Computational Investigation on the Seismic Performance of Self-Centering Tension-Only Braced Frames

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Abstract. The self-centering tension-only brace (SC-TOB) is a new type of flexible bracing system that provides both energy dissipation and re-centering capacities to the structure. In this paper, a computational investigation on the seismic performance of steel frames with SC-TOBs is conducted. Two main parameters, including the stiffness degradation factor and the activation strain of the SC-TOB, are investigated through pushover analysis. The results indicate that increasing the stiffness degradation factor leads to a larger second stiffness of the SC-TOB frames (SC-TOBFs), which is beneficial to make the distribution of drifts more uniform over the building height; the activation strain has a significant impact on the activation deformation of SC-TOBFs, but a slight effect on the distribution of drifts. The SC-TOBFs is deemed as a type of performance-tunable structure, which can be achieved by varying a frame’s adjustable design parameters.

1. Introduction
Inelastic ductility can be utilized to dissipate the input seismic energy so as to protect the primary structure. However, inelastic ductility is also prone to concentration of damage at certain stories or permanent deformations, leading to prohibitive costs of rehabilitation, interruption of building function, and a high collapse risk[1-4].

Applying pre-tensioning (PT) technology in bracing elements to achieve seismic resilience for braced frames has been demonstrated to be an effective solution. Christopoulos et al. developed a self-centering energy dissipative (SCED) brace, consisting of a PT system to provide a restoring force and a friction mechanism for energy dissipation[5]. Erochko et al. investigated the seismic performance of steel frames with SCED braces through a dynamic shake table test[3]. By using multiple self-centering systems, the self-centering capacity of SCED braces can be significantly improved[6-7]. The self-centering can also be introduced by pre-pressed springs[8]. Besides, shape memory alloys (SMAs) with characteristics of recentering and energy dissipation have been utilized to develop SMA-based self-centering braces[9-11].

Unlike the abovementioned relatively rigid bracing members, a novel flexible self-centering tension-only brace (SC-TOB) was developed by Chi et al.[12-13]. In this paper, a computational investigation on the seismic performance of SC-TOB frames (SC-TOBFs) is conducted through incremental static analysis.
2. SC-TOB Mechanics
A sketch of the SC-TOB is shown in figure 1: the cable is a bracing element using high-strength steel (HSS); the frictional device (FD) is adopted for energy dissipation; and the PT tendons are intended to provide a full self-centering capacity. The hysteretic behavior of the SC-TOB is illustrated in figure 2.

![SC-TOB sketch](image)

Figure 1. SC-TOB sketch.

![Hysteretic behavior of SC-TOB](image)

Figure 2. Hysteretic behavior of SC-TOB.

3. Prototype Building Design
The prototype building with nine stories is designed with SC-TOBs, as illustrated in figure 3. The load information is listed in table 1.

![Prototype building](image)

Figure 3. Prototype building: (a) elevation view; (b) plan view.

| Gravity loads | Floor   | Dead  | 4.5 kPa | Live   | 4.0 kPa |
|---------------|---------|-------|---------|--------|---------|
| Roof          |         | Dead  | 5.0 kPa |        |         |
|               |         | Live  | 2.0 kPa |        |         |
| Seismic load data | Basic acceleration of ground motion | 0.20 g |
4. Parametric Study
Two lateral load distributions are considered: the parabolic distribution (LD-1) and the uniform distribution (LD-2).

4.1. Effect of \( r \)
The stiffness degradation factor, \( r \), is defined as

\[
r = \frac{k_2}{k_1},
\]

where \( k_1 \) and \( k_2 \) are the initial axial stiffness and the post-activation stiffness of the SC-TOB, respectively. The effects of \( r \) on the base shear and on the inter-story drift of SC-TOBFs are shown in figures 4 and 5, respectively. The second stiffness of the SC-TOBFs increases significantly as \( r \) increases from 0.06 to 0.10, while the first stiffness of the structure remains constant. With the increase of \( r \), the distribution of drifts tends to be more uniform.

![Figure 4. The effect of \( r \) on the base shear of the SC-TOBFs: (a) LD-1; (b) LD-2.](image)

![Figure 5. The effect of \( r \) on the inter-story drifts of the SC-TOBFs: (a) LD-1; (b) LD-2.](image)
4.2. Effect of $\varepsilon_a$

The activation strain, $\varepsilon_a$, is defined as

$$\varepsilon_a = \frac{\Delta a}{l_c}$$  \hspace{1cm} (2)

where $\Delta a$ and $l_c$ are the activation deformation and the initial cable length of the SC-TOB, respectively. The effect of $\varepsilon_a$ on the base shear and on the inter-story drift of SC-TOBFs are shown in figures 6 and 7, respectively. With increasing $\varepsilon_a$ from 0.12% to 0.16%, the activation load of the SC-TOBFs increases remarkably, but the distribution of drifts seems to be unchanged.

![Figure 6](image1.png)

**Figure 6.** The effect of $\varepsilon_a$ on the base shear of the SC-TOBFs: (a) LD-1; (b) LD-2.

![Figure 7](image2.png)

**Figure 7.** The effect of $\varepsilon_a$ on the inter-story drifts of the SC-TOBFs: (a) LD-1; (b) LD-2.

5. Conclusion

A computational investigation on the seismic performance of SC-TOBFs is numerically conducted through incremental static analysis with emphasis on two main parameters including the stiffness degradation factor $r$ and the activation strain $\varepsilon_a$ of the SC-TOB. The results indicate that the SC-TOBFs is a type of performance-tunable structure, which can be achieved by varying a frame’s...
adjustable parameters. Increasing $r$ leads to a larger second stiffness of the SC-TOBFs, which is beneficial to improve the distribution of drifts over the building height. $\varepsilon_a$ has a significant impact on the activation deformation of SC-TOBFs, but a slight effect on the distribution of drifts.

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