USING SMAS TO ACHIEVE HIGH-PERFORMANCE SEISMIC-RESISTING SEGMENTAL PIER

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Extended Abstract

Precast segmental concrete columns (PSCCs) offer significant advantages for accelerated bridge construction, including superior quality control, reduced environmental impact, and rapid post-disaster reconstruction. Traditional self-centring (SC) PSCCs rely on unbonded post-tensioned (PT) tendons to achieve SC capability, yet they suffer from complex anchorage details, construction difficulties, limited deformation capacity, and challenges in post-seismic repair. To address these deficiencies, a novel high-performance SMA–based self-centring PSCC (SMA-SC-PSCC) has been developed, utilising superelastic shape memory alloy (SMA) bolts as the core recentring elements in lieu of conventional PT cables.

The proposed SMA-SC-PSCC follows a hybrid system philosophy but introduces crucial simplifications: (i) all segments are connected solely by bolts—SMA bolts at the column base where gap opening is designed to concentrate, and high-strength steel bolts for upper segments—thereby eliminating complicated PT anchorages and wet joints; (ii) the inherent flag-shaped hysteresis of superelastic SMA bolts provides both SC capacity and moderate energy dissipation (ED); (iii) supplemental steel angles can be installed at the base to enhance ED capacity; and (iv) steel flat slabs and steel jackets protect concrete corners and ensure that inelastic deformation concentrates at the base gap. This configuration achieves a fully precast, rapidly assembleable, and easily repairable system.

The development of the SMA-SC-PSCC was pursued through complementary numerical and experimental investigations. A refined finite element (FE) framework was first established in Abaqus, wherein superelastic constitutive models were adopted for SMA bolts, elasto–plastic models for steel elements, and concrete damaged plasticity for concrete segments. Component-level models of SMA bolts and steel angles were validated against previous cyclic tests, followed by system-level verification against a traditional PT-based PSCC. Parametric studies were subsequently conducted on eight FE models to investigate the influence of bolt prestrain (0%–0.04%), axial load index (ALI, 0.065–0.26), and longitudinal rebar diameter (D6–D16).

Building upon the numerical insights, a full-scale quasi-static experimental programme was conducted on a 1,555 mm-tall specimen comprising four precast concrete segments. The specimen featured four 20 mm-diameter dog-bone-shaped NiTi SMA bolts (12 mm effective diameter in the gauge length) at the base and 12.9-grade high-strength steel bolts elsewhere. A constant axial load of 100 kN (ALI ≈ 5%) was applied, followed by two consecutive cyclic loading protocols up to a 5% drift ratio and a final monotonic loading to failure. A refined FE model was further calibrated against the experimental data to examine detailed stress/strain distributions.

Both numerical and experimental results confirmed that the SMA-SC-PSCC exhibits desirable base-rocking behaviour, with the vast majority of inelastic deformation concentrating at the base gap while upper segments undergo near-rigid-body rotation. In the experimental specimen, cracking initiated around segment corners due to casting imperfections and bolt prestraining; however, after stabilisation at approximately 2% drift, no further crack development occurred during subsequent cycles, demonstrating successful low-damage design. The base gap opening contributed approximately 88%–94% of the total drift ratio. The specimen ultimately fractured at an 86 mm displacement (5.8% drift) during monotonic loading, with failure occurring at the upper cantilever corners of the bottom segment—above the steel-jacketed region—indicating effective protection of the base concrete.

The integrated numerical and experimental investigations demonstrate that the SMA-SC-PSCC is a promising high-performance, low-damage, earthquake-resilient alternative to traditional PT-based segmental columns. By leveraging the superelasticity of SMA bolts, the system achieves excellent self-centring capability, moderate energy dissipation, and remarkable reusability under severe cyclic loading, while the bolted connection philosophy drastically simplifies construction and post-seismic repair. The parametric studies provide practical design guidance, recommending controlled ALI (<0.15), adequate segment reinforcement to ensure rigid-body rotation, and only modest bolt prestrain. These findings offer a viable pathway toward resilient accelerated bridge construction in high-seismicity regions.

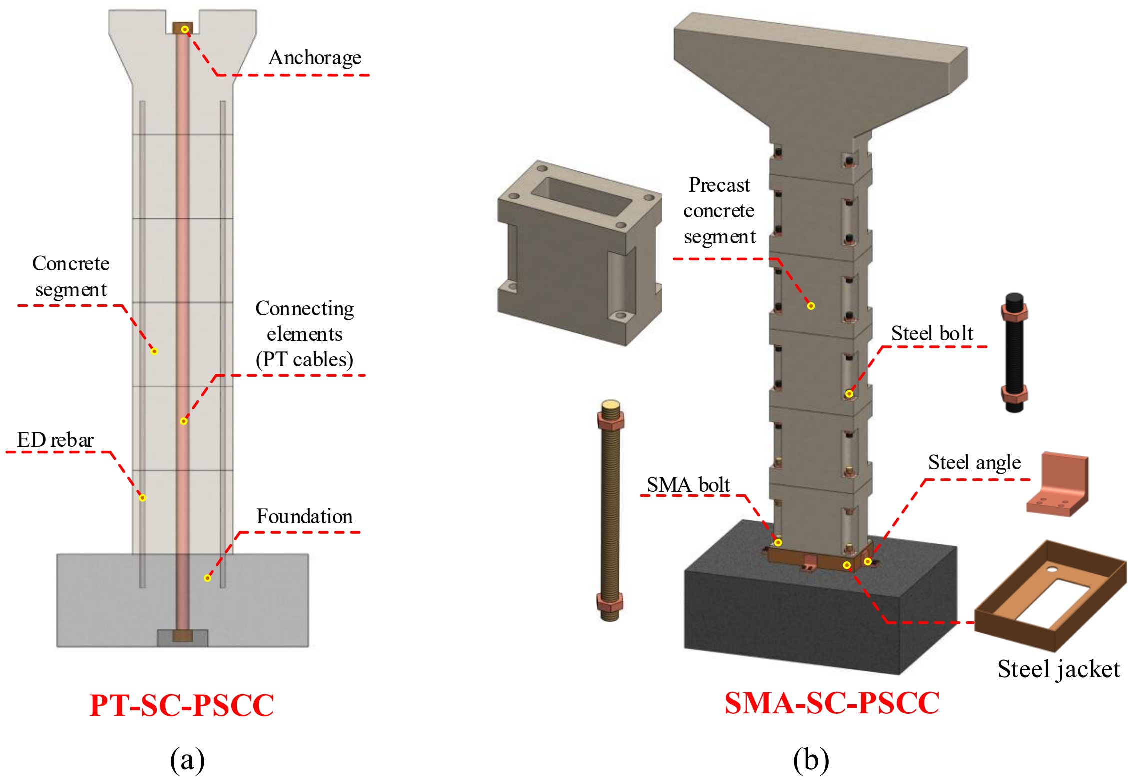

Figure 1. Design concept of the typical PT-SC-PSCC and SMA-SC-PSCC: (a) PT-SC-PSCC, (b) SMA-SC-PSCC

Keywords: *Shape memory alloy, Self-centring structure, Segmental column*