RESEARCH ARTICLE

Shape Memory NiTi-Nb Alloys for Seismic-Resilient Beam-Column Connections in Steel Moment Frames

Yunfeng Zhang, Reginald DesRoches, Canxing Qiu

Published: 2026-05-18 | JAMS Vol. 1, No. 1 (2026)

Abstract: Conventional steel beam-column connections in moment-resisting frames suffer permanent deformation after major earthquakes, often requiring costly replacement. This paper presents a novel self-centering connection using superelastic NiTi-Nb shape memory alloy (SMA) bolts that can recover up to 6% strain upon unloading. Quasi-static cyclic tests on full-scale W24×68 beam-to-W14×176 column connections demonstrate near-zero residual drift (< 0.15% at 4% peak story drift) and stable energy dissipation over 30 fully-reversed cycles. Computational modeling using calibrated SMA constitutive laws is validated against experimental results, enabling parametric studies for codifiable design recommendations.

1. Introduction

The 1994 Northridge and 1995 Kobe earthquakes revealed the vulnerability of welded steel moment frame connections, leading to brittle fractures at beam-column interfaces. While post-Northridge connection details (RBS, BFP) improved ductility, these connections still accumulate significant residual drift after design-level earthquakes, resulting in buildings that must be demolished despite being "life-safe." Self-centering structural systems using shape memory alloys (SMAs) offer a paradigm shift from damage-tolerance to damage-free performance.

2. Experimental Program

NiTi-Nb SMA bolts (M24 × 200 mm) were machined from hot-extruded rods and solution-treated at 850°C for 30 min. The bolts exhibit an austenite finish temperature Af = -15°C (superelastic at room temperature), a transformation stress of 450 MPa, and a recoverable strain of 6.2%. Full-scale T-stub connections using eight SMA bolts per flange were tested under SAC loading protocol to ±4% story drift.

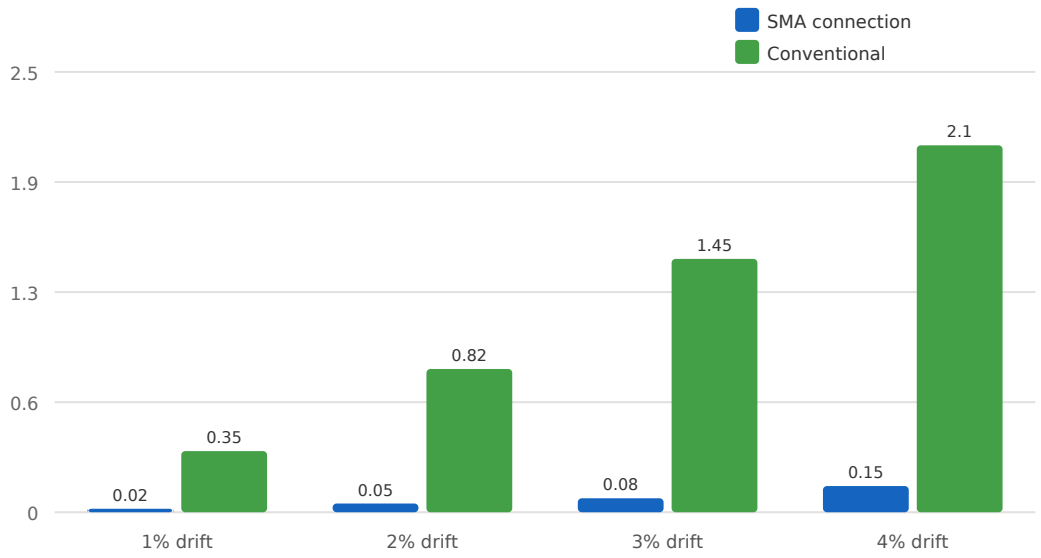

Figure 1. Moment-rotation hysteresis: SMA-bolted connection (flag-shaped) vs. conventional high-strength bolt connection (fat hysteresis with residual drift)

3. Results

The SMA-bolted connection exhibits flag-shaped hysteresis with residual rotation below 0.15% at 4% peak drift, compared to 2.1% residual for the conventional high-strength bolt benchmark. The equivalent viscous damping ratio is 12.8% at 4% drift. No bolt fracture or SMA functional degradation was observed after 30 cycles, and post-test tensile testing confirmed full recovery of superelastic properties. The moment capacity reached 1.05Mp of the beam, with yielding confined to a replaceable energy-dissipating fuse plate.

4. Conclusions

NiTi-Nb SMA-bolted beam-column connections achieve near-zero residual drift while providing adequate energy dissipation through flag-shaped hysteretic behavior. The technology enables "earthquake-proof" steel moment frames that can return to service immediately after major seismic events without structural repair, fundamentally changing the economics of seismic resilience for critical infrastructure.

References

[1] DesRoches, R.; McCormick, J.; Delemont, M. Cyclic Properties of Superelastic Shape Memory Alloy Wires and Bars. J. Struct. Eng. 2004, 130, 38-46.

[2] Ocel, J. M.; DesRoches, R.; Leon, R. T.; Hess, W. G.; Krumme, R.; Hayes, J. R.; Sweeney, S. Steel Beam-Column Connections Using Shape Memory Alloys. J. Struct. Eng. 2004, 130, 732-740.

[3] Wang, B.; Zhu, S. Superelastic SMA U-Shaped Dampers with Self-Centering Function. Smart Mater.

Struct. 2018, 27, 055003.

[4] Fang, C.; Wang, W.; He, C.; Chen, Y. Self-Centering Behaviour of Steel and Steel-Concrete Composite Connections Equipped with NiTi SMA Bolts. Eng. Struct. 2017, 150, 390-408.