INDIAN INSTITUTE OF TECHNOLOGY GUWAHATI
PhD-17 SHORT ABSTRACT OF THESIS

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SHORT ABSTRACT

Three-dimensional (3D) extrusion-based concrete printing is transforming construction by enabling complex geometries with reduced material use, shorter construction times, and lower labor demands compared to conventional methods. Despite these advantages, widespread adoption is limited by challenges in material formulation, structural design, computational modeling, and process optimization. In seismic regions, the demand for resilient and sustainable systems drives increased interest in 3D printed concrete (3DPC). Achieving sufficient ductility, energy dissipation, and effective reinforcement integration, while ensuring constructability and cost-efficiency, remains a critical challenge. Existing studies predominantly emphasize static performance, with limited focus on cyclic behavior, leaving significant knowledge gaps in understanding the seismic response of 3DPC systems. This research addresses these challenges by developing earthquake-resistant 3DPC walls through an integrated approach combining material-level innovation, codal design adaptation, advanced numerical modeling, and full-scale experimental validation. In the first stage, the material development process commences with a systematic investigation of constituent integration strategies. Preliminary trials incorporate coarse aggregate within the interlayer regions during printing, resulting in an increase of up to 32% in direct tensile strength. Subsequently, a range of fibers, including PVA, glass, and steel, are evaluated at dosages of 0.25–1.0% for their effect on buildability, extrudability, and mechanical properties. Steel fibers demonstrate superior performance, enhancing interlayer bonding and tensile behavior. To mitigate extrusion challenges, aggregates are incorporated during mixing and steel fibers are used at critical fiber volume determined through tensile and pull-out tests, while printing auger modifications ensure smooth aggregate passage. The optimized composite developed through this process exhibits distinctive strain-hardening behavior, with a yield point, strain-hardening factor of 1.62, ductility factor of 10.86, and energy absorption capacity of +105 kJ/m^3, confirming its suitability for seismic-resistant applications. Subsequently, a robust numerical modeling framework is established to simulate the in-plane cyclic behavior of 3DPC walls. A composite interface micro-model, combining Concrete Damage Plasticity (CDP) and cohesive zone modeling, is developed to account for interlayer effects and localized failure mechanisms. Model validation against benchmark experimental data demonstrates high accuracy in predicting hysteresis response, stiffness degradation, and energy dissipation. Results of parametric studies suggest that seismic performance of the 3DPC xi wall can be considerably enhanced by reducing height–width ratio and by inclusion of solid edge columns and continuous reinforcement throughout the wall. Incorporating the strain hardening 3DPC material further improves wall performance, with lattice shear walls exhibiting a 108% increase in deformability and flexural walls achieving a 59% strength gain relative to control walls. The third stage investigates the applicability of codal provisions (ACI 318-19, Eurocode 8, IS 13920:2016) for 3DPC wall design. Comparative analysis of single- and double-layer reinforcement systems under quasi-static cyclic loading shows that the double-layer configuration achieves 30.6% higher lateral load capacity (465.72 kN vs. 356 kN), 9.8% greater failure displacement, a higher ductility factor (4.36 vs. 4.01), and superior energy dissipation. The single-layer reinforcement, while lower in strength, maintains, reduces, and offers easier integration in 3DPC construction. To further enhance seismic performance, self-centering reinforcement and confined boundary elements are incorporated following codal guidelines, resulting in lateral strength gains of 54.08% and 46.89%, along with improved stability and damage tolerance. In the final stage of the research, following the development of the optimized material and the selection of wall geometry and reinforcement configuration based on simulation and design outcomes, it is observed that conventional infill geometries are unsuitable for the proposed reinforcement layout. Hence, a modified infill pattern with hollow side regions is developed to facilitate reinforcement placement and reduce material usage by ~20%. Numerical simulations confirm a ~20% increase in lateral load capacity and slower stiffness degradation. Subsequently, full-scale quasi-static cyclic tests are performed on three 3DPC wall systems: (i) a plain mortar wall (3DPM), (ii) a 3DPC wall with strain-hardening ductile mix (3DPC-CF), and (iii) a modularly reinforced wall incorporating prefabricated steel cages within the 3DPC CF matrix (3DPC-CFR). The experimental results demonstrate a clear progression in seismic performance, with 3DPC-CFR exhibiting the highest lateral strength (197%), delayed stiffness degradation, enhanced ductility (80%), and stable post-peak load retention compared to 3DPM. This research presents an integrated framework encompassing material-level innovation, codal design adaptation, advanced numerical modeling, and full-scale experimental validation of 3DPC structural walls. The findings advance the feasibility of deploying 3DPC for earthquake resistant applications, contributing critical insights toward safe, economical, and scalable adoption in large-scale construction.