials/structure performance. The small dimension of these sensors ($10^{-9}$ m to $10^{-5}$ m) is their greatest advantage [20] which offers easy embedding into the structure while construction. These small, smart and low cost piezoceramic-based multi-functional devices, areemployed to monitor early age concrete properties such as moisture, temperature, relative humidity and early age strength development. It helps to monitor the structure health monitoring, concrete corrosion and cracking and ultimately to avoid any unwell event in the future.The dedicated systems can also examine internal stresses, cracks and other physical forces in the structures over periods and provides an early indication of the health of the structure before any failure can occur.

**Contribution of Nanomaterials in Seismic Resilience**: The seismic resilience and recovery of the structure/construction strongly depends upon its strength, ageing and environmental conditions. The material and geometrical properties of the structure are highly responsible for the seismic resilience of the building over the years [9]. Therefore, utilization of high quality materials and periodic monitoring is essential for high seismic resilience and thereby nanomaterials can contribute a lot in this endeavor by providing high quality concrete, cement, steel and other building materials. Also, the better thermal insulation and fire resistance via nanomaterials and periodic monitoring of corrosion, cracking, and internal stresses other physical forces via Nanosensors can help to maintain the health of structure and warning before the occurrence of any failure event.

## III. CONCLUSION

The article showcasesthe importance and application of nanomaterials used in building materials for seismic resilience and futuristic failures. It displays the superiority of nanomaterials over conventional building materials and how nanotechnology has changed the aspects of civil engineering and building construction. The salient features of nanomaterials including increased strength, stability, ageing effects and durability of the structure against seismic resilience have been discussed. The applications of nanomaterials in concrete, cement, steel, glass, insulations and sensing technology have contributed a lot in terms of design and development of new construction technology. The presented paper divulges the correlation of nanomaterials with seismic resilience and demonstrates the advantages and benefits of nanomaterials in civil engineering to enhance the structural strength and durability.

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