

СЕКЦИЯ 3. МИКРО- И НАНОТЕХНИКА

UDC 681

NANO-ENGINEERED MATERIALS FOR EARTHQUAKE-RESILIENT STRUCTURES

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The seismic performance of reinforced concrete (RC) structures is governed by their ability to dissipate energy, control cracking, and maintain stiffness under cyclic loading. Conventional concrete exhibits brittle behavior and rapid stiffness degradation during earthquakes, leading to severe structural damage. Recent advances in nanotechnology provide promising pathways to engineer cementitious composites with enhanced ductility, toughness, and damage tolerance. This study presents a mechanistic framework linking nano-scale material modification to macro-scale seismic resilience of RC structures. The role of nano-silica and carbon-based nanofillers in improving interfacial transition zone (ITZ) densification, micro-crack bridging, and hysteretic energy dissipation is discussed. A simplified constitutive relation is proposed to relate nano-modification to effective stiffness and damage evolution under cyclic loading. The proposed approach highlights the potential of nano-engineered concrete for developing next-generation earthquake-resilient infrastructure.

Earthquake-induced failures in RC structures are primarily associated with brittle cracking, loss of stiffness, and limited energy dissipation capacity. Traditional approaches to improve seismic performance focus on reinforcement detailing and structural configuration, while material-level innovations remain underutilized. Nanotechnology enables the tailoring of cementitious materials at the nano-scale, offering the potential to fundamentally alter crack initiation, propagation, and energy dissipation mechanisms. However, most existing studies emphasize compressive strength enhancement, with limited focus on seismic performance parameters such as ductility and hysteretic behavior. This paper addresses this gap by proposing a nano-engineered material framework aimed at enhancing earthquake resilience of RC structures.

Nano-Scale Mechanisms for Seismic Resilience. Nano-silica particles refine pore structure and densify the ITZ, resulting in delayed crack initiation and improved stiffness retention. Carbon-based nanomaterials such as carbon nanotubes and graphene nanoplatelets provide crack-bridging at the nano-scale, enhancing tensile capacity and post-cracking toughness. These mechanisms contribute to improved hysteretic energy dissipation and reduced stiffness degradation under cyclic loading.

Mechanistic Modeling of Nano-Modified Concrete. The influence of nano-modification on effective stiffness degradation of concrete under cyclic loading may be expressed as:

$$E_{eff} = E_0 \cdot (1 + \alpha \cdot V_n - \beta \cdot D),$$

where E_{eff} is the effective modulus of elasticity, E_0 is the elastic modulus of conventional concrete, V_n is the nano-additive volume fraction, D is a damage parameter representing crack density, and α , β are material constants.

Implications for Earthquake-Resistant Design. Nano-engineered concrete exhibits enhanced ductility, reduced stiffness degradation, and improved energy dissipation capacity, which directly translate into improved seismic performance of RC members. The proposed framework provides a rational basis for incorporating nano-modified materials into performance-based earthquake engineering and future design guidelines.

Nano-engineered cementitious composites represent a promising pathway for developing earthquake-resilient structures. By linking nano-scale mechanisms to macro-scale seismic response, this study provides a foundation for material-level innovations in earthquake engineering. Future research should focus on experimental validation under cyclic loading and long-term durability assessment of nano-modified concrete.

References

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